**Program | Book of Abstracts**

1st International Conference and Scientific Exhibition on

# LIVING MATERIALS SYSTEMS

ENERGY AUTONOMY | ADAPTIVITY | LONGEVITY | SOCIETAL IMPLICATIONS

livMatS

universität freiburg

The 1st Living Materials Systems Conference is hosted by the Cluster of Excellence Living, Adaptive and Energy-autonomous Materials Systems (*liv*MatS) at the University of Freiburg.

# SCIENTIFIC ORGANIZING COMMITEE

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Deputy Director, Fraunhofer Institute for Mechanics of Materials, Freiburg

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Institute for Inorganic and Analytical Chemistry
University of Freiburg

**Andrea Kiesel**
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Institute for Psychology,
University of Freiburg

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Scientific Coordinator, Freiburg Center for Interactive Materials and Bioinspired Technologies (FIT),
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Full Professor, Design of Microsystems
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# CONTACT

| | | |
|---|---|---|
| Site map and Directions | | 4 |
| Social Program | | 8 |
| Program Overview | | 10 |
| Detailed Program | | 22 |
| Book of Abstracts | Keynote Speaker | 38 |
| Book of Abstracts | Plenary Speakers | 40 |
| Book of Abstracts | Invited Speakers | 49 |
| Book of Abstracts | Session Talks | 62 |
| Book of Abstracts | Posters | 171 |

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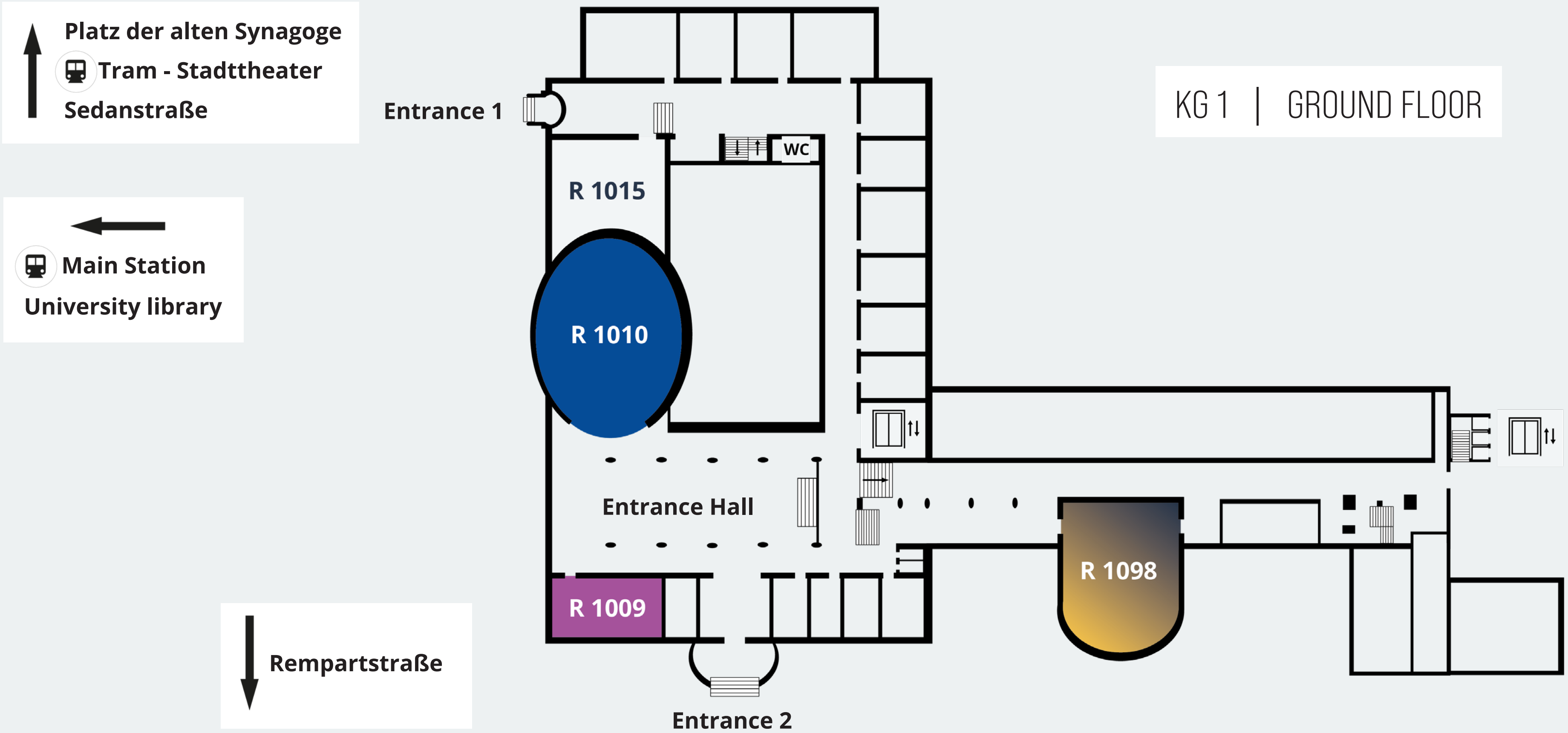
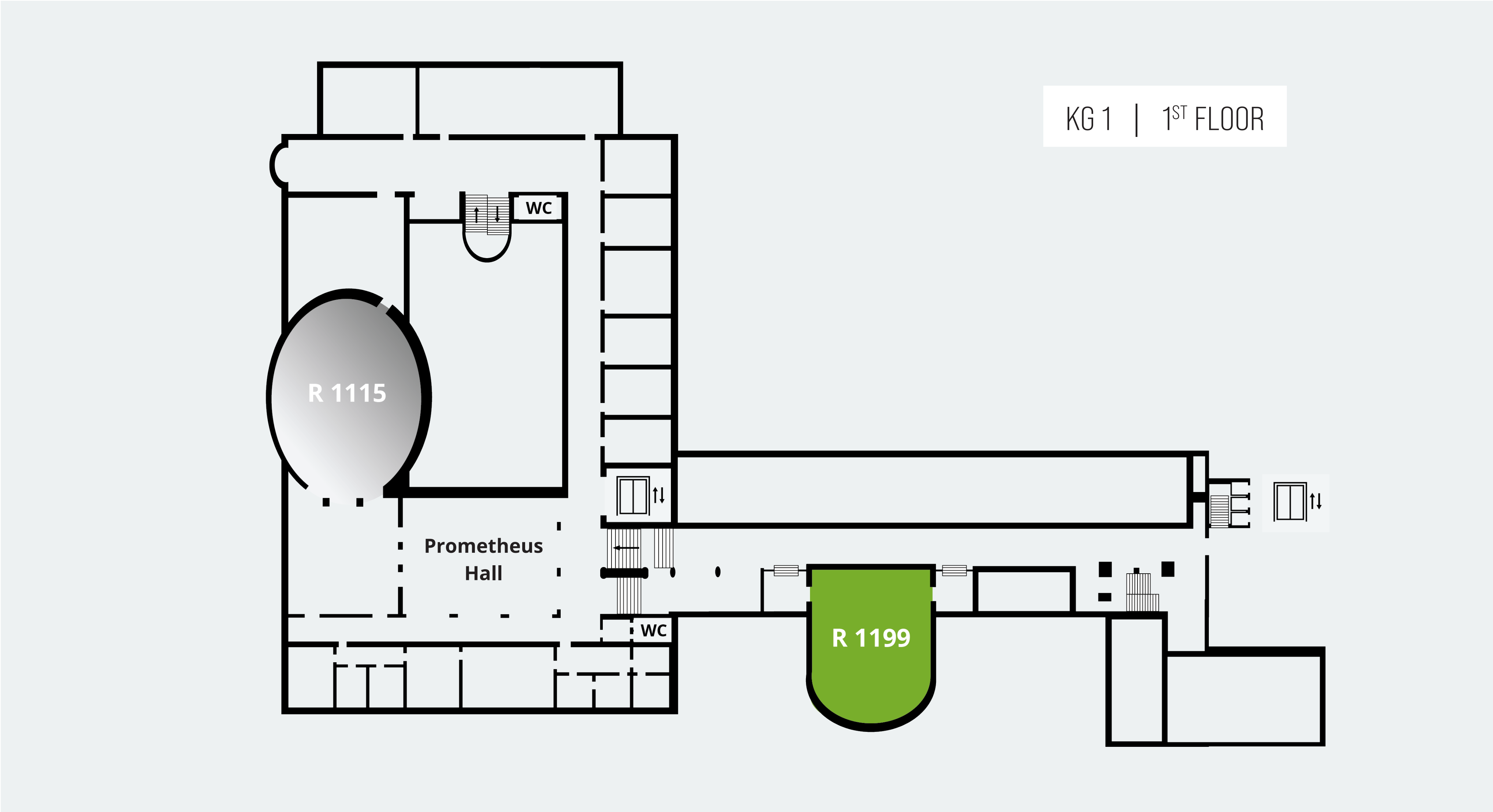



You can reach the Kollegiengebäude I of the University of Freiburg from central station with the lines 1 Littenweiler, 2 Hornusstraße, 3 Vauban and 4 Zähringen. Please exit at the station Stadttheater.

The building is only partially wheelchair accessible. Please contact Sonja Seidel if you need more information.

livMatS



# OFFER A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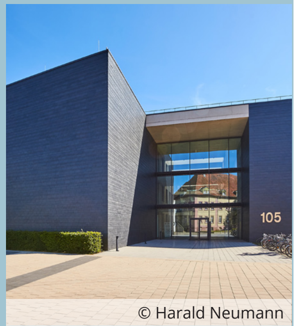
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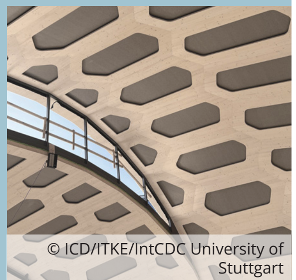
### Tour of the *liv*MatS Biomimetic Shell @ FIT

Visit the 200-square-meter building demonstrator, where scientists from the Universities of Freiburg and Stuttgart will research sustainable materials and alternative construction methods together.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### Freiburg City Tour „Lifestyle, Legends, History“

Learn how this charming town became what it is. Explore its pretty alleyways and its unusual shops but mind the rivulets. Get acquainted to Freiburgers who became world-famous erroneously. Listen to your guides‘ personal tips, and you will get an idea why it is worthwhile living here.

# OFFER B

### Tour of the Freiburg Botanic Garden & the bioinspired *liv*MatS Pavilion

Explore the more than 400-year-old Botanic Garden of the University of Freiburg and learn more about the research that is conducted there by following the biomimetic nature trail. Stop by the *liv*MatS Pavilion to learn how a combination of natural materials and advanced digital technologies enables a unique, bioinspired architecture and a sustainable alternative to conventional construction methods.


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### Tour of the Uniseum Freiburg

The Uniseum is the university museum of the Albert Ludwigs University. It is housed in the the oldest surviving building of Freiburg University, whose basement dates back to the time before the university was founded in 1457. On two floors, the Uniseum invites you to venture back through six centuries of university history. During a guided tour, learn how the Albert Ludwig University got its name, what student life used to be like, why the university had its own prisons – the Karzer – for a long time, and why the university once paid the professors in wine.

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# OFFER C


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### Tour of the Freiburg Botanic Garden & the bioinspired *liv*MatS Pavilion

Explore the more than 400-year-old Botanic Garden of the University of Freiburg and learn more about the research that is conducted there by following the biomimetic nature trail. Stop by the *liv*MatS Pavilion to learn how a combination of natural materials and advanced digital technologies enables a unique, bioinspired architecture and a sustainable alternative to conventional construction methods.

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### Freiburg City Tour „Lifestyle, Legends, History“

Learn how this charming town became what it is. Explore its pretty alleyways and its unusual shops but mind the rivulets. Get acquainted to Freiburgers who became world-famous erroneously. Listen to your guides‘ personal tips, and you will get an idea why it is worthwhile living here.


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## MONDAY | MARCH 20, 2023

| | | |
|---|---|---|
| **18:00** | **Conference Warming and Registration** | Faculty of Engineering \| Georges-Köhler-Allee 101 \| 79110 Freiburg im Breisgau |

## TUESDAY | MARCH 21, 2023

| | | |
|---|---|---|
| **08:00** | **Registration** | R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg im Breisgau |
| **09:00** | **Welcome**<br>Stefan Rensing \| Vice-President for Research and Innovation, University of Freiburg<br>Jürgen Rühe, Thomas Speck, Peter Woias, Bastian Rapp and Lore Hühn \| Presentation of *liv*MatS: Overview and Research Areas | R 1115 \| 1st floor |
| **10:30** | **Coffee Break** | |
| **11:00** | **Achim Menges**, University of Stuttgart, DE \| Invited Talk \| Bioinspired Architecture<br>*Rethinking architecture: interrelations between biology and building* | Chair: Thomas Speck<br>R 1115 \| 1st floor |
| **11:30** | **Bart Jan Ravoo**, University of Münster, DE \| Invited Talk \| Adaptivity<br>*Feedback control in adaptive hydrogels* | Chair: Henning Jessen<br>R 1115 \| 1st floor |
| **12:00** | **Christoph Weder**, University of Fribourg, CH \| Invited Talk \| Demonstrators<br>*Bio-inspired soft robots* | Chair: Jürgen Rühe<br>R 1115 \| 1st floor |

**12:30** **Poster Session and Lunch**

PARALLEL SESSIONS | 13:30 - 15:10

| Bioinspired Architecture | Adaptivity | Longevity | Demonstrators |
| --- | --- | --- | --- |
| Chair: Thomas Speck | Chair: Henning Jessen | Chair: Olga Speck | Chair: Falk Tauber |
| R 1098 | R 1199 | R 1010 | R 1115 |

**15:10** **Coffee Break**

**15:30** **Jean-Marie Lehn**, University of Strasbourg, FR | Keynote Talk — Chair: Jürgen Rühe
*From supramolecular towards adaptive materials* — R 1115 | 1st floor

**16:30** **Poster Flash Talks** — R 1115 | 1st floor

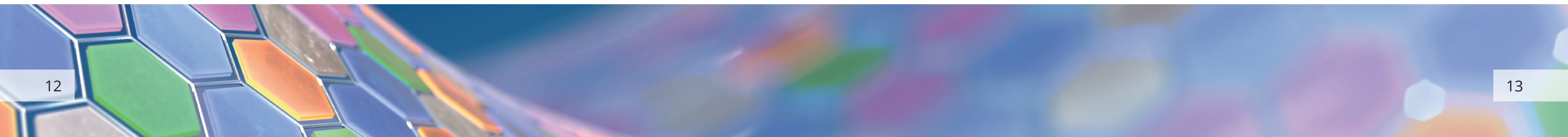
**17:30** **Poster Session and Refreshments**

## WEDNESDAY | MARCH 22, 2023

**08:00** **Registration** — R 1015 | KG I | Platz der Universität 3 | 79098 Freiburg im Breisgau

**09:00** **Zoubeida Ounaies**, Penn State University, US | Plenary Talk | LiMC² Lecture — Chair: Jürgen Rühe
*Field-assisted processing of polymer-based responsive materials: A path towards living multifunctional materials* — R 1115 | 1st floor

**10:00** **Coffee Break**



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|---|---|---|
| **10:30** | **Bilge Baytekin**, Bilkent University, TR \| Invited Talk \| Energy Autonomy<br>*Control of static charging by light* | Chair: Michael Walter<br>R 1115 \| 1st floor |
| **11:00** | **Katja Corcoran**, University of Graz, AT \| Invited Talk \| Societal Implications and Sustainability<br>*Acceptance of new technologies: examples from the energy sector* | Chair: Andrea Kiesel<br>R 1115 \| 1st floor |
| **11:30** | **Marek W. Urban**, Clemson University, US \| Invited Talk \| Longevity<br>*Self-healable key-and-lock and ring-and-lock copolymers* | Chair: Olga Speck<br>R 1115 \| 1st floor |
| **12:00** | **Poster Session and Lunch** | |

PARALLEL SESSIONS | 13:00 - 14:00

| **Bioinspired Architecture** | **Adaptivity** | **Longevity** | **Societal Implications and Sustainability** | **Demonstrators** |
|---|---|---|---|---|
| Chair: Olga Speck | Chair: Bizan Balzer | Chair: Viacheslav Slesarenko | Chair: Philipp Höfele | Chair: Falk Tauber |
| R 1098 | R 1199 | R 1010 | R 1009 | R 1115 |

| | | |
|---|---|---|
| **14:00** | **Moving Break** | |
| **14:15** | **Barbara Mazzolai**, Istituto Italiano di Tecnologia, IT \| Plenary Talk \| Demonstrators<br>*EcoRobots for sustainability* | Chair: Thomas Speck<br>R 1115 \| 1st floor |
| **15:30** | **Social Program** | |

# THURSDAY | MARCH 23, 2023

| | | |
|---|---|---|
| **08:00** | **Registration** | R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg im Breisgau |
| **09:00** | **Yuji Suzuki**, University of Tokyo, JP \| Plenary Talk \| Energy Autonomy<br>*Wearable/skin-attached energy harvesters with high-performance amorphous polymer electrets* | Chair: Peter Woias<br>R 1115 \| 1st floor |
| **10:00** | **Coffee Break** | |
| **10:30** | **Ullrich Steiner**, University of Fribourg, CH \| Invited Talk \| Demonstrators<br>*Disordered structural colour in nature* | Chair: Jürgen Rühe<br>R 1115 \| 1st floor |
| **11:00** | **Alexandra Houssaye**, Muséum National d'Histoire Naturelle, FR \| Invited Talk \| Demonstrators<br>*How can research on modern and fossil bones help us build more restistant structures?* | Chair: Thomas Speck<br>R 1115 \| 1st floor |
| **11:30** | **Marc Desmulliez**, Heriot-Watt University, UK \| Invited Talk \| Demonstrators<br>CANCELED | Chair: Olga Speck<br>R 1115 \| 1st floor |
| **12:00** | **Poster Session and Lunch** | |

## PARALLEL SESSIONS | 13:00 - 14:40

| **Energy Autonomy** | **Adaptivity** | **Longevity** | **Societal Implications and Sustainability** | **Demonstrators** |
|---|---|---|---|---|
| Chair: Michael Walter | Chair: Peilong Hou | Chair: Chris Eberl | Chair: Andrea Kiesel | Chair: Falk Tauber |
| R 1098 | R 1199 | R 1010 | R 1009 | R 1115 |

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|---|---|---|
| **14:40** | **Coffee Break** | |
| **15:00** | **Roman Truckenmüller**, Maastricht University, NL \| Invited Talk \| Adaptivity<br>*Mini dishes of live – engineered 3D cell environments in film-based microwells* | Chair: Bastian Rapp<br>R 1115 \| 1st floor |
| **15:30** | **Olli Ikkala**, Aalto University, FI \| Invited Talk \| Longevity<br>*Towards life-inspired soft matter* | Chair: Chris Eberl<br>R 1115 \| 1st floor |
| **16:00** | **Luca Illetterati**, University of Padua, IT \| Invited Talk \| Societal Implications and Sustainability<br>*Towards a non-naturalistic naturalism* | Chair: Lore Hühn<br>R 1115 \| 1st floor |
| **16:30** | **Coffee Break** | |
| **17:00** | **Sybrand van der Zwaag**, TU Delft, NL \| Plenary Talk \| Longevity<br>*Self-healing engineering materials: from the general concept to material class dependent realisations* | Chair: Olga Speck<br>R 1115 \| 1st floor |
| **18:00** | **Poster Session** | |
| **19:45** | **Conference Dinner** | Freiburger Markthalle \| Grünwälderstrasse 4 \| 79098 Freiburg im Breisgau |

# FRIDAY | MARCH 24, 2023

| | |
|---|---|
| **08:00** | **Registration** — R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg im Breisgau |
| **09:00** | **Hayden Taylor**, University of California, US \| Plenary Talk \| Adaptivity<br>*Digital light manufacturing in multi-phase volumes of material*<br>Chair: Bastian Rapp<br>R 1115 \| 1st floor |
| **10:00** | **Coffee Break** |
| **10:20** | **Kornelius Nielsch**, Leibniz Institute for Solid State and Materials Research, DE \| Invited Talk \| Energy Autonomy<br>*Micro-thermoelectric devices*<br>Chair: Peter Woias<br>R 1115 \| 1st floor |
| **10:50** | **Moving Break** |

## PARALLEL SESSIONS | 11:00 - 12:20

| Energy Autonomy | Adaptivity | Longevity | Societal Implications and Sustainability | Demonstrators |
|---|---|---|---|---|
| Chair: Anna Fischer | Chair: Bastian Rapp | Chair: Max Mylo | Chair: Lore Hühn | Chair: Thomas Speck |
| R 1098 | R 1199 | R 1010 | R 1009 | R 1115 |

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|---|---|
| **12:20** | **Poster Session and Lunch** |
| **13:15** | **Nancy Tuana**, Penn State University, US \| Plenary Talk \| Societal Implications and Sustainability<br>*Bridging community values and science to co-produce sustainable solutions*<br>Chair: Lore Hühn<br>R 1115 \| 1st floor |
| **14:15** | **Closing remarks** |

## MONDAY | MARCH 20, 2023

| | |
|---|---|
| **18:00** | **Conference Warming and Registration**<br>Faculty of Engineering \| Georges-Köhler-Allee 101 \| 79110 Freiburg |

## TUESDAY | MARCH 21, 2023

| | |
|---|---|
| **08:00** | **Registration**<br>R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg |
| **09:00** | **Welcome \| R 1115**<br>Stefan Rensing \| Vice-President for Research and Innovation, University of Freiburg<br>Presentation of *liv*MatS: Overview and Research Areas |
| **10:30** | **Coffee Break** |
| **11:00** | **Achim Menges**, University of Stuttgart, DE **R 1115**<br>Invited Talk \| Bioinspired Architecture \| Chair: Thomas Speck<br>*Rethinking architecture: interrelations between biology and building* |
| **11:30** | **Bart Jan Ravoo**, University of Münster, DE **R 1115**<br>Invited Talk \| Adaptivity \| Chair: Henning Jessen<br>*Feedback control in adaptive hydrogels* |
| **12:00** | **Christoph Weder**, University of Fribourg, CH **R 1115**<br>Invited Talk \| Demonstrators \| Chair: Jürgen Rühe<br>*Bio-inspired soft robots* |
| **12:30** | **Poster Session and Lunch** |

### PARALLEL SESSIONS | 13:30 - 15:10

**Session | Bioinspired Architecture** **R 1098**
Chair: Thomas Speck, University of Freiburg, DE

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|---|---|
| **13:30** | **Stephanie Ihmann**, Fraunhofer IKTS, DE<br>*Development of novel bioinspired building and construction materials by using biogenic carbonate mineralization* |
| **13:50** | **José Pinto Duarte**, Penn State Univesity, US<br>*Exploring the use of shape changing materials to design responsive facades: integrating sensing and actuation* |
| **14:10** | **Alale Mohseni**, Penn State Univesity, US<br>*3D printing mycelium-based composites: notes on material composition, extrudability and 3D printing workflow* |

**Session | Adaptivity** **R 1199**
Chair: Henning Jessen, University of Freiburg, DE

| | |
|---|---|
| **13:30** | **Daniel Werz**, University of Freiburg, DE<br>*Superfluorophors by rational design and serendipitous discoveries* |

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|---|---|---|
| 13:50 | **Giulio Ragazzon**, University of Strasbourg, FR<br>*Autonomous use of electrical energy by an artificial molecular machine* | |
| 14:10 | **Charalampos Pappas**, University of Freiburg, DE<br>*Phosphate-driven systems chemistry* | |
| 14:30 | **Emily Birch**, Newcastle University, UK<br>*Biodynamic architectures* | |
| 14:50 | **Michelle Modert,** University of Freiburg, DE<br>*Leaf unfolding pattern and biomechanical analyses of the lamina* | |

**Session | Longevity** R 1010

Chair: Olga Speck, University of Freiburg, DE

| | | |
|---|---|---|
| 14:10 | **David Schwarz,** University of Freiburg, DE<br>*Mechanical metamaterials switch auxeticity during compression* | |
| 14:30 | **Max Mylo**, University of Freiburg, DE<br>*Learning from the damage-resistant connection of the parasitic European mistletoe and its host for material compounds* | |
| 14:50 | **Frederike Klimm**, University of Freiburg, DE<br>*Tendrils of climbing plants as inspiration for soft robotics* | |

**Session | Demonstrators** R 1115

Chair: Falk Tauber, University of Freiburg, DE

| | | |
|---|---|---|
| 13:30 | **Fabian Meder**, Istituto Italiano di Tecnologia, IT<br>*Electrification of living plant leaves in wind and rain and its capability for energy harvesting* | |
| 13:50 | **Mona Küüts,** University of Tartu, EE<br>*Machine embroidery provides mechanical support for electroactive components in wearable robots* | |
| 14:10 | **Yingdan Wu**, Max Planck Institute for Intelligent Systems, DE<br>*Flow-powered millimeter-scale wheeled tube robot* | |
| 15:10 | **Coffee Break** | |
| 15:30 | **Jean-Marie Lehn**, University of Strasbourg, FR<br>Keynote Talk \| Chair: Jürgen Rühe<br>*From supramolecular towards adaptive materials* | R 1115 |
| 16:30 | **Poster Flash Talks** | R 1115 |
| 17:30 | **Poster Session and Refreshments** | |

## WEDNESDAY | MARCH 22, 2023

| | | |
|---|---|---|
| 08:00 | **Registration**<br>R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg im Breisgau | |
| 09:00 | **Zoubeida Ounaies**, Penn State University, US<br>Plenary Talk \| LiMC² Lecture \| Chair: Jürgen Rühe<br>*Field-assisted processing of polymer-based responsive materials: a path towards living multifunctional materials* | R 1115 |

| | | |
|---|---|---|
| **10:00** | **Coffee Break** | |
| **10:30** | **Bilge Baytekin**, Bilkent University, TR<br>Invited Talk \| Energy Autonomy \| Chair: Michael Walter<br>*Control of static charging by light* | **R 1115** |
| **11:00** | **Katja Corcoran**, University of Graz, AT<br>Invited Talk \| Societal Implications and Sustainability \| Chair: Andrea Kiesel<br>*Acceptance of new technologies: examples from the energy sector* | **R 1115** |
| **11:30** | **Marek W. Urban**, Clemson University, US<br>Invited Talk \| Longevity \| Chair: Olga Speck<br>*Self-healable key-and-lock and ring-and-lock copolymers* | **R 1115** |
| **12:00** | **Poster Session and Lunch** | |

PARALLEL SESSIONS | 13:00 - 14:00

## Session | Bioinspired Architecture — R 1098

Chair: Olga Speck, University of Freiburg, DE

**13:00** **Elena Vazquez**, UNC Charlotte, US
*Adaptive architecture: elastic instability for kinetic building shades*

**13:20** **Natalie Walter**, Penn State University, US
*Mycelium-based composites for sustainable architectural acoustics*

**13:40** **Juan Pablo Gevaudan**, Penn State University, US
*Bio-receptive magnesium oxysulfate cement for coastal infrastructures*

## Session | Adaptivity — R 1199

Chair: Bizan Balzer, University of Freiburg, DE

**13:00** **Andrea Belluati**, Technical University of Darmstadt, DE
*Ghost in the cell: artificial cells via enzyme-mediated polymer synthesis and self-assembly*

**13:20** **Michael Walter**, University of Freiburg, DE
*Mechanochemistry: a theoretical and experimental interplay*

**13:40** **Patrick Dondl**, University of Freiburg, DE
*A phase field model for soma-germline interactions in drosophila oogenesis*

## Session | Longevity — R 1010

Chair: Viacheslav Slesarenko, University of Freiburg, DE

**13:20** **Indre Jödicke**, University of Freiburg, DE
*Topology optimization of mechanical metamaterials using a fast-fourier-transformation based equilibrium solver*

**13:40** **Gerrit Felsch**, University of Freiburg, DE
*Generative design of curved beam metamaterials*

## Session | Societal Implications and Sustainability — R 1009

Chair: Philipp Höfele, Freie Universität Berlin, DE

**13:00** **Sabrina Livanec**, University of Freiburg, DE
*Bioinspired technologies and their concept of life: cognitive-affective mapping as a communication tool in interdisciplinary collaborations*

**13:20** **Andrea Kiesel**, University of Freiburg, DE
*Cognitive-affective maps as a novel research tool – bridging the gap between quantitative and qualitative research*

**13:40** **Wilhelm Gros**, University of Freiburg, DE
*Cognitive-affective mapping (CAM) as measurement tool - elaboration of reliability criteria*

**Session | Demonstrators** **R 1115**
Chair: Falk Tauber, University of Freiburg, DE

**13:00** **Thomas Speck**, University of Freiburg, DE
*Plant bioinspired material systems and structures with life-like properties*

**13:20** **Falk Tauber**, University of Freiburg, DE
*Environmental responsive multi-material artificial venus flytrap demonstrators*

**14:00** **Moving Break**

**14:15** **Barbara Mazzolai**, Istituto Italiano di Tecnologia, IT **R 1115**
Plenary Talk | Demonstrators | Chair: Thomas Speck
*EcoRobots for sustainability*

**15:30** **Social Program**

## THURSDAY | MARCH 23, 2023

**08:00** **Registration**
R 1015 | KG I | Platz der Universität 3 | 79098 Freiburg im Breisgau

**09:00** **Yuji Suzuki**, University of Tokyo, JP **R 1115**
Plenary Talk | Energy Autonomy | Chair: Peter Woias
*Wearable/skin-attached energy harvesters with high-performance amorphous polymer electrets*

**10:00** **Coffee Break**

**10:30** **Ullrich Steiner**, University of Fribourg, CH **R 1115**
Invited Talk | Demonstrators | Chair: Jürgen Rühe
*Disordered structural colour in nature*

**11:00** **Alexandra Houssaye**, Muséum National d'Histoire Naturelle, FR **R 1115**
Invited Talk | Demonstrators | Chair: Thomas Speck
*How can research on modern and fossil bones help us build more restistant structures?*

**11:30** **Marc Desmulliez**, Heriot-Watt University, UK **R 1115**
CANCELED

**12:00** **Poster Session and Lunch**

PARALLEL SESSIONS | 13:00 - 14:40

## Session | Energy Autonomy — R 1098

Chair: Michael Walter, University of Freiburg, DE

**13:40** **Johannes Hörmann**, University of Freiburg, DE
*Morphology, concentration, potential: exploring tunable adsorption film friction with molecular dynamics*

**14:00** **Guido Panzarasa**, ETH Zurich, CH
*Sustainable wood materials for energy applications*

**14:20** **Jingshi Zhang**, Penn State University, US
*Building-integrated reversible proton exchange membrane fuel cell (PEMFC) for energy harvesting and storage*

## Session | Adaptivity — R 1199

Chair: Peilong Hou, University of Freiburg, DE

**13:00** **Zaman Ataie**, Penn State University, US
*Additive manufacturing using nanoengineered microgels: towards granular living materials systems*

**13:20** **Dor Tillinger**, Penn State University, US
*3D printing of multi-hydrogel extrusion printing*

**13:40** **Monsur Islam**, Karlsruhe Institute of Technology, DE
*From 3D printing of carbon microarchitecture towards engineered living carbon*

**14:00** **David Böcherer**, University of Freiburg, DE
*Development of novel thiol-ene/epoxy dual-curing system for high-resolution 4D printing of microfluidic devices*

**14:20** **Pang Zhu**, University of Freiburg, DE
*Reusable photoresponsive hydrogels for high-resolution polymer replication*

## Session | Longevity — R 1010

Chair: Chris Eberl, University of Freiburg, DE

**13:00** **Jürgen Rühe**, University of Freiburg, DE
*Generation of adaptive structures through actuators responsive to heat, light or magnetic fields*

**13:20** **Naeim Ghavidelnia**, University of Freiburg, DE
*Bio-inspired programmable mechanical metamaterial with self-sealing ability*

**13:40** **Oliver Skarsetz**, University of Mainz, DE
*Programmable auxeticity in hydrogel metamaterials via shape-morphing unit cells*

**14:00** **Efstathios Mitropoulos**, University of Freiburg, DE
*Effects of local elasticity on the flow behavior and material transport in dendritic microfluidic designs*

**14:20** **Claas-Hendrik Stamp**, University of Freiburg, DE
*Smart fluidic devices based on hydrodynamically-coupled elastic elements*

**Session | Societal Implications and Sustainability** **R 1009**

Chair: Andrea Kiesel, University of Freiburg, DE

**13:00** **Julius Fenn**, University of Freiburg, DE
*A data-driven multi-method-approach for identifying ethical concerns of emerging technologies*

**13:20** **Angela Zhou**, University of Freiburg, DE
*Social acceptance of photovoltaic installation on buildings: the importance of building appearance, module visibility and aesthetic integration*

**13:40** **Martin Möller**, University of Freiburg, DE
*Development of a tiered methodological framework for a prospective sustainability assessment of novel technologies and materials systems (TAPAS)*

**14:00** **Louisa Estadieu**, University of Freiburg, DE | Yale University, US
*Ethical considerations on an integrative co-existence of nature, technology and society in the age of climate change*

**14:20** **Andrés Díaz Lantada**, Universidad Politecnica de Madrid, ES
*Taxonomy proposal for smart and living materials, structures and systems*

**Session | Demonstrators** **R 1115**

Chair: Falk Tauber, University of Freiburg, DE

**13:00** **Stefan Conrad**, University of Freiburg, DE
*3D printed pneumatic logic gates for the control of soft robots*

**13:20** **Edoardo Milana**, University of Freiburg, DE
*Embodying mechanical intelligence in soft machines via nonlinear networks of inflatable actuators*

**13:40** **Peter Kappel**, University of Freiburg, DE
*Grasping by relaxing – pneumatic actuators with ligaments and tendons*

**14:00** **Isabella Fiorello**, Istituto Italiano di Tecnologia, IT
*Climbing plant-like machines with micropatterned hooks for robotic and environmental applications*

**14:20** **Ardian Jusufi**, Max-Planck-Institute for Intelligent Systems, DE
*Novel smart adaptive actuators for robust locomotion*

**14:40** **Coffee Break**

**15:00** **Roman Truckenmüller**, Maastricht University, NL **R 1115**
Invited Talk | Adaptivity | Chair: Bastian Rapp
*Mini dishes of live – engineered 3D cell environments in film-based microwells*

**15:30** **Olli Ikkala**, Aalto University, FI **R 1115**
Invited Talk | Longevity | Chair: Chris Eberl
*Towards life-inspired soft matter*

**16:00** **Luca Illetterati**, University of Padua, IT **R 1115**
Invited Talk | Societal Implications and Sustainability |
Chair: Lore Hühn
*Towards a non-naturalistic naturalism*

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| **16:30** | **Coffee Break** |
| **17:00** | **Sybrand van der Zwaag**, TU Delft, NL **R 1115**<br>Plenary Talk \| Longevity \| Chair: Olga Speck<br>*Self-healing engineering materials: from the general concept to material class dependent realisations* |
| **18:00** | **Poster Session** |
| **19:45** | **Conference Dinner**<br>Freiburger Markthalle \| Grünwälderstrasse 4 \| 79098 Freiburg im Breisgau |

## FRIDAY | MARCH 24, 2023

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| **08:00** | **Registration**<br>R 1015 \| KG I \| Platz der Universität 3 \| 79098 Freiburg im Breisgau |
| **09:00** | **Hayden Taylor**, University of California, US **R 1115**<br>Plenary Talk \| Adaptivity \| Chair: Bastian Rapp<br>*Digital light manufacturing in multi-phase volumes of material* |
| **10:00** | **Coffee Break** |
| **10:20** | **Kornelius Nielsch**, Leibniz Institute for Solid State and Materials Research, DE **R 1115**<br>Invited Talk \| Energy Autonomy \| Chair: Peter Woias<br>*Micro-thermoelectric devices* |
| **10:50** | **Moving Break** |

### PARALLEL SESSIONS | 11:00 - 12:20

**Session | Energy Autonomy** **R 1098**
Chair: Anna Fischer, University of Freiburg, DE

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|---|---|
| **11:00** | **Taisiia Berestok**, University of Freiburg, DE<br>*Development of integrated photosupercapacitors* |
| **11:20** | **Jan Büttner**, University of Freiburg, DE<br>**CANCELED** |
| **11:40** | **Wei Wei**, University of Freiburg, DE<br>*Influence of interstitial Li on the electronic properties of $Li_xCsPbI_3$ for photovoltaic and battery applications* |
| **12:00** | **Rodrigo Delgado Andres,** University of Freiburg, DE<br>*Photoelectrochemical Energy Storage with Organic Solar Cells* |

**Session | Adaptivity** **R 1199**
Chair: Bastian Rapp, University of Freiburg, DE

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|---|---|
| **11:00** | **Lokman Alpsoy**, University of Freiburg, DE<br>*Production and functionalization of barcoded hydrogel beads* |
| **11:20** | **Jens Leonhardt**, University of Freiburg, DE<br>*Thermo-responsive liquid crystalline bimetal-like actuators* |
| **11:40** | **Alejandro Palacio-Betancur**, Penn State University, US<br>*Motion planning and control of friction-driven reconfigurable adaptive structures* |

**12:00** **Jasleen Lall**, University of Freiburg, DE
*Towards autonomous light-responsive actuators*

## Session | Longevity — R 1010

Chair: Max Mylo, University of Freiburg, DE

**11:00** **Olga Speck**, University of Freiburg, DE
*Charting the twist-to-bend ratio of plant axes: a matter of geometry, mechanical properties and tissue pattern*

**11:20** **Martí Verdaguer Mallorquí**, Heriot-Watt University, UK
*A morphologically inbuilt sawing safety mechanism in the ovipositors of sawflies*

**11:40** **Oswald Prucker**, University of Freiburg, DE
*Bioinspired hairy surfaces*

**12:00** **Felix Gatti**, Fraunhofer-Institut für Werkstoffmechanik, DE
*Programmable friction: development of stimuli-responsive tribosystems based on ionic liquid mixtures*

## Session | Societal Implications and Sustainability — R 1009

Chair: Lore Hühn, University of Freiburg, DE

**11:00** **Philipp Höfele**, Freie Universität Berlin, DE
*Nature-imitating technologies in the anthropocene: an assessment from the perspective of the history of philosophy*

**11:20** **Dennis Schuldzinski**, University of Freiburg, DE
*Mapping the major concepts of 'system' in the 20th century*

## Session | Demonstrators — R 1115

Chair: Thomas Speck, University of Freiburg, DE

**11:00** **Kadri-Ann Valdur**, University of Tartu, EE | Imperial College London, UK
*Amoeba-inspired granular rearrangement as an embodied adaptation strategy in unstructured environments*

11:20 **Falk Tauber**, University of Freiburg, DE
MOVED TO WEDNESDAY 13:20

**11:20** **Sören Bartels**, University of Freiburg, DE
*Mathematics of folding processes*

**11:40** **Kim Ulrich**, University of Freiburg, DE
*Material transitions and delamination resilience in pine cones from Pinus nigra and Pinus jeffreyi*

**12:20** **Poster Session and Lunch**

**13:15** **Nancy Tuana**, Penn State University, US — **R 1115**
Plenary Talk | Societal Implications and Sustainability |
Chair: Lore Hühn
*Bridging community values and science to co-produce sustainable solutions*

**14:15** **Closing remarks**

# KEYNOTE SPEAKER

**Jean-Marie Lehn**[1] | University of Strasbourg, FR

*From supramolecular towards adaptive materials*

Chair: Jürgen Rühe

Supramolecular chemistry is intrinsically a *dynamic chemistry* in view of the lability of the non-covalent interactions connecting the molecular components of a supramolecular entity and its resulting ability to exchange components. Similarly, dynamic covalent chemistry concerns molecular entities containing covalent bonds that may form and break reversibility, so as to allow a continuous modification in constitution by reorganization and exchange of building blocks. These features define a *Constitutional Dynamic Chemistry* (CDC) on both the molecular and supramolecular levels. One may define *constitutional dynamic materials*, as materials whose components are linked through reversible covalent or non-covalent connections and which may thus undergo constitutional variation, i.e. change in constitution by assembly/deassembly processes in a given set of conditions. Because of their intrinsic ability to exchange, incorporate and rearrange their components, they may in principle select them in response to external stimuli or environmental factors and therefore behave as *adaptive materials* of either molecular or supramolecular nature.

Applying these considerations to polymer chemistry leads to the definition of *constitutionally dynamic polymers*, DYNAMERS, of both molecular and supramolecular types, possessing the capacity of adaptation by association/growth/dissociation sequences. *Supramolecular materials*, in particular *supramolecular polymers* may be generated by the polyassociation of components/ monomers interconnected through complementary recognition groups. *Dynamic covalent polymers* result from polycondensation via reversible chemical reactions. They may undergo modifications of their properties (mechanical, optical, etc.) via incorporation, exchange and recombination of their monomeric components. . These features give access to higher levels of behavior such as healing and adaptability in response to external stimuli (heat, light, medium, chemical additives, etc.).

CDC introduces a paradigm shift into the chemistry of materials and opens new perspectives in materials science. A rich variety of novel architectures, processes and properties may be expected to result from the blending of supramolecular and constitutional dynamic chemistry with materials chemistry, opening perspectives towards *adaptive materials and technologies*.

[1]*Institut de Science et d'Ingénierie Supramoléculaires – ISIS, University of Strasbourg, France*

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# PLENARY SPEAKERS

**Barbara Mazzolai**[1] | Istituto Italiano di Tecnologia, IT

*EcoRobots for sustainability*

Chair: Thomas Speck

The advancement of technology has a profound and far-reaching impact on society, currently penetrating all areas of life. This advance, however, often negatively affects our ecosystems, with growing demands on energy, contributions to greenhouse gas emissions, and environmental pollution. Mitigating these adverse effects is among the grand challenges of our times and provides a strong motivation to push the research frontier on materials and robotics. A new wave of eco-friendly robots is envisioned by merging bioinspired soft robotics, material science, nanocomposite technologies, and environmental science.

Taking inspiration from natural systems can provide new insights for designing the next generation robots and rethinking robot bodies, control, and interactions with humans/world over their entire life (i.e., *a robotics life cycle*).

With this vision in mind, in this talk, I will present some of our results on plant- and soft animal-inspired robots with high morphological adaptability, distributed sensory systems, as well as energy-saving mechanisms, which are able to operate in natural habitats while minimizing waste and reducing their environmental footprint. These “green robots” will operate in unstructured environments for environmental monitoring, precision agriculture, reforestation, biodiversity protection, and remediation.

[1]*Center for Micro-BioRobotics, Istituto Italiano di Tecnologia (IIT), Italy*

**Zoubeida Ounaies**[1] | Penn State University, USA

*Field-assisted processing of polymer-based responsive materials: A path towards living multifunctional materials*

Chair: Jürgen Rühe

Materials research has advanced significantly through groundbreaking work on bioinspired materials, smart, adaptive and responsive materials, self-healing materials, and redesign of living cells through synthetic biology. A new paradigm is envisaged to develop materials with living attributes, such as resilience, adaptability, sensing and self-powering, while enhancing their sustainability. These *living multifunctional materials* leverage a synergy of materials and processing to achieve unprecedented control of material properties and functions. For example, a judicious distribution of the particles in polymers can result in complex and hierarchical micro-structures, where this structure complexity gives rise to multi-physics couplings and potential for unprecedented properties. In addition, the presence of the particles and the internal interfaces can further transform the performance of these materials by providing new mechanisms to engineer dielectric, electrical and electromechanical functionality, with important implications in energy harvesting and energy storage. In this presentation, I will discuss use of particles as a strategy to push functional polymers to the next level, in particular how external fields transform starting constituents sets into their final microarchitectures, essentially dictating effective material properties. An expected outcome is that our approach will lead to multi-material composites with locally tailored architectures where mechanical, electrical, magnetic and coupled properties can be tuned during fabrication for specific applications.

**Biography**

Zoubeida Ounaies is a professor of mechanical engineering and director of the Convergence Center for Living Multifunctional Material Systems (LiMC²) at the Pennsylvania State University. She is also the associate director of the Materials Research Institute. She joined Penn State in January

2011 as an associate professor with the Dorothy Quiggle Career Development Professorship in Mechanical Engineering. Previously, she was an associate professor of Aerospace Engineering and Material Science and Engineering at Texas A&M University. Her research focuses on the design and development of responsive polymer-based materials with unique combinations of mechanical, electrical, magnetic, and coupled properties. Broadly speaking, she aims to develop new lightweight smart materials for applications as varied as advanced electronics, autonomous robotics, aerospace, automotive, medical and consumer industries. At Penn State, she established the Electroactive Materials Characterization Laboratory (EMCLab), where she and her students focus on advancing the application of smart materials in energy storage, energy conversion and energy harvesting. She is associate editor of the Smart Materials and Structures Journal, and a fellow of ASME and SPIE.

[1]*Department of Materials Science and Engineering, The Pennsylvania State University, USA, https://limc2.psu.edu, https://www.me.psu.edu/emcl/*



**Yuji Suzuki** | University of Tokyo, JP

*Wearable/skin-attached energy harvesters with high-performance amorphous polymer electrets*

Y. Suzuki[1], T. Miyoshi[1]

Chair: Peter Woias

Wearable/skin-attached electronics have great potential in healthcare, sports, and biomedical applications. The development of these devices has led to a significant increase in the use of coin batteries, increasing their environmental impact. Energy harvesting is a method to capture ambient energy such as environmental vibration, ambient light, and body heat. Among them, energy harvesting from human motion is suitable for powering battery-less wearable devices and skin electronics.

In such applications, electret energy harvesters (EH) have advantages over other types of EHs due to the fact that low-frequency motion is dominant. In this talk, the development of new amorphous polymer electret materials based on quantum chemical analysis and machine learning as well as a novel stretchable electret material is presented. In addition, their application to rotational/stretchable electret EHs is introduced.

In the last 90 years since the first development of electret using Carnauba wax, electret materials have been developed by heuristic approaches. In the present study, for the first time, a novel high-performance amorphous fluorinated polymer electret based on quantum chemical analysis and machine learning is proposed. A new electret material based on CYTOP thus obtained offers a record-high surface charge density with extremely-high thermal stability of implanted charges. Novel stretchable electret material based on a cross-linked amorphous fluorinated polymer is also discussed.

As an application of the developed CYTOP electret, a novel low-profile rotational electret EH is prototyped. Output power up to 1 mW has been obtained at a low rotational speed of 1 rps with only 3 mm in thickness. Evaluation of the rotational EH for human walking and activities of daily living (ADL) is also discussed.

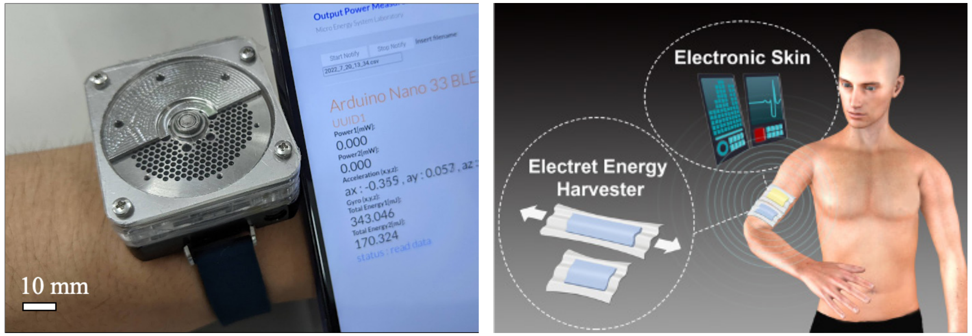


Fig. left) Wrist-worn rotational electret energy harvester with wireless measurement system, right) Concept of stretchable electret energy harvester for skin electronics.

[1]*Department of Mechanical Engineering, The University of Tokyo, Japan*

**Hayden Taylor**[1] | University of California, Berkeley, USA

*Digital light manufacturing in multi-phase volumes of material*

Chair: Bastian Rapp

There is an increasing variety of instances in photopolymer additive manufacturing where the structuring of multi-phase volumes of material is desired. One example is the printing of intricate nanocomposite green bodies composed of silica nanoparticles in a photopolymer binder, where the photopolymer is subsequently thermally extracted and the component is sintered. Other potential examples include the incorporation of reinforcing fibers into a photopolymer precursor, the dispersion of biological cells into a directly printed hydrogel precursor, fluid encapsulation for controlled-viscoelasticity structures, and the 'overprinting' of polymeric geometries binding to pre-existing structures of another material. All of these processing capabilities are potentially relevant for the production of living, reconfigurable, or stimulus-responsive structures.

Volumetric additive manufacturing (VAM) is attractive for these applications because it is amenable to far higher-viscosity precursors than established layer-based printing processes, avoids exposing the precursor to substantial shear stresses during geometry formation, and lends itself to the entrainment or immersion of solid particles and objects within the precursor material. Among the emerging volumetric techniques is computed axial lithography, which delivers a light dose to a 3D material volume via tomographic reconstruction. A major challenge to be overcome in the volumetric processing of multi-phase materials is achieving effective control of the propagation of light, when occlusion, refraction, and scattering effects can all be significant. Additional concerns include the mechanical performance of material interfaces within the volume, and the effect of gravity on bodies dispersed within the volume. This talk will describe some recent results in addressing the optical and mechanical challenges in multi-phase VAM.

**Biography**

Hayden Taylor is an Associate Professor of Mechanical Engineering at the University of California, Berkeley. His research spans the invention, modeling and simulation of manufacturing processes, with the aim of reducing materials and energy usage to support industrial decarbonization. Current research activities have the following themes: (A) processing of materials for sustainable construction, (B) multi-scale volumetric additive manufacturing, and (C) contact mechanics in semiconductor manufacturing. He holds B.A. and M.Eng. degrees in Electrical and Electronic Engineering from Cambridge University and a Ph.D. in Electrical Engineering and Computer Science from MIT.Zoubeida Ounaies is a professor of mechanical engineering and director of the Convergence Center for Living Multifunctional Material Systems (LiMC²) at the Pennsylvania State University. She is also the associate director of the Materials Research Institute. She joined Penn State in January 2011 as an associate professor with the Dorothy Quiggle Career Development Professorship in Mechanical Engineering. Previously, she was an associate professor of Aerospace Engineering and Material Science and Engineering at Texas A&M University. Her research focuses on the design and development of responsive polymer-based materials with unique combinations of mechanical, electrical, magnetic, and coupled properties. Broadly speaking, she aims to develop new lightweight smart materials for applications as varied as advanced electronics, autonomous robotics, aerospace, automotive, medical and consumer industries. At Penn State, she established the Electroactive Materials Characterization Laboratory (EMCLab), where she and her students focus on advancing the application of smart materials in energy storage, energy conversion and energy harvesting. She is associate editor of the Smart Materials and Structures Journal, and a fellow of ASME and SPIE.

[1]*Department of Mechanical Engineering, University of California, Berkeley, USA*

**Nancy Tuana**[1] | Penn State University, USA

*Bridging community values and science to co-produce sustainable solutions*

Chair: Lore Hühn

Although the role of ethics in sustainability science is acknowledged, the dominant vision of the relevance of ethical considerations is insufficiently robust. Scientific research is seen as delineating sustainable options and the likely impacts of the various choices; ethical analysis comes in only afterwards to assist decisionmakers in determining how to equitably rank the various options.

The dominant vision proposes too sharp a distinction between scientific activities and ethical and values deliberation. Ethical and value judgments are not limited to the policy-making arena, but often shape scientific research itself. Many decisions made in the course of scientific research are coupled ethical-epistemic choices in the sense that their consequences can be judged both from the perspective of epistemic values (values relating to how knowledge is obtained) as well as from the perspective of ethical values (such as concern for justice or ecosystem welfare). Sustainable solutions for communities require attention not only to the needs but also the values of those communities. Doing so involves addressing a series of questions, including: what are the most effective strategies for identifying relevant non-epistemic values and for ensuring that stakeholder values are being included in the development of decision support science?; what are some of the most effective ways to address value trade-offs in the design of scientific models?; how best to address issues of equity?

Drawing from work on climate adaptation decision support, I illustrate the importance of and techniques for working closely with relevant communities to identify central values that correlate to decision points throughout the decision support scientific research process.

[1]*Rock Ethics Institute, The Pennsylvania State University, USA*

**Sybrand van der Zwaag**[1] | TU Delft, NL

*Self-healing engineering materials: from the general concept to material class dependent realisations*

Chair: Olga Speck

Man-made engineering materials demonstrate an impressive range of mechanical properties of which strength and toughness are the most important as they determine the resistance to failure and as a consequence determine the effective lifetime of the construction. To this aim material scientist have focused on designing microstructures which minimise the risk of damage formation and even more so obstruct damage propagation. The underlying design principles stem from the '*damage prevention*' paradigm.

Nature also tries to minimise damage but follows the '*damage management*' paradigm: It accepts that local damage is unavoidable but can be made harmless by healing reactions. So, now damage will not only grow, as it invariably does in man-made materials, but can also shrink or even disappear.

For about two decades materials scientist have tried to 'copy' this healing behaviour of natural materials in a wide range of man-made materials. All approaches be rationalised from our '*local temporary mobility*' concept, but have to take into account the intrinsic nature of each class of material. In my presentation I will show successful examples of self healing behaviour in polymers, composites, asphalt, metals, ceramics and even concrete.

[1]*Department of Aerospace Structures and Materials, TU Delft, Netherlands*

# INVITED SPEAKERS

**Bilge Baytekin**[1] | Bilkent University, TR

*Control of Static Charging by Light*

Chair: Michael Walter

Upon mechanical rubbing/contact of insulator surfaces, static electricity is generated. The electrical energy generated this way is not insignificant as it is commonly thought – kV of electrical potential is developed with a simple contact. However, the utilization of this energy is hampered because the atomic-scale mechanism of this process has remained unanswered for millennia, and the methods to 'thame' this energy are not yet found. Here I will present the insulator polymer charging and its control by light. This recently discovered control method is based on fundamental chemical knowledge and uses simple chemical molecules such as organic dyes and charge-transfer complexes. The method provides wavelength control and spatial and temporal control for mitigating static charges on common polymer surfaces. This control over charge mitigation also allows the manipulation of macroscopic objects by static charging followed by light-controlled discharging. In living systems, chemical/electrical/mechanical energy conversions are used to power and control the living systems. The materials systems exhibiting life-like properties and functions surely will need efficient energy conversions. And light/charge interactions on surfaces may contribute to and be used to achieve these conversions in these systems.

[1]*Institute of Materials Science and Nanotechnology, Bilkent University, Turkey*

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**Katja Corcoran**[1] | University of Graz, AT

*Acceptance of new technologies: examples from the energy sector*

Chair: Andrea Kiesel

To prevent catastrophic consequences of climate change, we need to massively reduce greenhouse gas emissions within the next decade. To achieve this, transformation in many different sectors is necessary and the energy sectors is one of them. Transforming the energy sector includes technological and societal changes. Technology will provide alternatives to old technologies depending on fossil fuels (e.g., energy production and mobility) and also support optimizing energy usage and the energy market. However, often technological change also needs societal change. Only if people accept and adopt new technologies and are willing to change behavior and habits, transformation occur. In this talk, I will present empirical studies investigating psychological variables predicting the adoption of two technologies that are part of the transformation of the energy sector: smart meters and electric vehicles. Even though some psychological variables like risk-perception, technological affinity and environmental attitude are indeed related to acceptance of these technologies, it is important to acknowledge barriers in society for their uptake. I will discuss these barriers in connection of the concept "energy citizenship".

[1]*Institute of Psychology, University of Graz, Austria*

**Marc Desmulliez**[1] | Heriot-Watt University, UK

*The use of trade-offs in nature: from surgical saws to the measurement of traits*

Chair: Olga Speck

Living things are constantly subject to trade-offs, which can manifest themselves through measurement of their traits, extracted by consulting observations of botanists or zoologists or can be a posteriori discovered as in the case of ovipositors of sawflies. This talk will present an overview my current research in the topic with examples related to ammonite shells, sawflies and the use of Natural Language Processing (NLP).

[1]*Institute of Sensors, Signals and Systems, Heriot-Watt University, UK*

**Alexandra Houssaye** | Muséum National d'Histoire Naturelle, FR

*How can research on modern and fossil bones help us build more resistant structures?*

A. Houssaye[1], C. Etienne, J. Viot, Y. Gallic, F. Rocchia, J. Chaves-Jacob

Chair: Thomas Speck

Bone is an economical material. Indeed, since moving a heavy skeleton is energetically costly, the vertebrate skeleton is adapted to maximise the resistance to the stresses imposed with a minimum amount of material. Bone is therefore deposited where it is needed, not where it is not. The use of bone as a source of inspiration should therefore reduce the manufacturing cost (financial and ecological) and increase the strength (and life span) of bioinspired structures. Bone adapts at various levels. Comparative 3D analyses of bone shape enable to highlight shape features linked to particular mechanical properties. In addition, the 3D analysis of bone internal structure (through the characterization of the compact bone thickness and of the properties of the cancellous bone [density, orientation, thickness of trabeculae] at different locations in the bones) reveals functional microanatomical characteristics. Based on these analyses, biomechanical tests can be performed, consisting in first computer modelling and then mechanical tests with the construction of optimised structures by additive manufacturing. These tests make it possible to establish general biomechanical rules that can be used for bioinspiration in various fields. Yet, if current diversity is already a great possible source of bioinspiration, past diversity is naturally much richer and offers access to a much wider range of possibilities and to potential new extremes of functions that greatly enrich the spectrum from which biomechanical inferences can be established. Investigating the fossil record thus make it possible to obtain much more solid inferences, in addition to being able to answer even broader questions.

[1]*Muséum National d'Histoire Naturelle, France*

**Olli Ikkala[1]** | Aalto University, FI

*Towards life-inspired soft matter*

Chair: Chris Eberl

Soft matter functionalities have extensively been developing by stimulus-responsiveness, shape-memories, and bio-inspirations for ever more complex responses. Beyond them, dynamic dissipative feedback-controlled properties would be among the new desired functions, however, involving great complexity. Herein, we describe soft matter approaches inspired by functions of living systems. According to Kandel [1], classical (Pavlovian) conditioning, habituation, and sensitization are among the simplest „learning" concepts in behaviour. We first show soft matter systems inspired by Pavlovian conditioning [2,3]. We further show concepts inspired by sensitization using magnetic stimulus [4]. Finally, we show dynamic light-driven systems to allow homeostasis and dissipative signal transduction [5]. Life-inspired soft materials can provide the next generation of out-of-equilibrium dissipative platforms for functions for embedded materials intelligence [6].

[1]*Aalto University, Department of Applied Physics, FI-02150 Espoo, Finland*

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*[2] H. Zhang, H. Zeng, A. Priimagi, O. Ikkala, Nat. Commun. 2019, 10, 3267.*

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**Luca Illetterati**[1] | University of Padua, IT

## *Towards a non-naturalistic naturalism*

Chair: Lore Hühn

In this presentation I would like to give the perspective of what I call a non-naturalistic naturalism. To this end, I will start from the attempts that run through a not insignificant part of contemporary culture, aimed at eradicating the concept of nature, which is emblematic of a subjectivist, violent and predatory attitude not only towards the environment, but also towards women and, especially through the colonial experience, towards oppressed peoples. After pointing out the philosophical reasons for these attempts, I will try to show some of the dangers associated with this desired erasure of nature. In particular, I will try to argue how the obliteration of nature actually leads to the element of of externality that this concept represents, and how the dissolution of externality in fact tends to dissipate all the features of resistance and friction that this externality embodies. In this sense, what is at stake is not the abolition of the concept of nature, but its decolonization, that is, its liberation from a perspective according to which this concept would draw its meaning only from the implicit ontology of the natural sciences. To initiate this strategy of decolonization, I will focus on the concept of agency by revisiting Kant's, Schelling's, and Hegel's concepts of nature and interpret it (the notion of agency) as a notion that should not be read in opposition to nature's mode of being, but as an element that constitutes it.

[1]*Department of Philosophy, Sociology, Education and Applied Psychology, University of Padua, Italy*

**Achim Menges**[1] | University of Stuttgart, DE

## *Rethinking architecture: interrelations between biology and building*

Chair: Thomas Speck

Inspiration found in nature, together with advances in computational design and robotic fabrication, challenge existing approaches in architecture in a surprising manner, or even point out completely new possibilities for design and construction. Biology offers an almost inexhaustible reservoir of principles of form, structure and process that can be transferred to architecture. At the same time, computation profoundly transforms the building industry.

The presentation will showcase ways of tapping the full potential of digital technologies in architecture and construction through inspiration by nature, in order to go beyond the mere digitalization of established planning procedures and the automation of existing building processes towards truly integrative computational design and construction for future-proof architecture.

[1]*Institute for Computational Design and Construction (ICD) / Cluster of Excellence Integrative Computational Design and Construction for Architecture (IntCDC), University of Stuttgart, Germany*

**Kornelius Nielsch[1,2,3]** | Leibniz Institute for Solid State and Materials Research, DE

*Micro-thermoelectric devices*

Chair: Peter Woias

Sustainable energy harvesting and efficient thermal management are required for the development of highly integrated electronic devices, the Internet of Things, and flexible and wearable technology. Micro-thermoelectric devices, which are capable of generating electricity from waste heat or using electricity to generate local cooling, are a promising solution. The devices have, in particular, a smaller leg cross-section and height than their commercial, macroscopic counterparts and can thus offer a faster response, higher resolution and greater power density. They can also be integrated with multifunctional microelectronic devices. Here we present the development of micro-thermoelectric devices based on electrochemical deposition. We examine progress in device design, integration, characterization and performance, and explore potential applications in cooling, power generation and sensing. We also analyse the key challenges that need to be addressed to create high-performance devices and realize the full commercial potential of the technology.

[1]*Leibniz Institute for Solid State and Materials Science, 01069 Dresden, Germany*

[2]*Institute of Materials Science, TU Dresden, Dresden 01062, Germany*

[3]*Institute of Applied Physics, TU Dresden, Dresden 01062, Germany*

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**Bart Jan Ravoo[1]** | University of Münster, DE

*Feedback control in adaptive hydrogels*

Chair: Henning Jessen

The principle of self-assembly is emerging as a superior method for preparing responsive and adaptive nanomaterials. The structure and function of these materials are completely determined by the dynamic and weak interactions of the constituent molecular building blocks of the material. Since the interactions of the building blocks are rather weak, these versatile materials react to even small changes and stimuli in their environment. In addition, these materials are biomimetic and they can contain large amounts of water, so applications in biomedical engineering are foreseeable.

This talk will highlight our recent work on feedback control in adaptive hydrogels. The implementation of feedback loops in responsive materials can be considered a key step in the development of artificial adaptive nanosystems. Two case studies will be discussed in the lecture: redox-responsive supramolecular hydrogels regulated by enzymes and photo-responsive polymer hydrogels with embedded feedback. In particular in the latter case, interesting spiking behavior (pulsatile payload release) is observed.

[1]*Organisch-Chemisches Institut and Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster*

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**Ullrich Steiner**[1] | University of Fribourg, CH

*Disordered structural colour in nature*

Chair: Jürgen Rühe

The manipulation of light lies at the very core of how most organisms interact. While the physical and chemical underpinnings of "colour" are seemingly well established, the detailed investigation of how animals and plants manipulate the flow of light continues to surprise us. Structural colour, widely used in the animal kingdom, is commonly assumed to arise from highly periodic structures. Many organisms use, however, photonic effects (colour produced by light interference) that occur from seemingly disordered 100-nm morphologies. This presentation will start with an overview of how 500 million years of evolution have produced optical effects that are unparalleled in technological development. The challenges in understanding the principles of "disordered photonics" will then be described, followed by the progress currently being made. The second part of the presentation will focus on approaches to fabricating materials that implement the lessons learned from nature.

[1]*Adolphe Merkle Institute, University of Fribourg, Switzerland*

**Roman Truckenmüller**[1] | Maastricht University, NL

*Mini dishes of live – engineered 3D cell environments in film-based microwells*

Chair: Bastian Rapp

Petri dishes in their various forms are the most successful cell culture ware. Their flat, smooth and also stiff bottom, nowadays from oxidized tissue culture polystyrene, is the reference culture substrate in many assays. However, nature is three-dimensional and highly detailed. Accordingly, our understanding how cellular microenvironments in the year 2023 should look like, and also could look like in terms of bioengineering possibilities, has considerably grown since the microbiologist Julius Petri pioneered the glass version of his dish around 1880. In this talk, we will introduce the concept of miniaturized culture dishes and Boyden chambers/culture inserts in the form of polymer film-based microwells. They serve as engineered 3D cellular microenvironments for spheroids, also in the form of hybrid cell-micromaterial aggregates, embryoid bodies, organoids and (other) epithelial cell layers. The microwells can be enriched by decorating their bottoms and walls with micro- or nanotopographies and with (bio) chemical, cell-adhesive microdomains for the organization and instruction of cells, and provided with microporosity for the perfusion and supply with gas and nutrients, diffusion of cellular signals and migration/invasion of cells. Porous film-/membrane microwells can be also given cell-scale curvature for the establishment of bioinspired barrier tissue models. The delivery of engineered microobjects to the microwells makes further cell-instructive interfaces within their volume available. Envisioned applications of the above-introduced culture platforms range from advanced in vitro model systems to bottom-up tissue engineering and beyond.

[1]*MERLN Institute for Technology-Inspired Regenerative Medicine, Maastricht University, Netherlands*

**Marek W. Urban[1]** | Clemson University, US

*Self-healable key-and-lock and ring-and-lock copolymers*

Chair: Olga Speck

The effectiveness of van der Waals (vdW) interactions formulated the new path for the development of copolymers that exhibit self-healing via *key-and-lock* interactions. Taking advantage of the polarizability of copolymer side groups, the directionality of vdW interactions between neighboring macromolecular segments is enhanced, which upon mechanical damage return to their initial conformations. This process can be altered by polar interactions which, under certain conditions, can be accelerated. Viscoelastic responses controlling macroscopic autonomous multicycle self-healing can be also altered by copolymerized into one macromolecular chain ionic liquid units, thus providing an opportunity for applying electric fields to accelerate self-healing. Taking self-healable concept further, combining *key-and-lock* interactions with partially crosslinked entities can produce reprocessable covalent adaptive networks (CANs). Favorable inter-chain interactions between aliphatic side groups sandwiched by aromatic rings can form copolymer-dependent *ring-and-lock* associations driven by pi-polar-pi (π-p-π) interactions which also facilitates self-healing.

*[1]Department of Materials Science and Engineering, Clemson University, Clemson, SC 29634 USA, http://cecas.clemson.edu/urbanresearch/*

**Christoph Weder** | University of Fribourg, CH

*Bio-inspired soft robots*

L. F. Muff[1], A. S. Mills[2], S. Riddle[2], V. Buclin[1], A. Roulin[1], H. J. Chiel[2], R. D. Quinn[2], K. A. Daltorio[2], C. Weder[1]

Chair: Jürgen Rühe

Soft, earthworm-like robots that are mechanically compliant can, at least in principle, navigate through uneven terrains and constricted spaces that are inaccessible to traditional legged and wheeled robots. However, most worm-like robots reported to date contain some rigid components, such as electromotors or pressure-driven actuation systems, which limit their compliance. We present a mechanically compliant worm-like robot with a fully modular body that is based on soft polymers. The robot is propelled by strategically assembled, electrothermally activated polymer bilayer actuators. To maximize the performance of these elements, we developed semicrystalline polyurethane that display exceptionally large nonlinear thermal expansion coefficients. The individual work segments were designed on the basis of a modified Timoshenko model. Finite element analysis simulations were used to describe their performance. The robot's movements are controlled by electrical activation of the segments with basic waveform patterns. It can move through repeatable peristaltic locomotion on exceptionally slippery or sticky surfaces and it can be oriented in any direction. The soft body enables the robot to wriggle through openings and tunnels that are much smaller than its cross-section.

*[1]Adolphe Merkle Institute, University of Fribourg, Switzerland*

*[2]Case Western Reserve University, Cleveland, Ohio, USA.*

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*Muff, L.; Weder, C.; Bilayer bending actuators based on semicrystalline polyurethanes with large thermal expansion coefficients; Advanced Intelligent Systems 2023, 3, 2200265.*

*Muff, L.; Weder, C.; Exploiting Phase Transitions in Polymer Bilayer Actuators; Advanced Intelligent Systems 2020, 2, 2000177.*

# SESSION TALKS

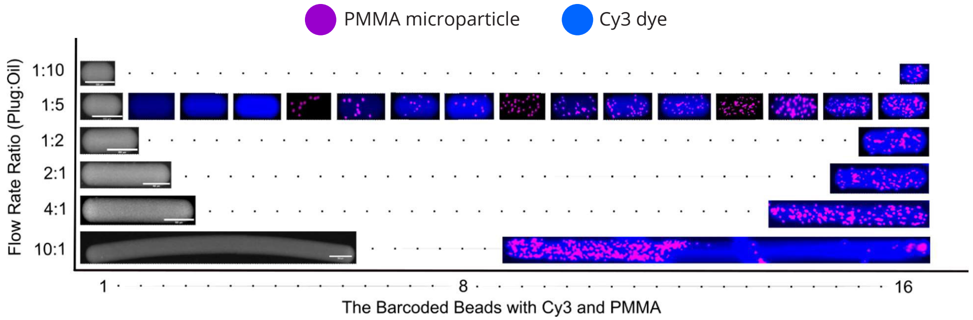
**Lokman Alpsoy** | University of Freiburg, DE — Friday | 11:00

*Production and functionalization of barcoded hydrogel beads* — R 1199

L. Alpsoy[1], A. S. Sedeky[1], T. Brandstetter[1], J. Rühe[1]

In medical diagnostics, the trend is toward personalized medicine in which each patient receives a specific medical treatment to reduce non-effective drugs and side effects. To apply for personalized medicine, lots of biomolecules from body fluids have to be identified. Enzyme-linked immunosorbent assay (ELISA) has been a gold standard for biomarker identification due to its sensitivity and specificity. However, improvements regarding analysis time, required sample volume, and its lack of multiplexing capability are still a concern [1]. In this regard, significant progress has been made in the field of multiplex analysis which uses beads for diagnostics and bioanalytical applications. Multiplex analysis enables us to detect targeted molecules, saving time, sample, and cost [2].

We present a new hydrogel bead-based platform for biomedical applications that can be easily fabricated, barcoded, and functionalized in a single step by using a microfluidic setup and photocrosslinking. The bead's size and shape can be controlled, mainly by polymer concentration and flow rate. Increasing flow ratio of plug: carrier fluid results in an elongation of the bead's length. Moreover, dyes can be used to expand bead's barcoding. For the bio-functionalization of the beads, biomolecules could be immobilized onto the beads to test samples from infected and non-infected patients. In the present study different-sized and colored beads with proteins are produced for multiplex immunoassay analysis. Furthermore, the sensitivity and specificity of the platform should be enhanced. Bead-based multiplex analysis fabricated in a single step for the detection of disease biomarkers will have a significant impact in medical diagnostics.




[1]*Chemistry and Physics of Interfaces, IMTEK, University of Freiburg, Germany*

**Keywords**

Barcoding of Hydrogel beads | Microfluidic system | Multiplex analysis; contribute to Adaptive Materials Systems

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| **Zaman Ataie** \| Penn State University, US | Thursday |
|---|---|
| *Additive manufacturing using nanoengineered microgels: towards* | 13:00 |
| *granular living materials systems* | R 1199 |

A. Sheikhi[1]*, Z. Ataie[1], S. Kheirabadi[1], J. Wanjing Zhang[1], A. Kedzierski[1], C. Petrosky[1], R. Jiang[1], C. Vollberg[1]

Granular hydrogels, composed of microscale hydrogel particle (microgel) building blocks [1], have significant advantages over bulk hydrogels for developing living materials systems, such as on-demand *in situ* formation of scaffolds with interconnected microscale pores. Singlecomponent granular hydrogel inks are extrusion threedimensional (3D) printable if the microgels are tightly packed; however, extreme packing of microgels compromises the microporosity of granular scaffolds. To overcome this challenge, we engineered interparticle interactions, yielding an extrudable and printable ink with preserved microporosity. We introduced the first class of nanoengineered granular bioinks (NGB, Fig. 1), fabricated based on the reversible self-assembly of heterogeneously charged colloidal nanoclay adsorbed onto the microgels [2]. NGB enabled printability with a high resolution, shape fidelity, and structural integrity. Topical seeding of fibroblasts showed no cell infiltration into the bulk scaffold, limited penetration into the jammed scaffold, and high infiltration into the NGB and unjammed (control) scaffolds. Overall, the results show that the NGB enables the 3D printing of tissue-mimetic scaffolds with high shape fidelity and structural integrity while preserving interconnected microporosity.

[1]*Department of Chemical Engineering, The Pennsylvania State University, University Park, PA*

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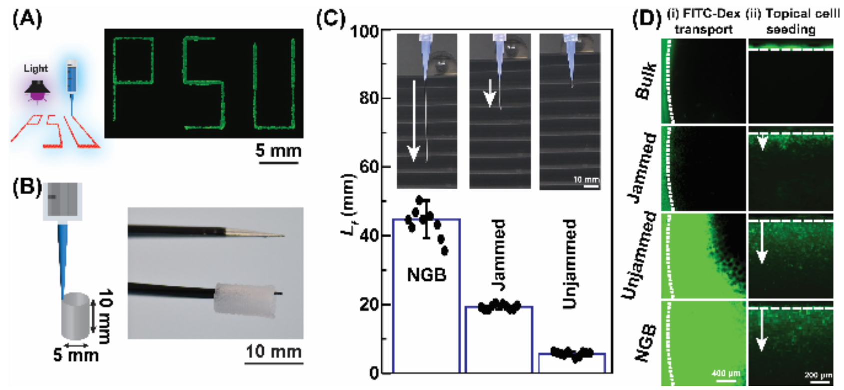



Fig. 1. (A) Printing PSU letters using the NGB with a high resolution. (B) Shape fidelity and structural integrity of a long hollow cylinder 3D printed using the NGB. (C) Hanging filament test of NGB, jammed, and unjammed inks. ****p<0.0001 is the significance among the groups. (D) FITC-Dex transport (i) and the topical seeding of NIH/3T3 fibroblast cells (ii) in the bulk, jammed, unjammed, or NGB scaffolds. Data are presented as average ± standard deviation. Oneway analysis of variance (ANOVA) was performed with Tukey's post hoc comparison (****p<0.0001) [2].

| **Sören Bartels** \| University of Freiburg, DE | Friday |
|---|---|
| *Mathematics of folding processes* | 11:40 \| R 1115 |

The folding of thin elastic sheets has various applications and is an important part of several biological processes. We present a mathematical model that results from a model reduction of threedimensional hyperelastic material descriptions. The model is a nonlinear bending model which restricts deformations to be isometric. It allows us to identify precise relations between the folding angle and curvature quantities related to the crease. Moreover, the model can be used to simulate thin-sheet folding processes. This is joint work with Andrea Bonito (Texas A& M), Peter Hornung (TU Dresden) and Philipp Tscherner (U Freiburg).

*Department of Applied Mathematics, University of Freiburg, Hermann-Herder-Str. 10, D-79104 Freiburg, Germany*

**Andrea Belluati** | Technical University of Darmstadt, DE — Wednesday

*Ghost in the cell: artificial cells via enzyme-mediated polymer synthesis and self-assembly* — 13:00

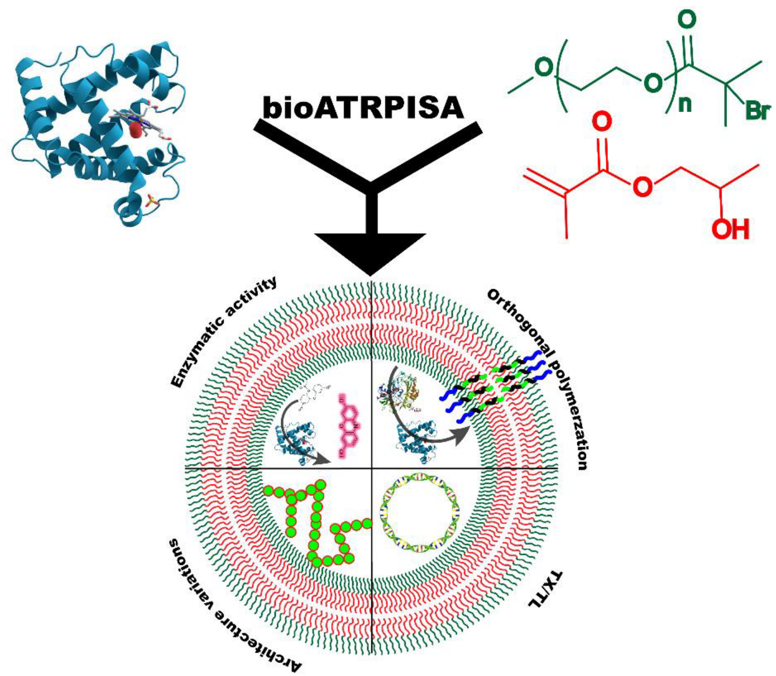
R 1199

A. Belluati[1], S. Jimaja[2], C. Glynn[1], M. Chami[3], N. Bruns[1]

Polymersomes are one of the most sought-after structures for artificial cells, thanks to their liposome-like structure, improved stability, and chemical versatility. However, the use of amphiphilic bloc copolymers is currently limited by the need to produce the building blocks beforehand, via classical organic synthesis methods. As various acrylate monomers can be polymerized directly in aqueous solution, using common enzymes such as horseradish peroxidase or laccase, we developed a myoglobin-mediated atom transfer radical polymerization (bioATRP) of 2-hydroxypropyl methacrylate (HPMA) with a monomethyl poly(ethylene glycol) macroinitiator, yielding a mPEG-*b*-PHPMA block copolymer that self-assembles in vesicles as the PHPMA chain is elongated, in a bio-inspired ATR polymerization-induced self-assembly (bioATRPISA).

Myoglobin could self-encapsulate into cell-sized vesicles, which effectively harboured a plethora of cargoes, from small molecules to nanoparticles, and several enzymes as well, becoming multi-functional microreactors, capable of becoming luminescent, fluorescent and use a second step of internal enzymatic polymerization to change their shape and size. Moreover, their ability to load up several cargoes allowed them to encapsulate bacterial lysate and plasmids as well, becoming able to express proteins on demand: from classical fluorescent proteins to an actin-based cytoskeleton and the biomineralizing alkaline phosphatase, which was ultimately able to entrap these artificial cells within a biosimilar calcium phosphate matrix.

[1]*Technische Universität Darmstadt, Darmstadt, Germany*
[2]*Université de Fribourg, Fribourg, Switzerland*
[3]*Universität Basel, Basel, Switzerland*




**Taisiia Berestok** | University of Freiburg, DE — Friday

*Development of integrated photosupercapacitors* — 11:00 | R 1098

T. Berestok[1,2,3], C. Diestel[1,2], J. Büttner[1,2,3], N. Ortlieb[1,2,3], S. W. Glunz[1,2,4,5,6], A. Fischer[1,2,3,6]

To be energy autonomous, off-grid devices should be able to harvest energy from their environment, convert it and store it in order to mediate between intermittent energy supply and demand. Such hybrid system can be realized via coupling a solar cell (SC) with an electrochemical storage using a three-electrode interconnection scheme with the shared electrode, allowing obtaining monolithic devices with the lowest areal foot-print.

In terms of electrochemical storage part, we opted for electrochemical double layer capacitors (EDLCs) with mesoporous nitrogen-doped carbon nanospheres (MPNCs) as an active material. MPNCs were synthesized via hard-templating strategy based on the polymerization and self-assembly of aniline in the presence of $SiO_2$ nanoparticles (7 nm) [1,2]. This resulted in highly monodisperse, 140 nm-diameter spherical MPNCs with a large specific surface area (825 $m^2\ g^{-1}$) and defined mesopores (~9 nm). Well-defined mesoporous network and the highly accessible electrochemical surface area enabled obtaining MPNC-based gel-electrolyte freestanding EDLC with capacitance up to 400 $F\ g^{-1}$ at 1 $A\ g^{-1}$.

Its further integration with a 12.5 % efficient, 1 $cm^2$-large hilide perovskite SC through a shared electrode in a three-electrode configuration resulted in the monolithic free-standing photosupercapcaitor. The resulting photosupercapacitor showed fast (< 5 s) photocharging up to 1 V under 1-sun illumination and an outstanding overall energy conversion efficiency of 11.8 % [3]. The proposed three-electrode design with shared electrode was extended to produce MPNC based monilithic photosupercapacitors with other types of solar cells, including Si-SCs and organic SCs [4,5].

[1]*Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies, University of Freiburg, Germany.*

[2]*Freiburg Center for Interactive Materials and Bioinspired Technologies (FIT), University of Freiburg, Germany.*

[3]*Institute of Inorganic and Analytical Chemistry, University of Freiburg, Germany.*

[4]*Fraunhofer Institute for Solar Energy Systems (ISE), Freiburg, Germany.*

[5]*Department of Sustainable Systems Engineering (INATECH), Freiburg, Germany.*

[6]*Freiburg Materials Research Center (FMF), University of Freiburg, Germany*

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**Emily Birch** | Newcastle University, UK — Tuesday

*Biodynamic architectures* — 14:30 | R 1199

E. Birch[1], M. Dade-Robertson[1], B. Bridgens[1], M. Zhang[1]

**Harnessing moisture sensitive bacterial spores into responsive, hybrid and living smart materials**

The urgency for energy efficient solutions to maintaining our internal environments (eg. humidity) is growing in response to the climate crisis and has propelled smart materials development to the forefront of scientific and architectural research (Koyaz, 2018; Lendlein et al., 2019). Can we develop passive, living, smart materials which utilize natures' unique adaptability for energy efficient humidity control within our built environment?

Hygromorphs respond passively to humidity. *Bacillus subtilis* develops environmentally robust, hygromorphic spores which, if fabricated within a latex bilayer, harnesses the simple expansion and contraction generating a directional response. Earlier explorations developed fabrication and spore culturing methodologies and achieved simple programmability (Birch et al., 2021) which we have progressed utilising a multidisciplinary methodological approach to produce an emerging material pallet of responses and programmability, leading to complex, refined deformations, and applications within the physical world.

Extensive exploration through iterative design has allowed quantitative experimental investigation of multiple variables including inert material type, thickness and resistance patterns, spore state, actuator shape and size, spore adhesion and deposition methodologies. Aggregation through utilization of a matrix allows individually small motions to contribute to a larger combined function and highlight how the comprehensive material pallet can inform production of bespoke, responsive architectures where the functional outcome can be pre-described and programmed.

Current investigations have bio-fabricated an environmentally-responsive, hygromorphically-actuated panel, created to produce a desired open area (%) at given relative humidities. Through mathematical modelling we have begun to program and laboratory test how these Biodynamic Architectures can passively regulate air flow and humidity exchange, working to inform developments for the architectural scale.

[1]*Hub for Biotechnology in the Built Environment, School of Architecture, Newcastle University, UK*

**Keywords**
Environmental adaptive actuators | environmental responsive materials | bio-inspired materials

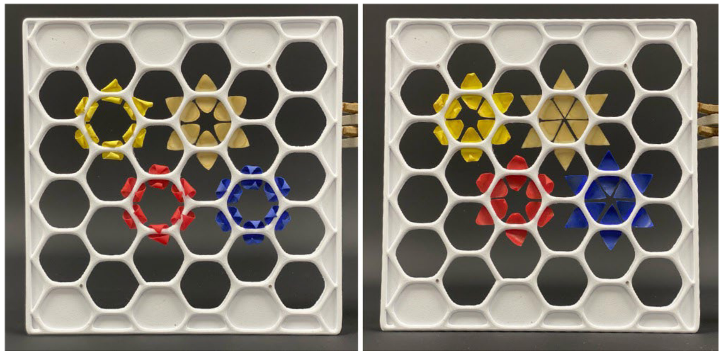

Fig. 1. Matrix hosting a range of B. subtilis hygromophic actuator types (0.2mm - yellow, 0.35mm - red, 0.4mm - blue, 0.5mm- natural) at 50% RH (left) and 100% RH (right).

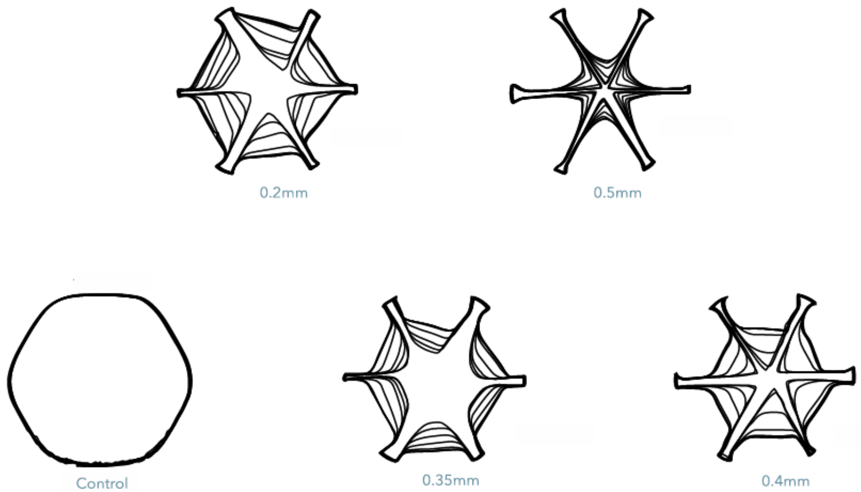


Fig. 2. Open aperture area recordings from matrix hosting a range of B. subtilis hygromophic actuator types (0.2mm, 0.35mm, 0.4mm, 0.5mm) taken at 50 second intervals while transitioning from 100% RH (minimum area) to 50% RH (maximum area).

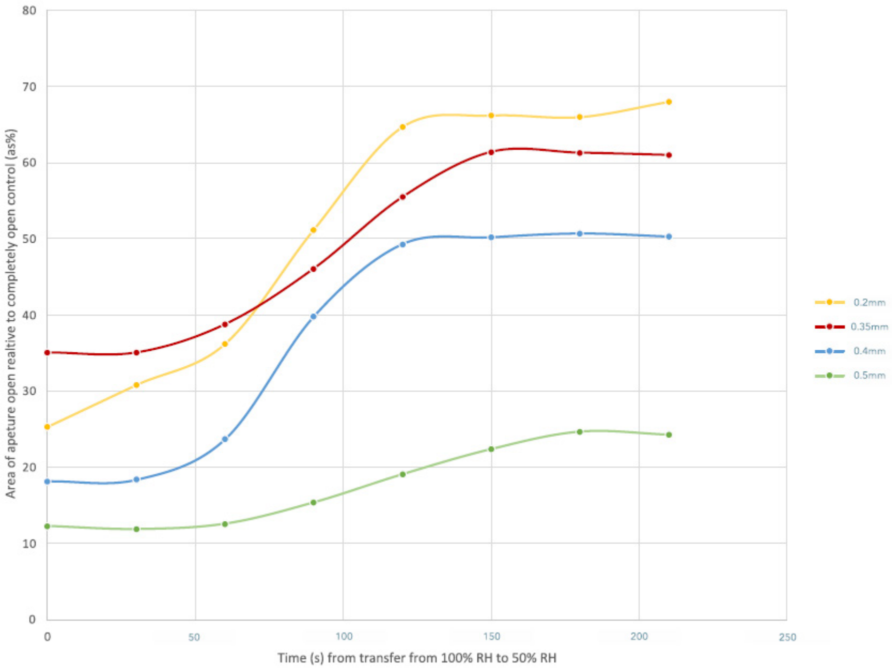


Fig. 3. The impact of latex thickness (0.2mm, 0.35mm, 0.4mm, 0.5mm) on open aperture area (as % of control) within taken at 50 second intervals while transitioning from 100% RH (minimum area) to 50% RH (maximum area).


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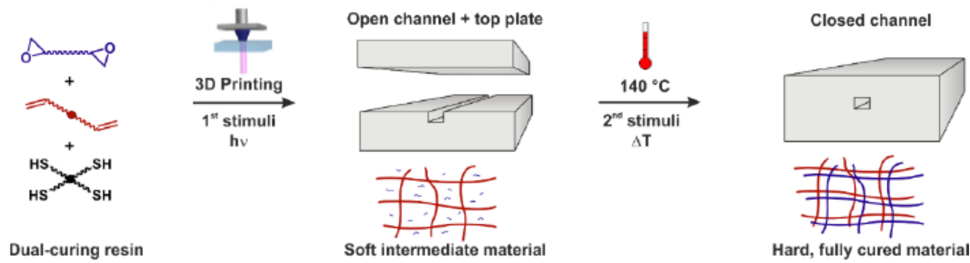
**David Böcherer** | University of Freiburg, DE

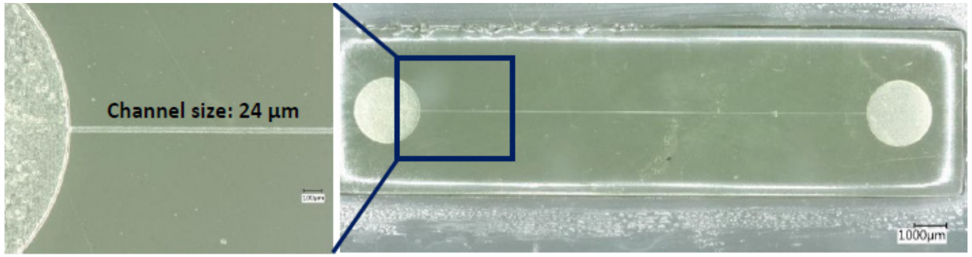
Thursday 14:00 R 1199

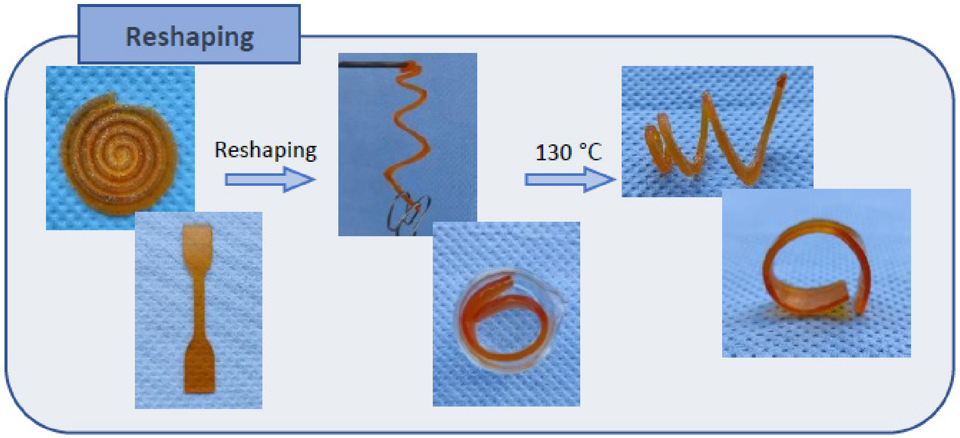
## *Development of novel thiol-ene/epoxy dual-curing system for high-resolution 4D printing of microfluidic devices*

D. Böcherer, B. E. Rapp, D. Helmer

The development of new materials with controllable mechanical properties is highly desirable for many advanced applications such as biomedical devices, on-site assembly of complex shape structures or smart actuators. 4D printing of dual-curing thermosetting systems is a versatile approach for creating such systems. Here, we present a novel formulation of thiol-ene/thiol-epoxy materials suitable for high-resolution 3D printing. The 3D printed intermediate materials with unreacted functional groups show soft mechanical properties with the ability for reshaping, healing and dry bonding. The combination of easy bonding process with the individuality of high-resolution 3D printing makes this dual-curing system a perfect material for the processing of microfluidic devices. We show the generation of high-resolution microfluidic designs with channel sizes < 100 µm. Furthermore, the reshaping and healing properties of the 3D printed intermediate materials are demonstrated.






**Keywords**

high-resolution 4D printing | dual-curing system | dry bonding | thermoresponsive material

**Jan Büttner** | University of Freiburg, DE

Friday 11:20 R 1098

*2D halide-perovskites as materials for batteries and photobatteries - dream or reality?*

J. Büttner[1,2,3], T. Berestok[1,2,3], S. Burger[2,4], M. Daub[1,2], H. Hillebrecht[1,2,3], I. Krossing[1,2,3,4], A. Fischer[1,2,3,4]

In recent years the development of autonomous photo-rechargeable batteries has received growing attention to power devices of the internet of things and industry 4.0. Especially highly integrated photobatteries based on multifunctional materials able to harvest sunlight and store charge carriers are the holy grail amongst such devices. Recently 2-(1-cyclohexenyl)ethyl ammonium lead iodide (CHPI) has been reported as multifunctional photoelectrode material for the design of highly integrated Li-ion photobatteries [1]. CHPI was thereby believed to be able to reversibly intercalate Li-ions from polar carbonate based electrolytes, typically used in Li-ion batteries (LIBs). Herein CHPI is examined closer to investigate its stability against dissolution, the possibility of Li-intercalation and photo-assisted deintercalation and its general behaviour under illumination in standard carbonate based electrolytes as well as in a newly developed low polarity electrolyte based on *ortho*-difluorobenzene (*o*-DFB).

Our study demonstrates that CHPI dissolves in contact with carbonate-based electrolytes while being stable in *o*-DFB based electrolyte and that no Li-intercalation takes place in the latter (Fig. 2). These results lead to the conclusion, that CHPI is neither a suitable nor a stable material for the design of Li-ion based photo-rechargeable batteries [2].

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*[2]Institute for Inorganic and An-alytical Chemistry, University of Freiburg, Albertstr. 21, 79104 Freiburg, Germany. [3]FIT Freiburg Center for Interactive Materials and Bioinspired Technologies, University of Freiburg, Georges-Köhler-Allee 105, 79110 Freiburg, Germany.*

*[4]FMF - Freiburg Materials Research Center, University of Freiburg, Stefan-Meier Str. 21, 79104 Freiburg, Germany.*

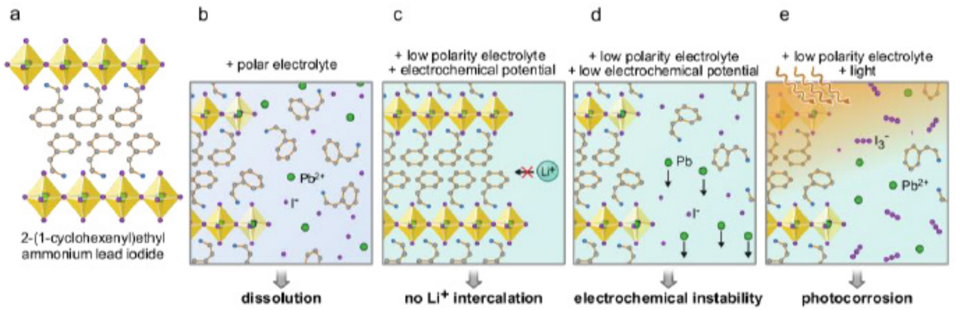


Fig. 1 Schematic of CHPI behavior for different scenarios. (a) Simplified schematic CHPI structure. (b) CHPI dissolution in polar solvents. (c) Stable CHPI in low polarity electrolyte, but no quantitative $Li^{+}$ intercalation needed for relevant energy storage, occurs. (d) Reductive electrochemical degradation of CHPI with $Pb^{0}$ formation. (e) Photo corrosion of CHPI under illumination

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**Stefan Conrad** | University of Freiburg, DE — Thursday

## *3D printed pneumatic logic gates for the control of soft robots*

13:00 | R 1115

S. Conrad[1], J. Teichmann[1], T. Speck[1], F. Tauber[1]

Novel developments in soft robotic control are paving the way to catch up with the autonomy of traditional metal-based robots. Pneumatic actuators play a major role in these developments, as they allow the construction of muscle-like motion systems. Although designed completely flexible, they are still controlled using electronics and metal valves, keeping the device still not fully compliant. Achieving a completely compliant and robust design is the first step to fully autonomous life like systems.

In our work, we invented fully compliant 3D printed pneumatic logic gates that perform Boolean operations imitating electric circuits (Fig. 1 A). Within 7 hours, a FDM printer is able to produce a flexible transistor module that serves as either an OR, AND or NOT gate. The logic function is defined by the assigned input signals. The work principle of the transistors is based on the interaction of pressurized chambers and a 3D printed 1 mm tube inside (Fig. 1 B). The innovative design makes it possible to print the hollow parts without a carrier material, so that the modules are ready for use immediately after printing. This novel technology has already proven its ability to form complex pneumatic circuits like oscillators and latches, and has the potential to replace electric components in soft robotic grippers, crawlers and walkers. This way our work is another step towards truly compliant and cost efficient soft robotic systems.

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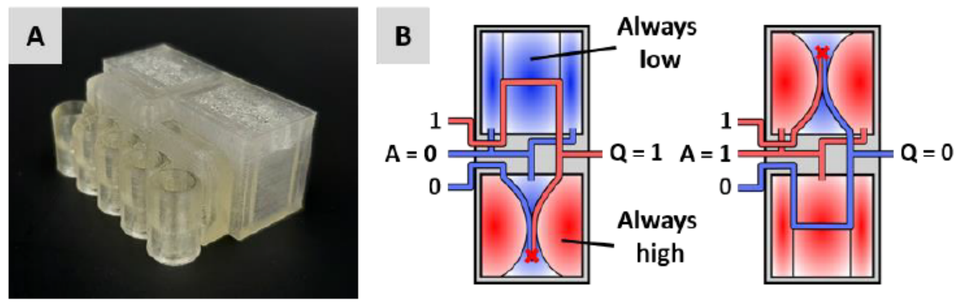


Fig. 1 Pneumatic logic gate for the control of soft robotic actuators. It can be configured as a logic AND, OR and NOT and operates without any kind of electronics. **A**: FDM 3D printed module made of TPU A70 with five sockets for tube connectors. **B**: Working principle of a gate configured as a logic NOT. A LOW signal (blue) on input A results in Q being connected to a pressure source outputting a logic 1. A HIGH signal (red) on A causes the upper chambers to expand and seal the tube in between. On the bottom side, the pressure works against the compressing side forces and opens a second tube to conduct the output to a logic 0.

**Rodrigo Delgado Andrés** | University of Freiburg, DE — Friday

*Photoelectrochemical energy storage with organic solar cells* — 12:00 | R 1098

R. Delgado Andrés[1,3,5], T. Berestok[1,2], R. Weßling[1,4], K. Shchyrba[1,3,5], A. Fischer[1,2],B. Esser[1,4], U. Würfel[1,3,5]

The global trend towards automatization and miniaturization of smart devices has triggered the development of reliable off-grid power sources with low economic and environmental impact. Such autonomy can be provided when a photovoltaic cell is integrated with an electrochemical storage device in one monolithic device. This work demonstrates a reliable and straightforward approach to monolithically integrate high-performance single and multijunction organic solar cells with mesoporous nitrogen doped carbon nanosphere-based supercapacitors or lithium-organic batteries in a single device with a three-electrode configuration. To assess the efficiency of these devices, a novel approach is presented that relies on the direct monitoring of both integrating parts during illuminated and dark phases and accounts for possible losses. This versatile approach is applicable for all kinds of integrated multifunctional photoconversion-storage systems. For the photosupercapacitors, the evaluation with the standard literature approach showed an outstanding performance with a peak photoelectrochemical energy conversion efficiency of 17 %. However, in our opinion this type of efficiency does not properly represent the real overall device efficiency. Based on our newly developed efficiency determination, a more modest overall cycle efficiency of 2 % is obtained. For battery-based devices, a higher output voltage is achieved, but at the cost of a lower, 0.3% cycle efficiency. In our view these values represent the real overall performance of the integrated device in a precise manner and will thus enable meaningful direct comparisons among different photoelectrochemical storage systems.

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[3]*Freiburg Material Research Center FMF, University of Freiburg*
[4]*Institute for Organic Chemistry II, University of Ulm*
[5]*Fraunhofer Institute for Solar Energy Systems (ISE)*

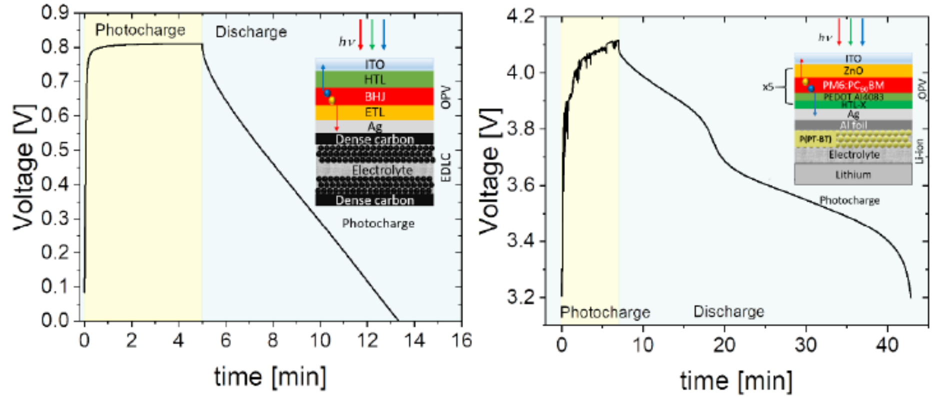


Fig. 1 (left) Voltage profile of photosupercapacitor during 5min photocharge and constant current discharge; (right) Volt-age profile of photobattery during 7 min photocharge and constant current discharge. On the inset of both plots, the schematic representation of the devices is shown.

**Andrés Díaz Lantada** | Universidad Politecnica de Madrid, ES — Thursday

*Taxonomy proposal for smart and living materials, structures and systems* — 14:20 | R 1009

A. Díaz Lantada[1], M. Islam[2]

Engineered living materials (ELMs), or simply living materials (LMs), are reformulating several industries, and transforming materials science and technology. LMs are commonly divided in two large kingdoms: biohybrid LMs, built by cells, bacteria, archaea, synthetic cells, and combinations thereof, capable of generating their own extracellular matrix as structural support; and biohybrid LMs, made of an abiotic chassis or scaffold colonized by the mentioned living entities [1,2]. Despite being a nascent field still facing several R&D challenges, engineering products, processes and systems involving living matter are bound to outperform the capabilities of traditional passive devices and systems made of abiotic components. In many ways, this transition to LMs evolves from decades or research in fields like tissue engineering, biofabrication, biohybrid systems, and from myriads of studies focused on more traditional "smart" materials and structures, with quasi-living autonomous or intelligent behaviors, based on abiotic multifunctional stimuli/ environmental-responsive materials like piezoelectric polymers and ceramics, shape-memory alloys and polymers, thermochromic materials, electroactive polymers, water-responsive networks, Mc Kibben muscles, Peltier cells or electrotextiles, to cite a few. Being the current panorama of living materials systems so vast and in a process of radical change due to the incorporation of LMs, we propose in this study a taxonomy for the field and for contributing to its organization. The taxonomy includes two fundamental domains, depending on the abiotic or living nature of the materials employed. Then, for living materials systems based on living matter, we apply our recently published taxonomy for LMs, which connects the higher taxonomic ranks with those from the taxonomy of life and the lower taxonomic ranks with the families of materials that constitute their extracellular matrices or chassis [3]. As regards living materials systems based on abiotic materials with quasi-living behavior, we propose two kingdoms depending on the smartness of the material, structure, or system. Those based on traditional "smart" materials acting as simple transducers, without processing information, are considered as stimuli-responsive, while those involving processing, decision-making or communication of signals are classified as truly smart [4]. Families within this domain are also classified according to the type of abiotic material employed. Finally, for all smart and living materials, structures and systems, the lowest taxonomic rank deals with their applications. The scheme for this taxonomy is presented in Fig. 1, to initiate debated and reach consensus.

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**Keywords**

Engineered living materials | living materials | smart materials and structures | intelligent systems

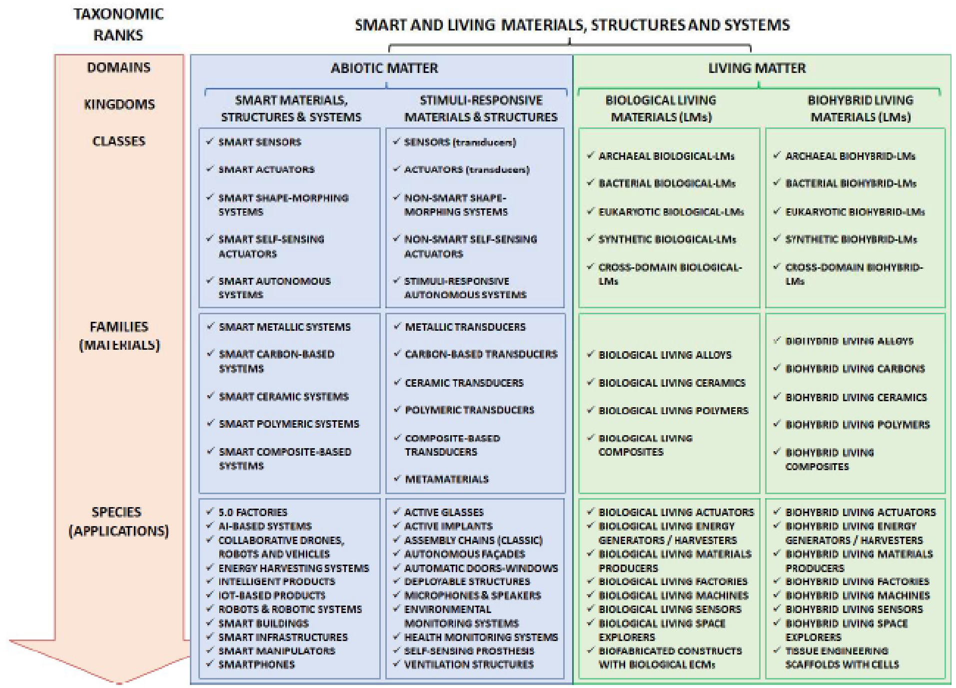


Fig. 1. Proposed taxonomy for smart and living materials, structures and systems.

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**Patrick Dondl** | University of Freiburg, DE — Wednesday

*A phase field model for soma-germline interactions in drosophila oogenesis* — 13:40 | R 1010

V. Weichselberger[1,2,3], P. Dondl[4,5], A. Classen[1,2,6]

In [1], we study the signals mediating the mechanical interaction between somatic epithelial cells and the germline of Drosophila. We discover that, during the development of the egg chamber, the transcriptational regulator “Eyes absent” (Eya) modulates the affinity of the apical surface of epithelial cells to the nurse cells and the oocyte in the egg chamber. Using a phase field model, we develop a quantitative, mechanical description of epithelial cell behavior and demonstrate that the spatio-temporal expression of Eya controls the epithelial cells’ shape and movement during all phases of Drosophila oogenesis to establish a suitable match between epithelial cells and germline cells (see Fig. 1). Further we show that differential expression of Eya in follicle cells also controls oocyte growth via cell-cell affinity.

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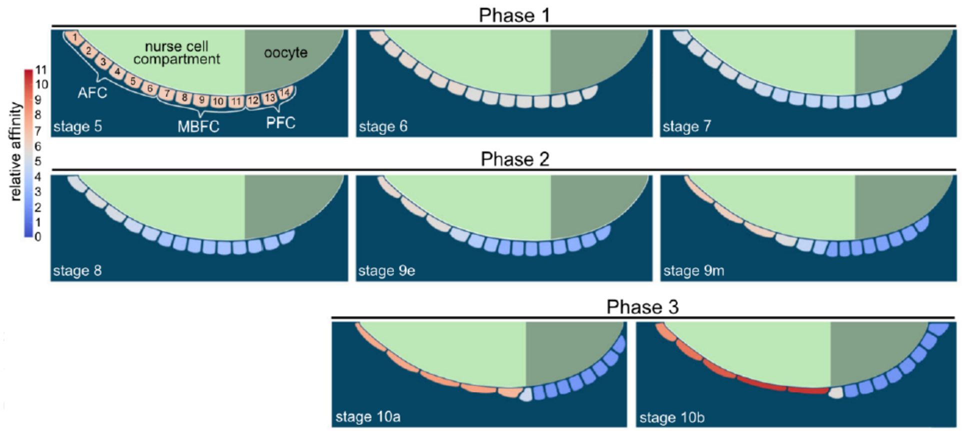


Fig. 1. The phase field model shows the matching between anterior, main body, and posterior follicle cells (AFC, MBFC, PFC) to the oocyte and nurse cell compartment, respectively, during Drosophila oogenesis (Extracted from Fig. 4 in [1], under license CC BY 4.0, http://creativecommons.org/licenses/by/4.0/)

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**Louisa Estadieu** | University of Freiburg, DE, Yale University, US

Thursday 14:00 R 1009

## *Ethical considerations on an integrative co-existence of nature, technology and society in the age of climate change*

One of the greatest challenges of the 21st century is to stop climate change and its devastating consequences. Reacting to this challenge, philosophical debates have shown a tendency to dissolve traditional dualisms and one-sided power relations associated with these dualistic views, such as nature vs. humans, humans vs. technology, technology vs. nature. Particularly prominent in this context is the so-called New Materialism. Based on a critique of the anthropocentric thinking of the last centuries, New Materialism argues that a gradual merge of nature, technology and society offers the potential to contribute to the solution of climate change. At the same time, however, the dangers of a radical merging of nature, technology and humans are also considered, for example in the debates initiated by the geologist Jan Zalasiewicz about our life in a „technosphere".

The aim of this paper is to analyze the possibilities and limits of New Materialism against the background of current climate debates: First, I will outline the main ideas of New Materialism. Then I will discuss the potentials and limits of New Materialism on the basis of concrete scenarios in which a merge of nature, technology and humans is taking place. Finally, I will analyze to what extent *liv*MatS contributes to an alternative world view by developing materials that do not simply transform or merge with nature and humans, but rather adapt to the environment in an integrative way.

**Gerrit Felsch** | University of Freiburg, DE

Wednesday 13:40 | R 1010

## *Generative design of curved beam metamaterials*

G. Felsch[1], V. Slesarenko[1]

Materials whose properties are determined by their internal architecture in addition to composition – so-called metamaterials – have emerged as a growing field of study over the past decades [1]. These materials are usually assembled from periodically arranged unit cells. While the mechanical properties of these materials can be predicted though finite element simulations, many applications also require to identify architectures with specific target properties [2]. To solve this inverse problem, we introduce a deep-learning framework (see Fig. 1a) for generating metamaterials with desired properties. By supplying the generative model with a guide structure in addition to the target properties, we are not only able to generate a large number of alternative architectures with the same properties, but also to express preference for a specific shape.

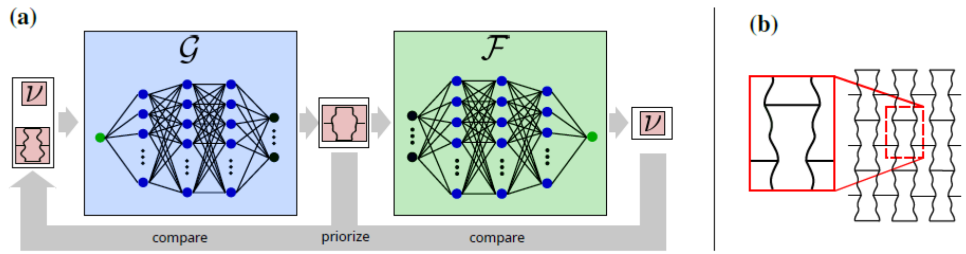


Fig. 1 The proposed deep-learning framework. (a) The generative network G generates a unit cell based on target properties and a guide structure. The generated unit cell it then fed to a pre-trained predictive network F, which estimates the properties so they can be compared to the target ones for training. (b) A representative unit cell and a resulting system comprised of 3 x 3 unit cells.

To demonstrate the capabilities of this approach we applied it to generate unit cells for a new class of reentrant-hexagonal metamaterials based on curved beams (see Fig. 1b). Reentrant-hexagonal metamaterials are well known to be able to exhibit a wide range of different material properties based on their architecture. This includes properties tied to unusual behavior such as a negative Poisson's ratio [3], which can be tuned by adjusting the angles between beams. However, changing the angles also influences the overall dimensions of the unit cells. By replacing straight beams with curved ones, it is possible to control the Poisson's ratio of reentrant-hexagonal metamaterials without affecting the overall dimensions. We show that our deep-learning framework is able to accurately generate unit cells fitting specific properties for curved beam metamaterials.

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**Keywords**

Machine learning | Metamaterials | Unit cell design

**References**

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**Julius Fenn** | University of Freiburg, DE — Thursday, 13:00, R 1009

## *A data-driven multi-method-approach for identifying ethical concerns of emerging technologies*

J. Fenn[1], P. Höfele[3], M. Gorki[1], A. Kiesel[1,2]

Emerging technologies are characterized by immense uncertainties, because such technologies are at an early stage of development and possible negative or positive (side-) effects of future developed technologies are hardly predictable. Ethical concerns of emerging technologies are thereby highly relevant to inform possible design decisions of technologies in the early process of development and that technologies, finally developed, are accepted by a broader public. Importantly, only in an early stage of development, because of less development costs invested and less path dependencies, technologies are easier to modify. To identify possible ethical concerns as early as possible, ethics must be informed empirically and operate in real time. For this endeavor, we have developed an "Ethics Scale for Technology Assessment" [4], and a recent data collection [2] and a data analysis tool [1] of an innovative explorative method called "Cognitive-Affective Maps" (CAMs).

Three types of data (survey, Cognitive-Affective Maps, open text question) have already been collected in a previous article, which focused on questions of acceptability of a specific climate engineering technology [3]. By systematically reanalyzing the three types of data it allows us (1) by analyzing CAM and text data to identify a broad range of ethical concerns and (2) by analyzing survey data to test structural relationships of ethical concerns to core constructs of technology acceptance (affect, risk & benefit perception, trust, previous knowledge, and personality factors). Our aim is to propose a generalizable and complex methodology that is applicable to a wide range of emerging technologies.

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[3]Institute of Philosophy, Freie Universität Berlin, Germany

[4]Institute of Psychology, University of Kassel, Germany

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**Isabella Fiorello** | Istituto Italiano di Tecnologia, IT — Thursday 14:00, R 1115

## *Climbing plant-like machines with micropatterned hooks for robotic and environmental applications*

I. Fiorello[1], A. Mondini[1], F. Meder[1], B. Mazzolai[1]

Bioinspired miniaturized machines can offer innovative solutions for operating in dynamic real-world terrains by adapting their morphology to complex three-dimensional (3D) surfaces. We mimicked the ratchet-like parasitic attachment mechanism of the hook-climber *G. aparine* [1] to propose innovative micropatterned machines with hook-shaped microstructures for strong and reversible anchoring to different rough substrates (Fig. 1) [2,3]. By mimicking the morphological and biomechanical features of the natural microhooks of *G. aparine*, we designed and microfabricated climbing plantlike microhooks-based adhesives using high-resolution 3D micro-manufacturing techniques, either directly or in combination with molding and casting of favorable materials. Then, we demonstrated and characterized the strong and reversible shear-induced adhesive strength ($F_{shear}$) of the microhooks to different substrates, including textiles, skin tissues and leaf surfaces (up to $F_{shear}$ = 14 N/cm$^2$). Finally, we exploited the use of our microhook-based systems in different machines for different *proof-of-concept* demonstration scenarios, including robotic and targeted environmental applications. These microhooks-based machines include (1) climbing robots at different scales (from centimeter to millimeter size), (2) flexible wireless multi-parameter “OnLeaf” sensors to monitor the leaf microclimate and (3) biodegradable and dissolvable “OnLeaf” patches for *in-plant* drug delivery. Our research provides advances in bioinspired soft robotics by proposing innovative miniaturized technologies inspired by plants and capable to precisely work on complex unstructured and/or confined real-world scenarios. These systems have promising applications in different fields, including robotic manipulation, environmental inspection and monitoring, targeted payload release to leaf or skin tissues and space exploration.

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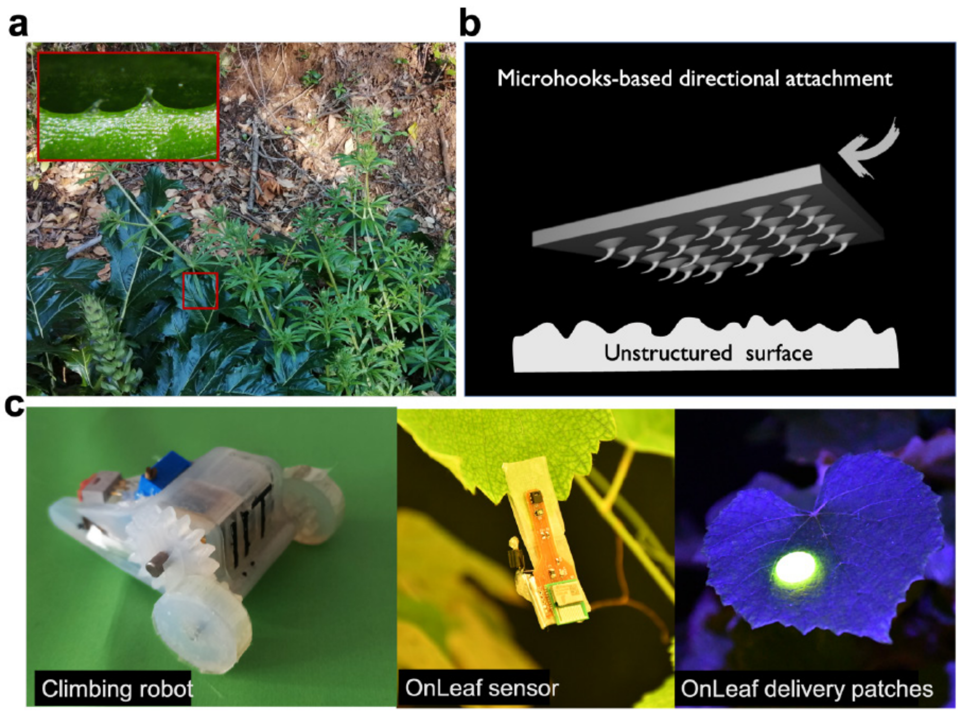


Fig. 1. Climbing plant-inspired machines with micropatterned hooks. (a) The hook- climber *Galium aparine* climbing host vegetation. (b) Schematic view of microhook-based attachment system. (c) Different proof-of-concept machines integrating plant-inspired microhooks, including climbing robots, on-leaf sensors and on-leaf delivery patches (from left to right).

**Felix Gatti** | Fraunhofer-Institut für Werkstoffmechanik, DE

Friday 12:00 R 1010

*Programmable friction: development of stimuli-responsive tribosystems based on ionic liquid mixtures*

The direct but non-mechanical control or programming of the frictional properties of bodies moving against each other is one of the main objectives of tribology [1]. A suitable combination of lubricant and internal or external trigger that can modify the friction is an enormous challenge. Using ionic liquid mixtures (ILMs) consisting of a long-chain cation and anions differing in functional groups and an external applied electric potential represent such a promising combination (Fig.1). By applying an electrical potential to the tribological system, a surface charge can be induced on the friction partners. Depending on the polarization, the molecular adsorption and accumulation of cations or anions in the friction gap is promoted, leading to a change in the coefficient of friction (COF) compared to the uncharged state. The coupling of the tribosystem with the electrical potential via a „tribo-contoller“ enabled a timedependent autonomous programming of the COF to predefine values (Fig.2) [2].

The mechanisms that have been partially explored at the nanoscale now need to be transferred to the macroscale [3]. In particular, surface charge density, current flow, properties of the ILM and tribological parameters such as lubricant film thickness or temperature are considered. This could lead to the development of a programmable tribo-system that automatically adapts to changing conditions (pressure, temperature, wear...) and sets the optimum operating point.

**References**

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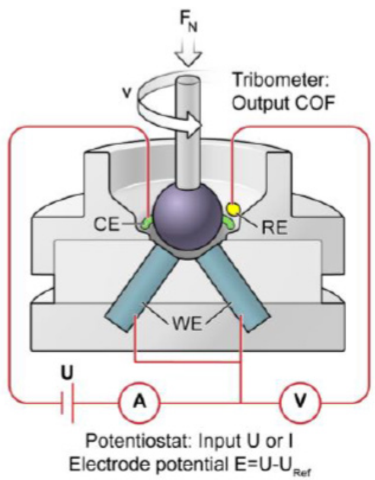


Fig. 1 Tribological set-up with connected potentiostat [2].

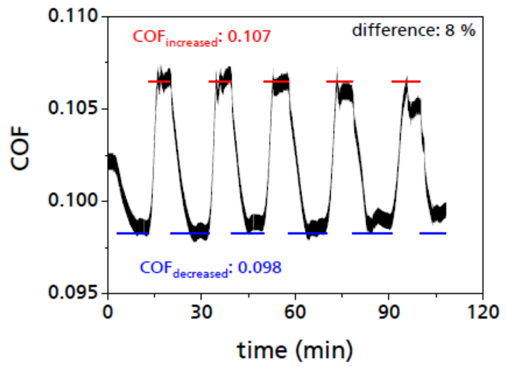


Fig. 2 Autonomous reversible course of the COF between two preset values.

**Juan Pablo Gevaudan** | Penn State Univesity, US — Wednesday

*Bio-receptive magnesium oxysulfate cement for coastal infrastructures* — 13:40 | R 1098

Shorelines and coastal areas constitute the habitat of unique and rich ecosystems [1] and host diverse human activities such as agriculture, industry and tourism. To protect and preserve the natural and the built environments on the shorelines, costal infrastructures are widely deployed. In most cases, ordinary Portland cement (OPC)-based concrete is used for its mechanical properties, durability in seawater and its low cost. However, OPC-based concrete is responsible of 7 to 8% of annual anthropogenic $CO_2$ emissions [2] and doesn't contribute to the rehabilitation of local ecosystems that provide critical ecological services [3]. To mitigate the environmental impacts associated with marine infrastructures and support coastal biodiversity and ecosystems, our work aims at developing a bio-receptive, carbon-neutral magnesium oxysulfate cement. Our approach consists in (i) customizing the pore solution chemistry through the addition of acids containing abiotic nutrients to decrease the pH and promote organisms' settlement, (ii) using metakaolin (MK) as a mineral admixture to optimize the mechanical properties of the cement and (iii) sourcing the precursors from olivine and incorporating hemp to achieve a carbon-neutral formulation. Our preliminary results show the existence of an optimum MK content for the compressive strength of our material. Moreover, using the life cycle assessment methodology, we show that our formulation has a global warming potential 50% less than OPC. These results strongly suggest that magnesia cement can be tailored to achieve a lifepromoting and low-emission building material for marine infrastructures.

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**Naeim Ghavidelnia** | University of Freiburg, DE — Thursday

*Bio-inspired programmable mechanical metamaterial with self-sealing ability* — 13:20 — R 1010

N. Ghavidelnia[1], B. Cao[1], O. Speck[3], C. Eberl[1,2,4]

Dealing with mechanical damages is a key element in achieving longevity in materials. The reaction to cope with mechanical damages such as a crack or cut is a fundamental function of biological systems in nature called the self-repair mechanism. The self-repair mechanism can be subdivided into two main phases: self-sealing and self-healing. The knowledge of the self-sealing mechanism as an initial phase of the repairing process can be transferred from living nature to engineering materials systems. Bio-inspired self-sealing materials systems from biological role models can be implemented with mechanical metamaterials which their extraordinary mechanical properties are defined by their complex inner structure. Programmability in mechanical metamaterials can be obtained from a combination of logical elements to result in particular functionalities. In this talk, we present a novel design of a mechanical metamaterial with a programmable function of self-sealing. Mechanically triggered by pressure change, due to the incoming damage, is the main characteristic of the metamaterial's unit cell which the initial change of the unit cells at the cracked zone will be transferred to the adjacent unit cells in the metamaterial to squeeze and close the crack gap. Simulation of the designed structure under actual conditions is the most significant step which should be done to evaluate the functionality of the mechanical metamaterial. Hence, realistic finite element modelling will be developed to simulate the nonlinearity and large deformation behaviour of a single unit cell and describe the self-sealing process in the whole metamaterial composed of a large number of unit cells.

**Keywords**

mechanical metamaterials | self-sealing, longevity | finite element method

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**Wilhelm Gros** | University of Freiburg, DE — Wednesday

*Cognitive-affective mapping (CAM) as measurement tool - elaboration of reliability criteria* — 13:40, R 1009

W. J. Gros[1,2], J. Fenn[1], L. Reuter[1,3], D.Schuldzinski[2,4], A. Kiesel[1,2]

Cognitive Affective Mapping (CAM) is a novel tool that can be used for assessing acceptance by displaying the relationships between concepts as well as between cognition and their affective connotation in a network. In recent years, the implementation of the method of CAM advanced, quantitative as well as qualitative analysis methods were explored concerning CAM and CAM was applied successfully on several research questions. In this study, we aim to gain further knowledge of the core quality criteria of CAM. For this, we assess the reliability of CAM via applying a test-retest reliability approach. We measure a psychological measurement object which is justifiable stable at a first measurement time point and at a second measurement time point after a week. Statistically, we correlate pre and post measurements of CAM parameters (e.g. mean valence, number of concepts, density, …) by using Pearson's R. Differences between the first and second measurement time point show potential measurement errors and deliver a first hint on the reliability of CAM. This will help to better understand and implement this method. In the end, the assessment of the acceptance of living materials systems via CAM becomes more credible.

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**Keywords**

Prospective technology assessment | Empirical assessment on technology acceptance | Quantitative empirical research | Methods for the assessment of technology acceptance | Bridging science and society

**Philipp Höfele** | Freie Universität Berlin, DE
Friday
*Nature-imitating technologies in the anthropocene: an assessment from the perspective of the history of philosophy*
11:00
R 1009

The overall aim of this talk is to outline a philosophical-ethical evaluation system with respect to nature-imitating technologies. To this end, it seeks to uncover and evaluate the theoretical and normative implications of the concepts of imitation of nature that underlie current debates about an appropriate nature-technology relationship oriented towards the concept of technical imitation of nature. From a historical perspective, the aim is to mobilize the discourses of imitation of nature in the history of the philosophy of technology since the end of the 19th century and to connect the two parallel lines of discourse on the concept of imitation of nature – one informed by the history of philosophy and one deployed in the context of contemporary natural and technical sciences that favor nature-imitating technologies as solutions to challenges articulated in the Anthropocene debate.

For nature-imitating technologies require a philosophical and ethical evaluation that the established approaches, such as technology assessment, cannot provide alone. The theoretical and normative implications of the concepts and forms of nature that are taken as models result from the fact that they are historically and culturally shaped in an essential way. The appropriate method for assessing nature-imitating technologies is therefore a philosophical-historical return to the tradition of the philosophy of technology, insofar as it deals with the concept of imitation of nature, since the concept of imitation of nature that continue to shape current discourses have already been reflected upon in detail.

**Keywords**
Ethics of technology | Philosophical reflection on technology | Philosophical reflection on nature and life | Biomimetics | Anthropocene

**References**
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*Höfele, P.*, Reuter, L.*, Estadieu, L., Livanec, S., Stumpf, M., and Kiesel, A. 2022: Connecting the methods of psychology and philosophy: Applying Cognitive-Affective Maps (CAMs) to identify ethical principles underlying the evaluation of bioinspired technologies, in: Philosophical Psychology, 1–24 [*shared co-first authorship]. DOI: https://doi.org/10.1080/09515089.2022.2113770*

*Möller, M.*, Höfele, P.*, Kiesel, A., and Speck, O. 2021: Re-actions of sciences to the Anthropocene: highlighting inter- and transdisciplinary practices in biomimetics and sustainability research, in: Elementa: Science of the Anthropocene 9,1, 1–16 [*shared co-first authorship]. DOI: https://doi.org/10.1525/elementa.2021.035*

**Johannes Hörmann** | University of Freiburg, DE
Thursday
*Morphology, concentration, potential: exploring tunable adsorption film friction with molecular dynamics*
13:40
R 1098

J. L. Hörmann*, C. Seidl, L. Pastewka

Ionic solutes in aqueous solution aggregate on immersed surfaces. The composition and structure of compact adsorption films and the complementing diffuse layers influence interfacial friction. Active friction control is possible by tuning this adsorption behavior. We focus on three parametric dimensions governing film composition and morphology, namely the involved ions themselves, ion concentrations, and electrostatic potential, and show their impact on friction mechanisms on the molecular level by means of probe-on-flat and flat-on-flat shear simulations via molecular dynamics.

**Introduction –** Surfactant adsorption films at the solid-liquid interface undergo phase transitions controlled by various environmental parameters. The anionic model surfactant sodium dodecyl sulfate (SDS) forms flat-lying monolayers at low concentrations at the aqueous solution–gold interface. With increasing surface coverage, stripe-like aggregates of hemicylindrical nature assemble. Sufficiently strong attractive electrostatic potential induces another transition towards densely packed bilayers. Active tuning of concentrations and electrostatic potential allows for precise friction control at the nanoscale by navigating the adsorption film's phase diagram [1]. Moreover, the background electrolyte's nature and concentration is known to alter surfactant aggregation behavior as well. We explore the molecular mechanisms behind concentration- and potential-dependent friction response in the model.

**Methods –** By means of all-atom molecular dynamics simulations, we slide an atomic force microscope (AFM) tip model laterally across SDS films at the $H_2O$–Au(111) interface. Thereby, we shine a light upon the molecular mechanics behind distinct friction force responses of different film phases under shear [2]. Fig. 1, for instance, compares sliding on a dense monolayer (a) with sliding across hemicylinders (b) on the basis of friction and load evolutions at the onset of lateral motion. In another batch of simulations, we use a constant potential approach by dynamic charge optimization to investigate potentialdependent friction of sodium chloride, a commonly encountered background electrolyte, in aqueous solutions confined within a nanogap [3].

**Discussion –** In the particular comparison between sliding on different aggregates shown in Fig. 1, the hemicylindrical configuration exhibits less resistance under comparable load. The model allows us to attribute changes in tribological response directly to structural properties, such as molecular alignment within the surfactant film or potential-induced alteration of the saline solution's electrochemical double layer. Automized screening of the parametric space spanned by concentrations and electrostatic potentials enables us to identify parameter-dependent friction trends.

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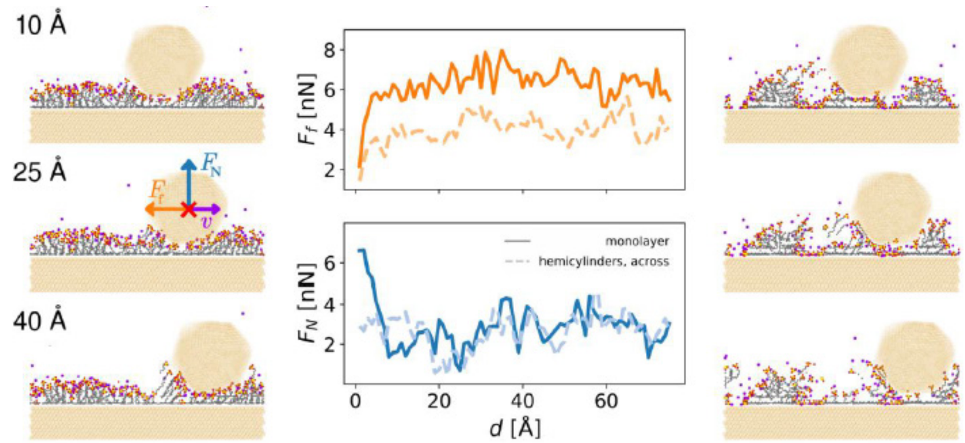


Fig. 1 Friction $F_f$ (top, center) and load $F_N$ (bottom) felt by AFM tip (radius $r$ = 25 Å ) during initial sliding phase on SDS monolayer (solid lines in plot and conceptual sketch on the left) and across hemicylinders (dashed lines, right sketch) at surface packing density $n = 3\ nm^{-2}$ , fixed surface–surface distance $a$ = 10 Å and velocity $v$ = 10 $ms^{-1}$. Labels in left hand side conceptual sketch indicate laterally travelled distance $d$ for each snapshot.

**Stephanie Ihmann** | Fraunhofer IKTS, DE — Tuesday 13:50, R 1098

*Development of novel bioinspired building and construction materials by using biogenic carbonate mineralization*

S. Ihmann[1], O. Reinhardt[2], M. Ahlhelm[1], M. Gelinsky[2]

Due to increasing population, urbanization and thus, increasing infrastructure development, global cement consumption will rise by 12-23 % by 2050 compared to 2014 [1]. With respect to the Sustainable Development Goals (SDG) and the goals of the Paris Climate Conference (2015) [2] it is essential to strive for sustainable approaches and building concepts.

In this respect the BMBF-funded project BioCarboMin (13XP5162A) aims to fill the gap and addresses (inspired by nature) the development and specific structural design of Living Building Materials (LBMs) capable of controlled and directed uptake of $CO_2$ and conversion to carbonate via Microbially induced Calcium Carbonate Precipitation (MICP) using cyanobacteria [3] or other microorganisms to produce bio-based materials.

In BioCarboMin we focus on engineering well-defined LBM constructs which allow for large-scale dimensions and large-scale production by powder technological processing routes and additive manufacturing. The key to success lies a) in the control of porosity during shaping (providing optimized conditions regarding nutrition, $CO_2$ uptake, light), b) in the used immobilizing media and c) in added filler materials.

In the first phase, the viability of bacteria embedded in different immobilization matrices (organic/inorganic hydrogels) and filler materials (e.g., kaolin, bentonite, sand), was determined. Positive results of viability in the immobilization matrices were followed by first positive results of biomineralization in different shaped parts. These promising results show that the BioCarboMin approach is not only a potential way of creating biogenic building and construction materials but also a possible alternative to established $CO_2$ reduction techniques.

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[2]Centre for Translational Bone, Joint and Soft Tissue Research, Technische Universität Dresden, 01069 Dresden, Germany

**Keywords**

Sustainable Development Goals (SDG) | bioinspired materials | Living Building Materials (LBMs) | Microbially induced Calcium Carbonate Precipitation (MICP) | biogenic building materials

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**Monsur Islam** | Karlsruhe Institute of Technology, DE — Thursday 13:40, R 1199

## *From 3D printing of carbon microarchitecture towards engineered living carbon*

M. Islam[1], J. G. Korvink[1], A. Díaz Lantada[2]

Engineered living materials (ELMs) is considered to be one of the most relevant contemporary revolutions in the field of materials science. ELMs aim to outperform current examples of "smart", active, or multifunctional materials, enabling countless industrial and societal applications [1]. Current examples of ELMs have mostly focused on either cell-derived biofilms or polymer-based hybrid living materials (HLMs) [2]. Here we postulate carbon as an ideal material for the abiotic counterpart in an HLM system due to its unique properties, including excellent biocompatibility, adjusted electromechanical properties, and tunable electrochemical properties [3]. 3D printing of carbon structures allows the design freedom enabling customizable geometrical features, which can further facilitate printing of shape-morphing carbon structures, leading to 4D architectures. Upon culturing living cells, 3D and 4D carbon structures can work synergically with the cells to express novel functionalities, which can be of high importance for several biomedical and biotechnological applications. Here, we propose a biohybrid dynamic system as a model engineered living carbon system, where the cells can actuate the motion of a 4D printed carbon scaffold. To date, we have fabricated novel 4D structures of glassy carbon using microstereolitographic and carbonization technique. Furthermore, cell-culture study within these 3D and 4D printed carbon scaffold has exhibited excellent cytocompatibility and 3D cell colonization, which are essential for the novel engineered living carbon materials. Current work is focusing on establishing the synergy between cells and carbon to achieve cell-driven actuation. Such biohybrid systems can be highly useful for several biomedical applications, including smart scaffolds, or surgical tools for remote body interiors.

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[2]Department of Mechanical Engineering, Universidad Politécnica de Madrid, José Gutiérrez Abascal 2, 28006 Madrid, Spain.

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**Indre Jödicke** | University of Freiburg, DE

Wednesday 13:20 R 1010

*Topology optimization of mechanical metamaterials using a fast-fourier-transformation based equilibrium solver*

Mechanical metamaterials are materials whose mechanical properties are largely influenced by their structure. This allows them to achieve properties unattainable by classical materials, e.g. a negative Poisson's ratio. The design of mechanical metamaterials is therefore an ongoing topic of research. A method to systematically design structures is the method of topology optimization, which is already well-established [1]. However, an ongoing challenge for topology optimization is its high computational cost. This cost is largely due to the fact that each topology optimization requires the repeated solution of the physical equilibrium.

The standard approach to solve the static mechanical homogenization problem during the topology optimization of mechanical metamaterials is the Finite Element Method. In our project [3] we propose to use instead a Fast-Fourier-Transformation (FFT-) based solver with compatibility projection [2], which promises to became a very efficient tool for the solution of this kind of problem. Therefore, we adapt the adjoint method—a standard method to efficiently calculate the gradient of a topology optimization problem—to the FFT-solver. As prove of concept, we solve small-strain, 2D-topology optimization problems. In this presentation, I will discuss examples of optimizing unit cells for specific elastic properties.

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**Ardian Jusufi** | Max-Planck-Institute for Intelligent Systems, DE

Thursday 14:20 R 1115

*Novel smart adaptive actuators for robust locomotion*

Conventional Robots are excellent at performing complex tasks in controlled situations, but they lack the adaptability and flexibility needed in a variety of fields, including exploration, inspection, and search and rescue missions in irregular environments. Biomechanical studies have shown the advantages of an animal's musculoskeletal system and proprioceptive awareness to move seemingly unaffected in unfamiliar environments.

Biologists and engineers can utilize robophysical platforms as „model animals" to advance our understanding of nature's solutions, while also giving robots new locomotion capabilities. We showcase this approach with two bio-inspired robots: A climbing robot, inspired by the Asiatic gecko (Cosymbotus platyurus), consists of specially designed whegs to drive in steep inclined surfaces and a soft active tendon-driven tail to stabilize the pitch back and reduce the force required by the whegs. We optimized the stiffness and morphology of the tail by testing the climbing performance with multiple 3d printed soft tails with different stiffnesses, coefficients of friction, and tail lengths. An optimized tail has made the robot more versatile regarding its operational conditions.

Combining soft sensors and flexible actuators, the second model animal is a soft robotic fish platform to investigate the effect of co-contraction on body stiffness control for optimal swimming performance. With our control design approach using [m, m]-Padé approximation reduced the output tracking error compared to the previously used PID-Controller. This bio-inspired fish tail robotic experimental platform allows for the discovery of the effect of tail stiffness and frequency on thrust generation.

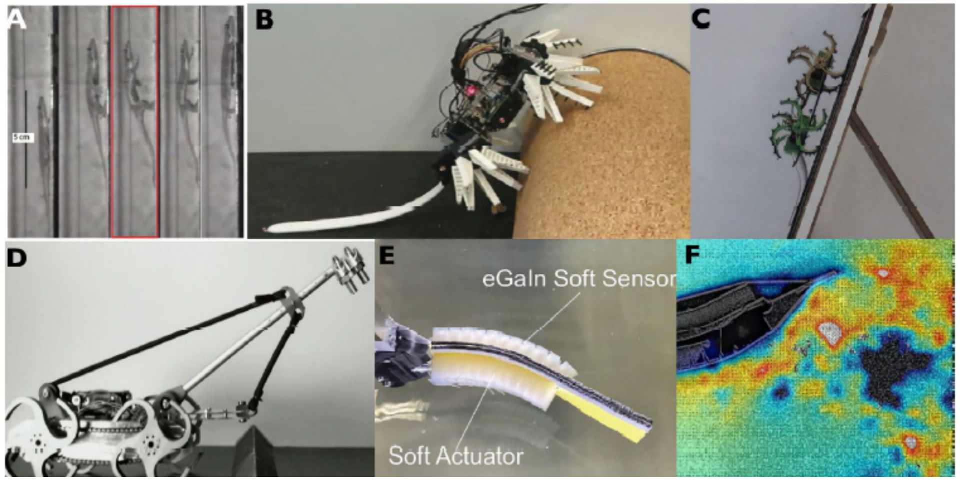


Fig. 1 (A) Side view of a climbing gecko (Hemidactylus platyurus), showing the use of the tail to recover from a forefoot slip [1] (B) Climbing robot prototype with soft, sensor-integrated stabilizing tail traversing obstacle successfully [1]. (C) Top view of the slope climbing robot prototype, showing the drive components and the holder for a centre-biased added mass. [1] (D) Side view of the elastic suspension robot prototype. [1] (E) Top view of soft robotic fish with soft actuator and sensor [2]. (F) PIV results showcasing the undulatory locomotion of soft fish robophysical platform.

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**Peter Kappel** | University of Freiburg, DE — Thursday

*Grasping by relaxing – pneumatic actuators with ligaments and tendons* — 13:40 | R 1115

P. Kappel[1,2], L. Kürner[1,2], T. Speck[1,2], F. Tauber[1,2]

Industrial hard robots often require complex sensor systems to handle objects, which differ in qualities or even to interact with living beings. Due to their soft and compliant properties, soft machines are a better-suited platform for robots that adapt to such qualities as shape, size, weight, and fragility. Widely established actuators for macroscopic applications of soft machines use embedded pneumatic networks (PneuNets) [1]. However, due to the soft properties of their bodies, classic PneuNets bending actuators have to be continuously actuated to grasp and hold an object. Therefore, the amount of energy required in form of compressed air is often relatively high. Role models from nature, such as the human hand, consist not only of soft actuators (muscles) but also of many other soft components, such as facial tissue, ligaments and tendons. Due to their elastic properties, these structures often support grasping motions in hands or claws. We developed FDM printed bioinspired pneumatic bending actuators that extend by actuation and thereby pre-stretch integrated elastic ligaments. When actuation stops, bending occurs as the ligaments relax. Through this principle, energy input is only needed for opening– gripping or holding an object is powered by the relaxation of the ligaments and the energy stored there. Inspired by the digital tendon locking mechanism of the avian foot [2], we significantly reduced the maximum air pressure required for extending the actuator by integrating a free moving tendon, while the locking of the tendon during grasping led to an increased blocking force.

[1]Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Tech-nologies
[2]Plant Biomechanics Group (PBG) Freiburg, Botanic Garden of the University of Freiburg

**Keywords**
Soft robotic grippers | Bioinspiration | Demonstrators | 3D Printing

**References**

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**Andrea Kiesel** | University of Freiburg, DE — Wednesday 13:20 R 1009

## *Cognitive-affective maps as a novel research tool – bridging the gap between quantitative and qualitative research*

A. Kiesel[1], L. Reuter[1], J. Fenn[1], W. Gros[1], S. Livanec[1], M. Stumpf[1]

Cognitive-Affective Maps (CAMs) can be applied to visualize attitudes and beliefs in a network. Each concept node in the network is affectively connotated as positive, negative, neutral, or ambivalent and the nodes can be related to each other by lines characterizing supporting or opposing relations. To demonstrate that Cognitive-Affective Mapping is useful in empirical and mixed methods research, we applied CAMs in online studies. Thereby, we used CAMs as the dependent variable in different empirical designs. In a pre-post comparison, we investigated whether participants' cognitive-affective representations of the corona pandemic changed more due to leisure walking than in a control group. Additionally, we applied CAMs to explore students' attitude change over the course of an ethics seminar. In a further study, we explored whether network parameters of CAMs are suitable to predict the variable perceived coronavirus threat. And finally, CAMs can be used in form of an independent variable. Here we tried to change attitudes of participants by asking them to first draw a CAM on a controversial topic and then presenting them with a CAM with an opposing assessment of this topic. To assess attitude change, we applied a mixed-measure approach with CAMs and questionnaires as pre-post measures.

Taken together, CAMs can be analyzed by quantitative and qualitative analysis techniques. They are useful as a stand-alone research instrument as well as in mixed-measure studies as an additional variable. We conclude that the potential to combine quantitative and qualitative elements with CAMs represents a promising approach for mixed methods research.

[1]Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies and Institute for Psychology, University of Freiburg

**Keywords**
Quantitative empirical research | Qualitative empirical research | Methods for the assessment of technology acceptance

**Frederike Klimm** | University of Freiburg, DE — Tuesday 14:50 | R 1010

## *Tendrils of climbing plants as inspiration for soft robotics*

F. Klimm[1-3], T. Speck[1-3], M. Thielen[1,2]

Plants as rooted, sessile organisms are not usually associated with moving and, therefore, rather unexplored as inspiration for robotics. Many plants do move a lot though, which is particularly evident for climbing plants. Via growth processes and continuous adaptation of their body, these plants use several different methods to attach themselves to external supports for growing upwards. Within the GrowBot project, we investigate climbing plant movement as an inspiration for a new paradigm of movement in robotics (GrowBot EU H2020, grant agreement no. 824074).

As tendril climbers, the passionflowers *Passiflora caerulea* and *P. discophora*, for example, feature multiple filamentous tendrils, which allow them to anchor to a variety of different supports either via “grasping” (contact coiling) relatively thin slender structures (*P. caerulea*) or by forming attachment pads, allowing them to adhere even to flat supports (*P. discophora*). Eventually, the tendrils coil along their length axis, forming a spring-like structure. Our analyses show how coiling shortens the tendrils, thus lashing the plant stem to its support and that the dampening springs of tendrils render the attachment structures a highly energy dissipating, fail-safe system, both on the level of individual tendrils and via the interaction of a multitude of these attachment organs [1,3]. Climbing plant tendril motion and anchoring has already fostered the development of novel actuators and gripping devices [e.g. 2,3].

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[2]*Freiburg Materials Research Center (FMF), University of Freiburg*

[3]*Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Tech-nologies, University of Freiburg*

**Keywords**

biomimetics | bioinspiration

**References**

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**Mona Küüts** | University of Tartu, EE

Tuesday 13:50 R 1115

*Machine embroidery provides mechanical support for electroactive components in wearable robots*

Modern health and care technologies, from being worn as an accessory to entirely conforming to the skin, are required to be safe, soft, flexible, breathable, and light in weight [1]. Consequently, textiles intertwined with electroactive components are a promising material-level platform in wearable robotics. As one prevalent approach, the actuators are cut from a sheet of fabric to allow for off-plane displacement. Cutting interrupts mechanical force chains in threads and can compromise the textile’s structural integrity. A method for combining active and load-supporting functions in the same textile is therefore needed. We demonstrate machine embroidery as an exclusive method to program actuation modes already in the textile fabrication phase, preserving thread integrity. The embroidering method was demonstrated on a leaf-inspired tunable-transpiration textile [2], suggesting the uninterrupted threads to be functional in structural strength, similar to veins that support a leaf lamina. We demonstrate the program-defined alignment of individual threads as a method for simultaneously supporting off-plane actuation as well as providing longitudinal stiffness. Consequently, the fibrous support results in the engagement of soft electroactive components in a mechanically robust platform. The capability for thread placement in arbitrary patterns via embroidery allows for the design of complex actuation patterns on a conformable surface, enabling new wearable technologies.

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**Jasleen Lall** | University of Freiburg, DE — Friday
*Towards autonomous light-responsive actuators* — 12:00 | R 1199

J. Lall, H. Zappe, G. Sick[1], E. Sick[1]

Among the different stimuli to actuate soft-matter-based actuators, light is particularly attractive in many ways as its properties – wavelength, polarization, and intensity can be optimized as per the target application. Liquid crystalline-based actuators are a promising candidate from the family of soft-matter-based actuators for obtaining light-responsive actuation. The actuation profile can be programmed by defining the orientation of liquid crystals. By modifying the polymer matrix, it is possible to alter the mechanical performance of these materials.
We present here a toolbox for developing such light-responsive liquid crystalline-based actuators. Using photoalignment, it is possible to align the liquid crystals in any arbitrary pattern as per the target actuation profile. By selectively polymerizing the network with spatially structured light, it is possible to structure the actuators without needing extra processing steps such as laser machining. By carefully selecting the photoswitches, we will also demonstrate the wavelength-selective photoactuation with different response times.

[1]*Chair of Micro-optics, Department of Microsystems Engineering, University of Freiburg*

**Jens Leonhardt** | University of Freiburg, DE — Friday
*Thermo-responsive liquid crystalline bimetal-like actuators* — 11:20 | R 1199

J. Leonhardt[1,2], J. Rühe[1,2]

Materials science was always inspired by biological systems. Notably, anisotropic and cross-linked liquid crystalline (LC) polymeric systems are often referred to as artificial muscles, exhibiting extraordinary and reversible actuation behaviours with strains of up to several hundred percents [1]. The shape-switching is driven by the thermally triggered and reversible anisotropic-isotropic transition ($T_{ni}$) of the LC order (that has been locked-in during a previous polymerization step), inducing an orientational change of the LC molecules (mesogens) within the polymer network. This combined push-pull effect of all single mesogens translates into the macroscopical actuation of the whole polymer system (Fig. 1).

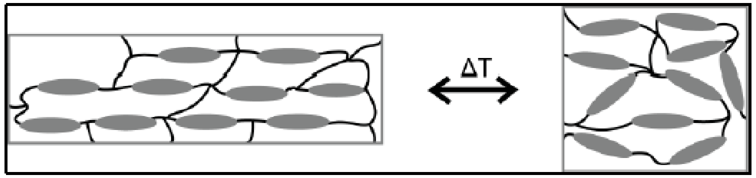


Fig. 1 Thermally triggered and reversible actuation of cross-linked liquid crystalline polymer system with uniaxial alignment, leading to a contraction/elongation along the alignment director of the mesogens.

In our work we fabricate both uniaxially aligned (anisotropic) and unaligned (isotropic) single LC polymer films by the so-called glass-cell filling, where the mesogens are aligned with the aid of surface rubbing (Fig. 2, a) [2]. Hereafter, by glueing together two of such films (Fig. 2, b), we obtain Bimetal-like LC bilayer systems whose thermal actuation behaviour results in a bending motion due to the different shape-switching of both single LC layers, which is the contraction/elongation and "normal" positive thermal expansion for uniaxial aligned and unaligned films, respectively (Fig. 3). By changing the chemical composition of the LC systems and thereby varying their properties (i.e. $T_g$, $T_{ni}$, young's modulus, actuation stress), we can finely tune the bending motion of the bilayers (i.e. actuation temperature, curvature, work capacity).

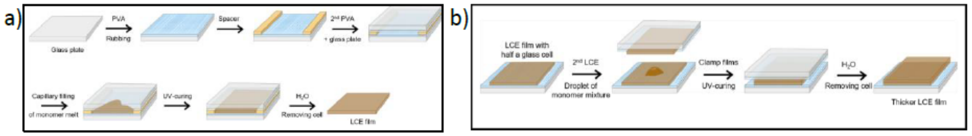


Fig. 2 a) Glass-cell filling for the fabrication of LC polymer films. b) Glueing process to fabricate LC bilayer systems.

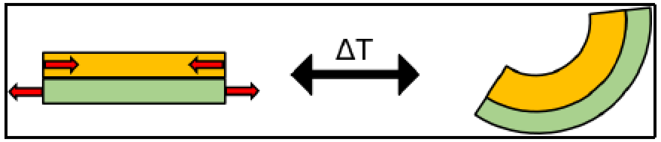


Fig. 3 Scheme for the bending motion of a Bimetal-like LC bilayer system.

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[2]*FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies, University of Freiburg, Freiburg, Germany*

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**Sabrina Livanec** | University of Freiburg, DE — Wednesday

## *Bioinspired technologies and their concept of life: cognitive-affective mapping as a communication tool in interdisciplinary collaborations*

13:00
R 1009

S. Livanec[1], P. Höfele[2], J. Fenn[1], L. Reuter[1], M. Stumpf[1], A. Kiesel[1]

Originally, Cognitive-Affective Maps (CAMs) were intended to visualize attitudes and beliefs in ideological conflict situations as a coherent network consisting of nodes representing a cognitive content together with its affective rating, connected by supportive or opposing lines. CAMs were initially a pure visualization tool to depict existing data sets, e.g., from qualitative interviews. We have recently advanced the method to the end that CAMs can now also be used to collect large data sets—in face-to-face situations or for online data collection with the browser-based software *Valence* or C.A.M.E.L. To validate the method, we examine different use cases for Cognitive-Affective Mapping.

In the study we present here, we proposed CAMs as a facilitator of interdisciplinary communication by exploring the notion of life as one of the defining concepts for the development of bioinspired technologies. We asked researchers from eight different disciplines related to the development of bioinspired technologies to draw a CAM on their concept of life. We hypothesized, first, that an enrichment of the concept of life can be conducive to research on bioinspired technologies and, second, that an examination especially of the differences between the discipline-specific definitions can lead to scientific and technological innovations. Asking researchers to draw a CAM proved to be a practical, timeefficient method that leads to easily graspable and vivid visualizations, and we propose to use CAMs as a tool in contexts of inter- and transdisciplinary communication and knowledge transfer as well as innovation management.

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**Keywords**

Quantitative empirical research | Qualitative empirical research | Interdisciplinarity | Transdiciplinarity | Methods for the assessment of technology acceptance

**Fabian Meder** | Istituto Italiano di Tecnologia, IT

Tuesday 13:30 R 1115

*Electrification of living plant leaves in wind and rain and its capability for energy harvesting*

F. Meder[1], S. Armiento[1], B. Mazzolai[1]

Leaves constitute one of the largest and most crucial biointerfaces on Earth and this surface is frequently interacting with wind and raindrops. This mechanical interaction with the leaf surface and related energy transfer are partially converted into static charges on the outer leaf cuticle. The charges created on the leaf surface through solid-solid and liquid-solid contact electrification depend on the leaf's composition like the epicuticular wax layer structure [1]. Moreover, the charges interact with the cellular tissue operating as an ion-conductive electrode. This material-based energy conversion capability of plant leaves can be augmented when the leaves are combined with tailored artificial materials, especially in the case of wind-energy harvesting. Adapted to interact with the leaf under natural conditions artificial leaves can be combined with plants to increase the efficiency of surface charging, for example through transient contact-and-separation movements in wind and by connecting electrical circuits to the inner plant tissue [2,3]. Here, we show our recent results on fundamental aspects of energy conversion by wind and rain drops on the leaves and, moreover, exploit living plants and their materials as components of high-tech devices such as wind energy harvesters and sensors (some examples are displayed in Fig. 1). The technology has application potential in internet of things, wireless sensor networks as well as smart forestry and agriculture.

*[1]Bioinspired Soft Robotics, Istituto Italiano di Tecnologia, Genoa, Italy*

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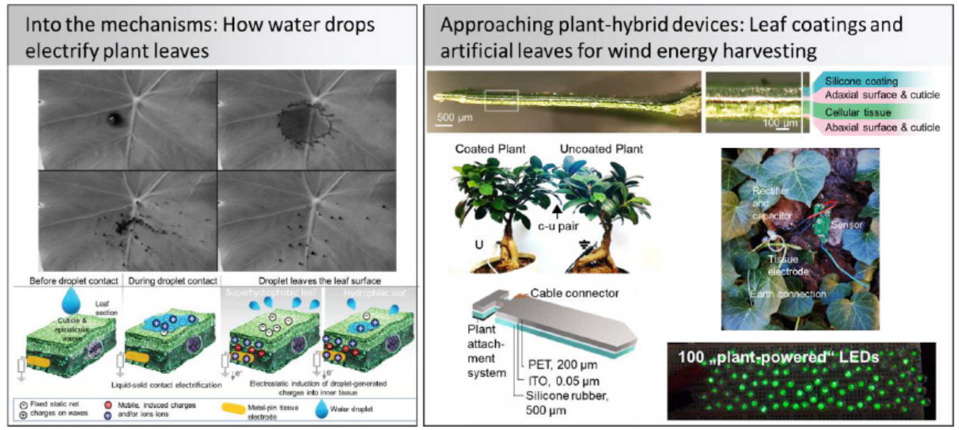


Fig. 1 Preview of some results that will be presented. Left: Mechanism of electrification of the leaf cuticle by water droplets. Right: Plant-hybrid devices for energy harvesting in which energy conversion is partially done by the plant tissue.

**Edoardo Milana** | University of Freiburg, DE

Thursday 13:20 R 1115

*Embodying mechanical intelligence in soft machines via nonlinear networks of inflatable actuators*

E. Milana[1], B. Gorissen[1]

Elastic inflatable actuators (EIAs) are a popular technology to drive the motion of soft machines, due to their simple fabrication process, low costs, large deformations and fast responses. The

functionality and versatility of tasks that a soft machine can perform depend on its number of actuators. However, the major drawback of EIAs is the need for dedicated valves to control their movements, where such valves are typically bulky and made of hard materials, compromising the softness of the machine in untethered configurations. Therefore, implementing a large number of EIAs becomes critical as the gains in functionality are canceled out by the increase of stiff hardware components. An elegant solution is to interconnect multiple EIAs and passive valves in a fluidic network that is controlled by a single pressure source and shift the control rules from the software to the hardware of the soft machine (Fig. 1). In this context, mechanical intelligence can be encoded in the body of the soft machines by harnessing the nonlinear properties of the fluidic networks, either caused by the pressure-volume characteristics of the actuators or the flow-pressure characteristics of the passive valves. In this work, we report on the recent advances in embodying mechanical intelligence through nonlinear fluidic networks, showing a soft articulated tetrapod that walks in an underactuated configuration and a system of bending actuators that move with a metachronal pattern inspired by biological cilia using a single pressure input.

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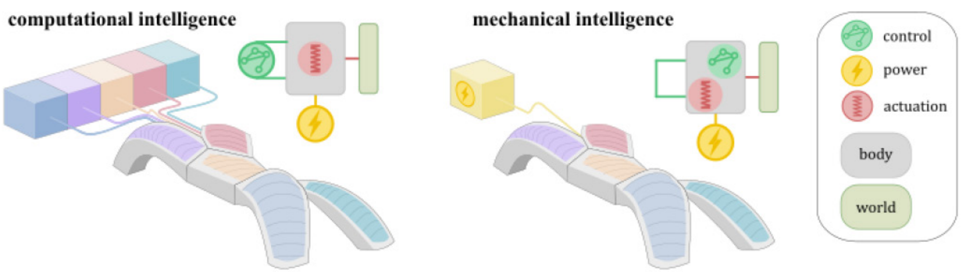


Fig. 1. Schematic overview of the difference between classical computational intelligence, where the control rules are encoded in the software of a microcomputer, and embodied mechanical intelligence, where the control rules are encoded in the nonlinear mechanical characteristics of the soft machine. By harnessing mechanical intelligence, less rigid external components are required.

**Efstathios Mitropoulos** | University of Freiburg, DE — Thursday 14:00, R 1010

*Effects of local elasticity on the flow behavior and material transport in dendritic microfluidic designs*

E. Mitropoulos[1,2], C. Stamp[1,2], T. Pfohl[1,2]

The longevity of an autonomous adaptive material system can benefit from responsive and reconfigurable fluidic networks allowing for communication between parts of the system. In this study, dendritic microfluidic networks in elastomers were designed to control the transport and propagation of substances flowing through them and the direction of those processes. The designs, based on constructal laws, reduce the pumping power required to facilitate directional flow for a given amount of available space for transport channels. This feature is further improved by introducing thin membranes as channel walls. The thickness and shape of the membranes allow for the control of the local elasticity. To study the responses of the networks to different stimuli, experiments with different working fluids (e.g., non-swelling water, swelling isopropanol, viscoelastic solution) were performed. For water and isopropanol flows, different network designs exhibit linear flow behavior for low pressure or flow rate values. After exceeding critical values of these parameters, the hydrodynamic resistance for parts of the networks decreases non-linearly due to membrane deflections, which promotes flow through these parts. Similarly, in parallel-flow experiments of swelling and non-swelling fluids the total flow rate can change for the same total pressure, if the individual inlet pressures are reversed for each fluid. Finally, for viscoelastic flow effects possibly associated with elastic turbulence were observed for channels surrounded by membranes introducing a way to modify the local hydrodynamic resistance. Our results can be used towards the design of a case-sensitive network to be embedded in autonomous and adaptive material systems.

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[2]*Institute of Physics, University of Freiburg*

**Michelle Modert** | University of Freiburg, DE

Tuesday

*Leaf unfolding pattern and biomechanical analyses of the lamina* 14:50 | R 1199

M. Modert[1,2], T. Masselter1, T. Speck[1,2,3]

Leaf unfolding is widespread in nature and has a variety of patterns: found e.g. in tree leaves, tropical climbers or floating waterlilies. This diversity makes leaves promising models for bio-inspired (un)packaging systems. However, reliable and reproducible methods for analysing the unfolding mechanisms are still lacking and previous studies address single species and/or mathematical modelling only. Here, three approaches will be established to set up measurement criteria and to assess leaves' biomechanical properties: (1) Tensile experiments on isolated leaf areas, (2) documentation of lateral forces during natural leaf unfolding, and (3) artificially induced unfolding in a tensile testing machine with documentation of required forces for unfolding. These approaches will first be performed on *Syngonium podophyllum* and subsequently, leaf species with different lamina properties and distinct unfolding principles will be analysed and compared. A special focus will be placed on unfurling movements since two principles seem to have evolved here: simultaneous vs. successive unfurling of the two leaf halves. The former pattern can be observed in *Pilea peperomioides* and different waterlilies, for example, and the latter occurs in *Syngonium podophyllum* and other species of the Araceae family. The envisaged biomechanical approaches will allow comparison of different leaf species, independent of their unfolding principle, their habitat or environmental conditions, and will contribute to a better understanding of leaf unfolding in plants laying the basis for technical implementation.

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[2]*Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies – Germany*

[3]*Freiburg Materials Research Center (FMF) – Germany*

**Alale Mohseni** | Penn State Univesity, US

Tuesday

*3D printing mycelium-based composites: notes on material composition, extrudability and 3D printing workflow* 14:50 R 1098

The construction industry has a significant contribution to global $CO_2$ emissions. Material extraction, processing, and demolition account for most of its environmental impact. As a response, there is an increasing interest in developing and implementing innovative biomaterials that support a circular economy, such as mycelium-based composites. Mycelium is the fibrous root system of fungi. Mycelium-based composites are renewable and biodegradable biomaterials obtained through ceasing mycelium's growth on organic substrates, including agricultural waste. Cultivating mycelium-based composites within molds, however, is often wasteful, especially if molds are not reusable or recyclable. Shaping mycelium-based composites through 3D printing can minimize mold waste while allowing intricate forms to be fabricated [1,2,3].

In the *MycoPrint* research, we explore the use of waste cardboard as a substrate for cultivating mycelium-based composites and the development of extrudable mixtures and workflows for 3D printing mycelium-based building components. In the conference presentation, we will first review existing research about the use of mycelium-based materials in architectural design, including the recent 3D printing efforts. We will then present the *MycoPrint* experiments that we have conducted, and focus on the main challenges that we have faced (i.e. contamination) and the ways in which we addressed them. In this on-going effort, our current emphasis is on the integration of a 6-axis industrial robotic arm into the 3D printing process, which will allow for further flexibility during the fabrication process. Mycelium is a *living material*, and robotic 3D printing can shape the mycelium mixtures in unconventional ways to produce *living materials* with enhanced adaptability.

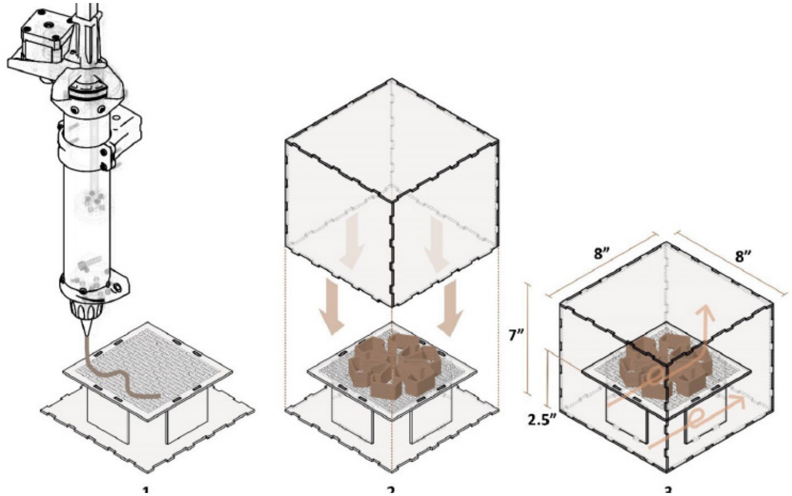


Fig. 1. Isolation acrylic box. (1) 3D printing on the printing bed, (2) enclosing the box, (3) airflow in the box helping the mycelium growth.

Fig. 2. 3D printed mycelium-based component growing in the isolation box for 7 days.

| | 1st day | 3rd day | 5th day | 7th day |
|---|---|---|---|---|
| **1st 3D printed sample** | | | | |
| **2nd 3D printed sample** | | | | |
| **3rd 3D printed sample** | | | | |
| **1st Petri dish** PH (1g) + Water (10 mL) | | | | |
| **2nd Petri dish** MC (2.5 g) + Water (10 mL) | | | | |
| **3rd Petri dish** MC (2.5 g) + Water (10 mL) + PH (1 g) before 3D printing | | | | |
| **4th Petri dish** MC (2.5 g) + Water (10 mL) + PH (1 g) after 3D printing | | | | |

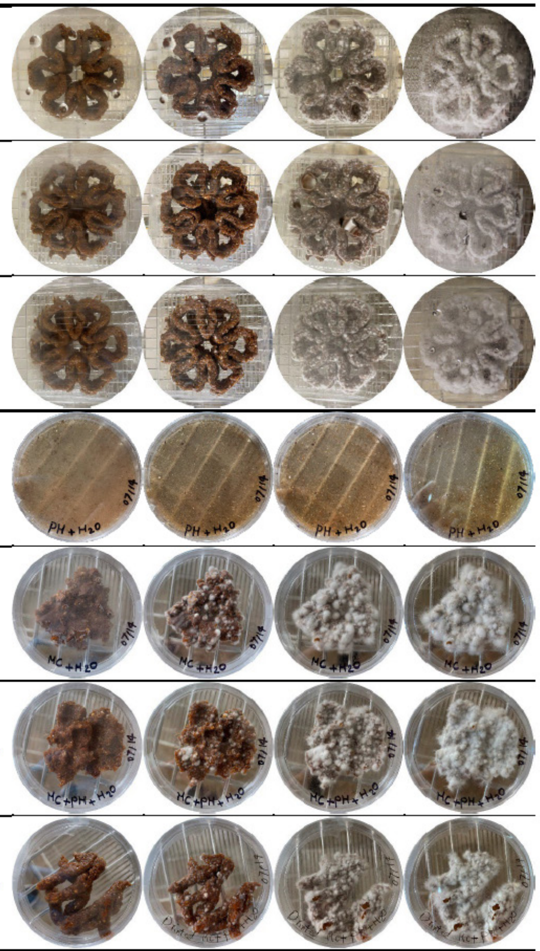

Table 1. The 3D printed samples kept in the sterile-isolated acrylic box, and isolated materials in the Petri Dishes on each step of mixing before 3D printing.

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**Martin Möller** | University of Freiburg, DE — Thursday, 13:40, R 1009

*Development of a tiered methodological framework for a prospective sustainability assessment of novel technologies and materials systems (TAPAS)*

M. Möller[1,2], R. Grießhammer[2]

Sustainability assessments of technologies and materials systems at an early stage of their development often face the challenge of insufficient data availability, which makes them lag behind the pace of innovation. Against this background, this contribution presents TAPAS (***T**iered **A**pproach for **P**rospective **As**sessment of Benefits and Challenges*) as a new, tiered methodological framework that enables actors in the innovation process to start conducting robust assessments autonomously and as early as possible.

TAPAS is based on the approach of prospective technology assessment, which attaches great importance to the self-reflection of the actors involved. As an evolution of this approach, TAPAS envisages a tiered assessment in which, depending on the maturity of the analyzed object as well as on the data available, low-threshold instruments with different level of detail are applied that cover both opportunities and risks: For example, a prospective chemicals screening is conducted as part of an "early warning system". In the context of an "early encouraging system", new methodological ground was broken with the development of a detailed benefit analysis using an indicator set derived from the 2030 Agenda.

In order to test the applicability of TAPAS in praxis, two case studies were conducted within the *liv*MatS framework. These proved the developed tools to be fundamentally suitable for R&D projects in the field of basic research, with their application providing concrete suggestions for substituting solvents of toxicological concern (e.g., DMF). Furthermore, promising fields of application for the *liv*MatS materials systems (e.g., energy supply for off-grid sensors) could be identified.

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[2]Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies, University of Freiburg, D-79110 Freiburg, Germany

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**Max Mylo** | University of Freiburg, DE — Tuesday, 14:30, R 1010

*Learning from the damage-resistant connection of the parasitic European mistletoe and its host for material compounds*

M. D. Mylo[1,2,3], M. Hofmann[1,2], C. Eberl[1,3], T. Speck[1,2], O. Speck[1,2]

The European mistletoe (*Viscum album*) is an evergreen (hemi-)parasite that deprives its host trees from water and solved nutrient salts (Fig. 1A). Mistletoes form a so-called haustorium that forms a close physiological and mechanical connection with their host (Fig. 1B), enabling a lifespan of 20+ years and a size of 2 meters in diameter. However, despite the resulting own weight of the mistletoe and additional wind loads, the connection between the two species never fails. This makes it a perfect role model for a long-lasting, damage-resistant connection between two materials systems with differing mechanical properties. To uncover the underlying functional principles, we conducted anatomical (light microscopy), morphological (comparative µCT scans with tissue segmentation), and biomechanical (uniaxial tensile tests) analyses of the mistletoe-host interface. A clear cellular dividing line between the two species was apparent. However, the transition from lignified host tissue to predominantly parenchymatous mistletoe tissue is marked by a gradual decrease of cells with thickened or lignified walls, smoothening the structural and mechanical transition (Fig. 1 C&D). Several small sinkers anchor young mistletoes inside their host and increase the contact area. Over the years, these grow together and form one large main sinker [1]. The redundant anchoring mechanisms is also apparent in the force-displacement curves of the mechanical analyses (Fig. 1E-G), which is prolonged by the pre- and post-failure events of the individual sinkers, increasing the energy required for sample failure [2]. Based on our findings of this hierarchically structured, multifunctional plant materials system with gradient and redundancy mechanisms, we see a great potential for bioinspired joining of technical materials with different mechanical properties.

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*[2]Plant Biomechanics Group @ Botanic Garden Freiburg, University of Freiburg, Germany*

*[3]Department of Microsystems Engineering, University of Freiburg, Germany*

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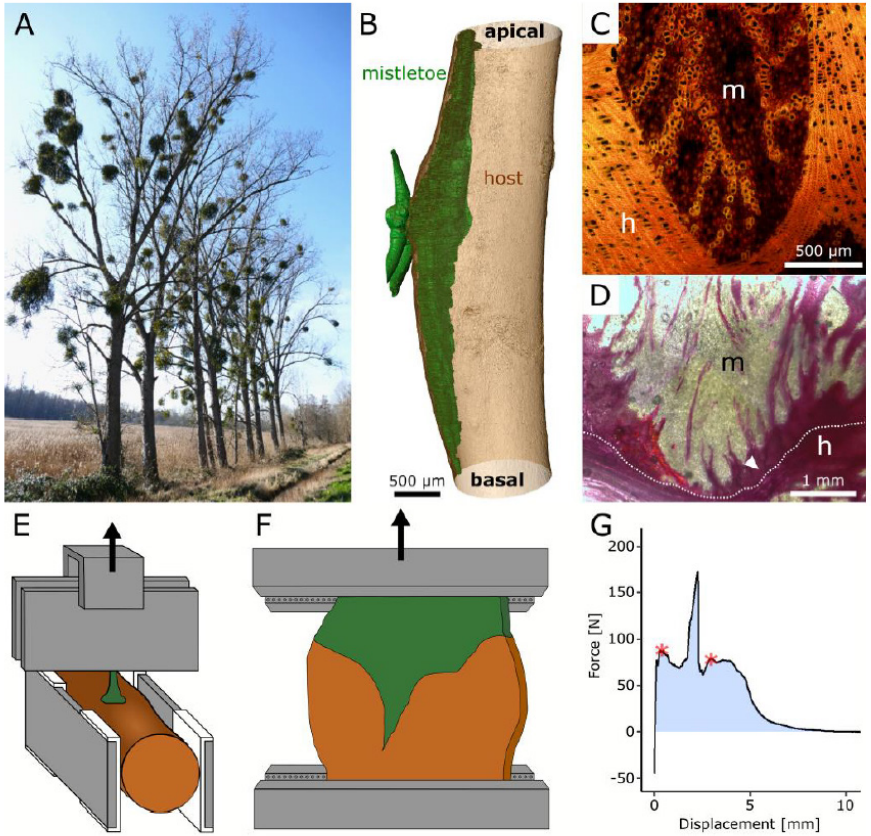


Fig. 1 (A) Mistletoe (*Viscum album* ssp. *album*) infested trees during winter in Southern Germany. (B) Segmented µCT scan of a 4-year-old mistletoe (colored in green; with cut leaves) inside the host branch (colored in transparent brown). Stained thin sections (C: acridine orange stain; D: Phloroglucinol-HCl stain) of the interface between mistletoe (m) and host (h). Drawing of uniaxial tensile tests of (E) intact and (F) sliced (cut through the attachment site) mistletoe-host samples for mechanical characterization of their connection. (G) Representative force-displacement curve of a tensile test on an intact sample with pre- and post-failure events (red asterisks) and the work of fracture (integral plotted as blue area) marked. B-D are adapted from Mylo et al., 2021 and E-G are adapted from Mylo et al., 2022, all published under the terms of the Creative Commons Attribution License (CC BY 4.0).

**Filipe Natalio** | Weizmann Institute of Science, IL — Wednesday, 13:20, R 1115

*Living materials as biological factories for the production of functional textiles with unnatural tailored properties*

Harnessing biological living systems is one of humanity's ultimate frontiers. Yet, the intrinsic complexity of higher organisms and the lack of a comprehensive, in-depth understanding of the underlying mechanisms and their interactions across a multitude of scales have primarily hindered their use as living materials to bio-manufacture materials with desired and unnatural properties. In order to successfully use living systems as biofactories and take full advantage of their capabilities, a shift toward integrating data from diverse disciplines and a deep understanding of mechanisms from the molecular to the organism level is required. I will discuss our recent progress in combining the chemical design of building blocks carrying specific functions, exploration of plant physiology, tissue culture, and biochemistry of cotton (*Gossypium hirsutum*) toward the biomanufacturing of cotton fibers with desired and unnatural properties. This novel and multidisciplinary strategy has the potential to pave the way for promoting the exploration of green, clean production processes that make use of living materials, which are essential to the implementation of a future bio-based global economy.

**Alejandro Palacio-Betancur** | Penn State University, US — Friday, 11:40, R 1199

*Motion planning and control of friction-driven reconfigurable adaptive structures*

A. Palacio-Betancur[1], A. Rácz[2], M. A. Maghsoudlou[2], V. Slesarenko[2], M. Gutierrez Soto[1]

The conventional design of materials for engineering applications consists of achieving high performance for specific conditions or average performance for a broader range of conditions. However, implementing living materials can improve their performance for external conditions by adding a reconfiguration capacity. This is achieved by implementing multiple elements connected by joints to create a system that can move and adapt in real-time. These systems can be visualized at the macroscopic level with adaptive facades, mesoscopic level with deployable origami-inspired structures and mechanical metamaterials, and microscopic level with microelectromechanical devices. In robotics, these mechanisms usually require many actuators that enable a wide range of motion and capabilities. However, the energy requirements increase exponentially with the length scale of the system, and the control tasks become challenging. This study proposes an alternative solution that relies on semi-active joints with tunable properties, such as friction-based joints that are activated with external non-mechanical stimuli combined with a single linear actuator that will allow the change of shape of the entire system. Since this system only has a single active component, the shape control is restricted to the actuator's linear motion and the joints' locking states, making motion planning a non-trivial problem. Therefore, this research introduces motion planning algorithms based on Rapidly-exploring Random Trees and sub-slider-crank systems that explore the system's state space stepwise through single degree-of-freedom motions. The proposed solutions are investigated toward the realization of reconfigurable adaptive building facades for future adaptive architecture in smart cities.

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[2]*University of Freiburg, Germany. METALAB research group: https://slesarenko-lab.com/ORC ID: 0000-0003-2689-9918*

**Keywords**

Material based actuators | environmental adaptivity | adaptive material systems | adaptive architecture | artificial intelligence

**Related Publications**

*Skarsetz, Oliver, Viacheslav Slesarenko, and Andreas Walther. „Programmable Auxeticity in Hydrogel Metamaterials via Shape-Morphing Unit Cells." Advanced Science 9, no. 23 (2022): 2201867.*

*Palacio-Betancur, Alejandro, and Mariantonieta Gutierrez Soto. „Adaptive tracking control for real-time hybrid simulation of structures subjected to seismic loading." Mechanical Systems and Signal Processing 134 (2019): 106345.*

*Palacio-Betancur, Alejandro, and Mariantonieta Gutierrez Soto. „Recent Advances in Computational Methodologies for Real-Time Hybrid Simulation of Engineering Structures." Archives of Computational Methods in Engineering (2022): 1-26.*

## Guido Panzarasa | ETH Zurich, CH

*Sustainable wood materials for energy applications*

Thursday 14:00 | R 1098

G. Panzarasa[1], I. Burgert[1,2]

Since the last years, wood materials science is experiencing an amazing revival, with several research groups worldwide exploring the use of wood as a scaffold, embedding new functionalities resulting in materials for advanced applications. This requires both to make good use of wood's intrisinc hierarchical structure, but also to ensure that the benefits of wood itself (renewability, $CO_2$-storing ability, biodegradability) are kept to the maximum extent possible in the final material. This presentation will showcase recent advances in the design and production of sustainable wood materials that could help consistently improve the energy efficiency of smart buildings by enabling the production of energy from mechanical movement by piezo- and triboelectric mechanisms („wood nanogenerators") [1,2]. The preparation of electrically-conductive wood materials by an innovative technique, iron-catalyzed laser-induced graphitization (IC-LIG) [3], will also be showcased together with its applications for e.g. wood electroluminescent devices.

[1]*Wood Materials Science, Institute for Building Materials, Department of Civil. Environmental and Geomatic Engineering, ETH Zürich, Laura-Hezner-Weg 7, 8093 Zürich, Switzerland.*

[2]*WoodTec group, Cellulose and Wood Materials, Empa – Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland*

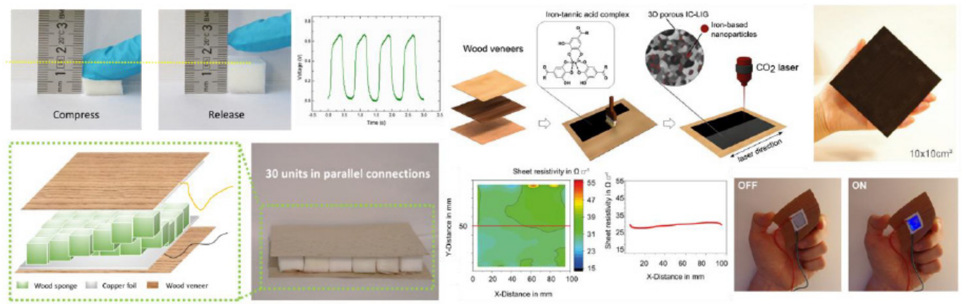


Fig. 1. (a) Piezoelectric wood sponge nanogenerator. From ref. 1. (b) Iron-catalyzed laser-induced graphitization on wood [3].

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## Charalampos Pappas | University of Freiburg, DE

*Phosphate-driven systems chemistry*

Tuesday 14:10 | R 1199

Biopolymers such as proteins and DNA carry out functions central to life in a task specific manner. These compound classes require the spontaneous oligomerisation of the constituent monomers to be controlled, yielding biopolymers with highly specific structures in water. In the realm of proteins, their overwhelming molecular complexity largely results from combinations of just twenty amino acids that are found across all life forms [1]. Such processes emerge from a single amino acid activation using the chemical energy, which is stored in phosphate bonds and drive organic synthesis in water, reactivation mechanisms and formation and degradation pathways in a fully automated manner. This phosphate-driven life-like matter of self-organised structures unravels new pathways towards the synthesis of structure and function in future self-assembling systems [2]. Inspired by such dynamics, we follow a systems chemistry pathway towards adaptivity in peptide libraries. Herein, we demonstrate the spontaneous formation of peptide oligomers emerging from single monomers, which are capable of forming supramolecular structures in water. The autonomous construction of chemically activated libraries is achieved through modification of single amino acids with phosphate esters. Upon reactivating the libraries with phosphate "food", the system is capable of achieving selectivity, as a result of self-assembly. Moreover, pathway-dependent complexity is triggered upon offering into the system competing nucleophiles, such as alcohols, demonstrating phosphate-driven non-equilibrium self-assembly, involving fuels with high-information content. The chemically activated approach enables access to materials that respond to the presence of chemical energy and displaying mnemonic effects.

**Keywords**

Systems Chemistry | Peptide self-assembly | Chemically fueled networks

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**José Pinto Duarte** | Penn State Univesity, US

Tuesday 14:30 R 1098

*Exploring the use of shape changing materials to design responsive facades: integrating sensing and actuation*

In a context of severe climate change, designing buildings that adapt to changes in the environment in real time is of paramount importance. The goal of such adaptive response is to optimize performance, while minimizing the consumption of energy. A possible strategy to design responsive facades uses smart materials integrating sensing and actuating capabilities. Smart materials are designed to adapt and transform in response to environmental stimulus, reversibly altering their properties. They can act as sensors, actuators, and regulators at the same time, without the need for any additional energy for mechanical or electronic control. In shape-changing smart materials, a stimulus (i.e. heat, water) causes a strain in the material, thus changing its shape. Shape-changing materials have become increasingly popular among architects in designing responsive systems. One of the greatest challenges of designing with these materials is their dynamic nature, which requires architects to design with the fourth dimension, time. This abstract presents a study that formalizes the shape-changing behavior of three-dimensional printed wood-based composite materials and the rules that serve to compute their shape change in response to variations in relative humidity. In this research, we first developed custom three-dimensional printing protocols and analyzed the effects of three-dimensional printing parameters on shape-change. We thereafter three-dimensional printed kirigami geometries to amplify hygroscopic material transformation of wood-based composites. Finally, we discuss future research steps.

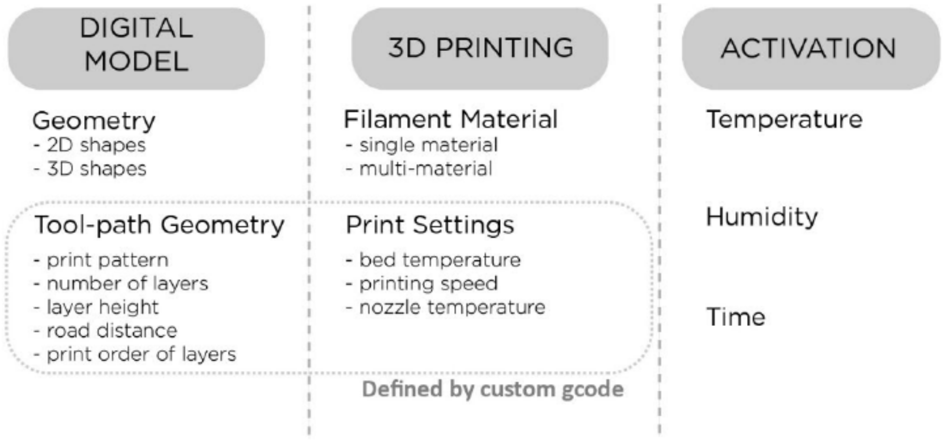


Fig. 1. The framework for systematic explorations in 3D printing bilayer composite materials.

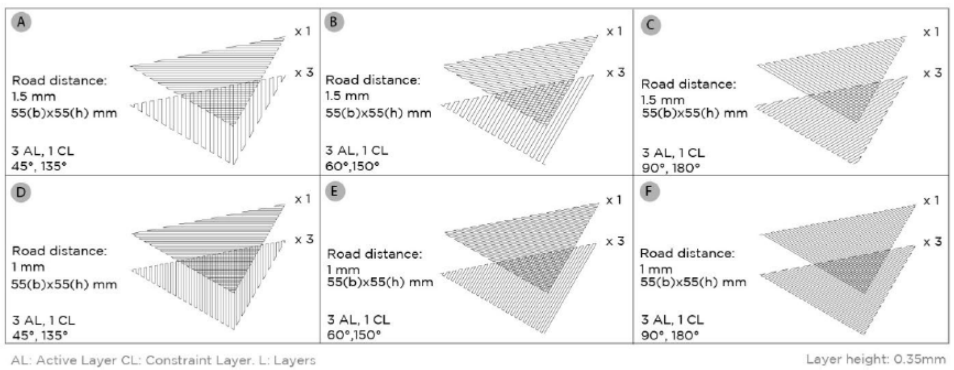


Fig. 2. Toolpaths of six bilayer composite samples to be printed with wood filament.

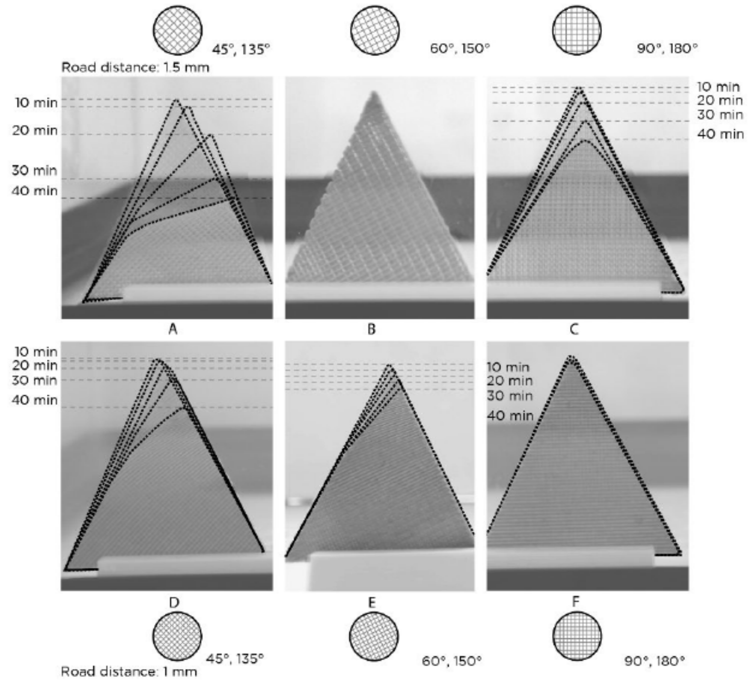


Fig. 3. The shape changes of the six-bilayer wood-based bio composite samples with 10 minute intervals for a total duration of 40 minutes.

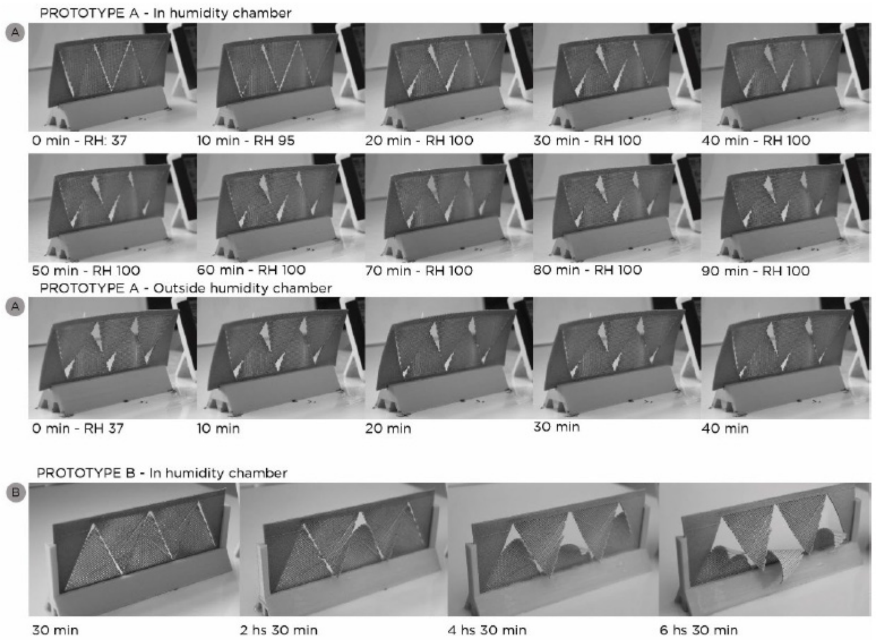


Fig. 4. A) The shape-changes of the Prototype A with 10-minute intervals, B) The shape-changes of Prototype B with 2 hours intervals.

**Oswald Prucker** | University of Freiburg, DE — Friday

*Bioinspired hairy surfaces* — 11:40 | R 1010

O. Prucker[1], S. Müllers[1], J. Rühe[1]

Everywhere in our natural environment, we can find various types of hairy surfaces. Some make surfaces water repellent as on plant surfaces [1], others ensure the strong adhesion of gecko feet on surfaces [2] or act as insulation layer against the cold as animal fur [3]. Polymer hairs are usually made via conventional methods such as microreplication [1]. These techniques are, however, often limited to rather small sample areas and low aspect ratios.

We developed a template assisted method (Fig. 1) which represents a simple and fast way to produce high aspect ratio polymer hairs (up to >100) with less sample size limitations. For our process we use different microporous templates for either microreplication and/or nanodrawing. The aspect ratio of the microstructure depends on fabrication parameters such as molding- / demolding-temperature, molding time, pressure or pore size. Our current work concentrates on the conditions needed for nanodrawing and high aspect ratio structures. This process requires the delicate balance between the frictional force inside the pores of the template during the demolding step and the yield force of the polymer material. A theoretical model considering these two parameters will be presented. The calculations fit well with our experimental results using HDPE (high density polyethylene) as substrate with a PC (polycarbonate) template (pore diameter 0.2 µm – 10 µm). Furthermore, our research shows that there are drastic changes in the wetting properties of the used polyethylene surface. The microstructured surface can be rendered super hydrophobic by this approach.

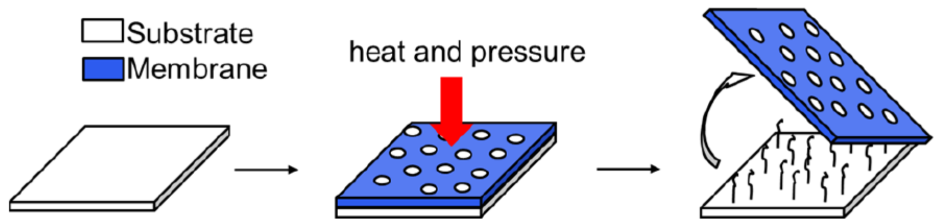


Fig. 1 Membrane assisted method for generating artificial bioinspired hairy surfaces.

[1]*IMTEK, Albert-Ludwigs Universität Freiburg, Germany*

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**Giulio Ragazzon** | University of Strasbourg, FR — Tuesday

*Autonomous use of electrical energy by an artificial molecular machine* — 13:50 | R 1199

G. Ragazzon[1], M. Malferrari[2], A. Arduini[3], A. Secchi[3], S. Rapino[2], S. Silvi[2, 4], A. Credi[4,5]

The ability to exploit energy autonomously is one of the hallmarks of Life. Mastering such processes in artificial nanosystems can open unforeseen technological opportunities. In the last decades, light- and chemically-driven autonomous systems have been developed in relation to conformational motion and self-assembly [1]. On the contrary, the autonomous exploitation of electrical energy remains essentially unexplored, despite being an attractive energy source.

In this work [2], we demonstrated the autonomous operation of an electrochemically-powered self-assembling nanomachine [3]. Threading and dethreading motions of a pseudorotaxane take place autonomously in solution, between the electrodes of a scanning electrochemical microscope [4]. This innovative actuation mode allows operating a molecular machine with one of the highest energy efficiencies reported to date for autonomous molecular systems.

The strategy is entirely general and can be applied to any redox-driven system, including molecular pumps that perform work repetitively and redox-controlled supramolecular polymers.

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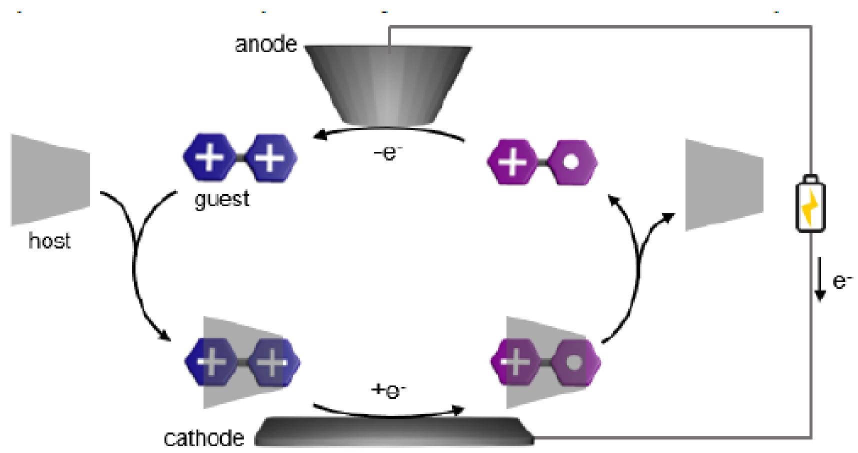


**Keywords**

energy autonomy | adaptivity

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**Jürgen Rühe** | University of Freiburg, DE | Thursday | 13:00 | R 1010

*Generation of adaptive structures through actuators responsive to heat, light or magnetic fields*

C. Eger[1,3,4], D. Rusitov[1,3,4], A. Bleiziffer[1,3,4], P. Straub[1,3,4], D. Song[1,3,4], J. Leonhardt[1,3,4], N. Geid[1,3,4], T. Speck[2,3,4], S. Poppinga[2,3,4], J. Rühe[1,3,4]

We describe the generation of actuators for use in adaptive systems. We focus on the one hand on actuators, which can be driven completely energy-autonomous, i.e. which harvest the energy directly from the environment. On the other hand, further actuators will be driven by energy harvested externally, e.g. through a solar cell. The actuators are based on liquid crystalline networks or surface attached polymer networks obtained through C,H-insertion reactions [1].

Hydromorphic structures are produced from highly polar polymer networks which are inspired by the pine-cone. We discuss the influence of a variety of thermodynamic parameters onto the actuation of both the natural and artificial systems [2].

Other microactuators are formed by a combination of soft lithography and C,H-insertion crosslinking or written following a two-photon crosslinking (2PC) protocol developed by us [3]. In all cases the activated chromophores react with neighbouring C,H groups on polymer chains leading to crosslinking or it can react with C,H groups on the substrate surface, leading directly to covalent immobilization of the microstructure.[1,2]. The incorporation of magnetic nanoparticles leads to three-dimensional micro magnets in a one-step procedure.

An important application for such adaptive actuators, are adaptive facades which adjust to changes in the weather conditions to increase the energy efficiency of buildings. Examples of adaptive facades already in use today are controlled by electric sensors and motors that reduce the potential energy savings. In this work, we describe the generation of polymeric actuators, which can autonomously adapt to changes in humidity and undergo hygromorphic shape changes.

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*[4]livMatS Cluster of Excellence University of Freiburg, Georges-Köhler-Allee 105, 79110 Freiburg*

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**Dennis Schuldzinski** | University of Freiburg, DE | Friday | 11:20 | R 1009

*Mapping the major concepts of 'system' in the 20th century*

D. Schuldzinski[1]

The notion of system emerged simultaneously in the second half of the 20th century in various sciences. In this talk, I will offer a tentative hermeneutic and historic reconstruction of the various conceptions beneath the term system as it becomes ever more central to different fields. Specifically, I will focus on analyzing the ontological questions at the heart of these conceptions and which assumptions they make concerning the reality of nature, technology, and society, as well as their interplay. In a first step, this is achieved by comparing different theoretical approaches like General Systems Theory, Cybernetics, and the Theory of Complex Systems. Ultimately, however, my aim is to unveil the historically specific constellations in which those systems theories originated and through which the meaning of their core concepts was constituted. This genealogy is the result of the first work package of Area D's project "'System' as interdisciplinary concept and the research on living materials systems." As adaptivity is a central to the material systems designed by *liv*MatS, I will use my analysis to sketch possible meanings of 'adaptivity' as a system's property in a brief outlook.

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**Keywords**

Philosophical reflection on technology | Philosophical reflection on nature and life | Response, acclimation, adaptation

**David Schwarz** | University of Freiburg, DE — Tuesday

*Mechanical metamaterials switch auxeticity during compression* — 14:10 | R 1010

D. Schwarz[1], F. Tauber[1], S. Schiller[2], V. Slesarenko[1]

Auxetic metamaterials exhibit a fascinating trait under mechanical load. While conventional materials expand, auxetics shrink laterally during compression. Such behavior associated with negative Poisson's ratio is achieved thanks to the rational geometrical and topological organization of the metamaterial and can therefore be tuned depending on a specific application. Traditional auxetic metamaterials continuously shrink in all directions with an increase in compressive load. Here we propose to analyze the sinusoidal lattice capable of both shrinking and expanding amid mechanical loading, depending on the applied force value (Fig. 1). The geometrical change from straight connections (e.g., as in reentrant lattices) to curvy beams (sinusoidal lattice) results in a strain and load-dependent sign of the Poisson's ratio. Meaning, under compression, negative transverse strain occurs only before the point of self-contact in the metamaterial. Thereafter the observed Poisson's ratio is positive, thus creating a toggle point for the metamaterial auxeticity. The unit cell geometry determines the critical compressive strain for such a switch. Here we use finite element simulations to characterize this not yet studied phenomenon. We perform mechanical testing on additively manufactured specimens to back numerical predictions. Ultimately, this observed phenomenon can be harnessed in the design of mechanical switches or as an if-then condition for minimum exerted compressive force. With the developed framework, similar metamaterials can be designed with their mechanical behavior tailored to novel use cases.

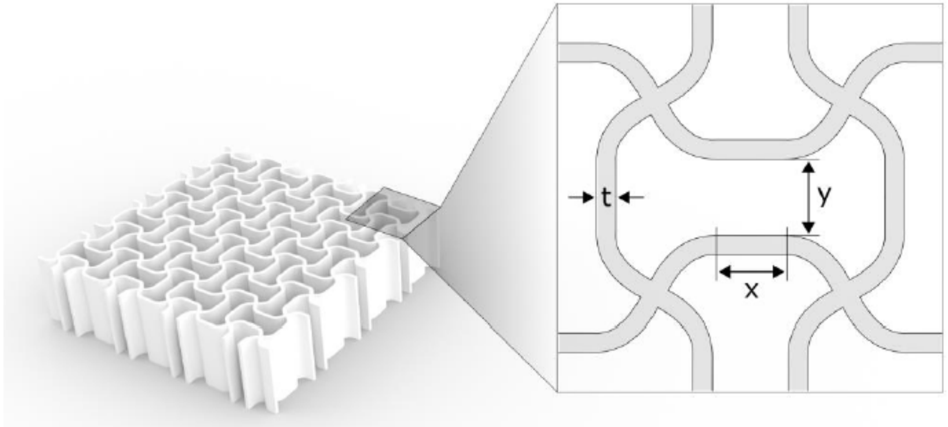


Fig. 1 Sinusoidal lattice with 4 x 4 unit cells. A single unit cell is displayed in detail. Mechanical properties and toggle point depend on geometrical parameters such as wall thickness (t), contact length (x) and gap width (y).

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**Keywords**

Metamaterials | Force/Function systems | Functional and structural integrity

**Oliver Skarsetz** | University of Mainz, DE — Thursday 13:40, R 1010

*Programmable auxeticity in hydrogel metamaterials via shape-morphing unit cells*

O. Skarsetz[1], V. Slesarenko[2], A. Walther[1]

Shape morphing mechanical metamaterials are architectured materials consisting of stimuli-responsive in combination with passive materials where structural reconfiguration with tunable response to applied mechanical forces is achieved through basic kinematic motion. However, metamaterial reconfiguration is mostly limited to bending or buckling motion. Herein, we show shape morphing of a hydrogel metamaterial architecture via one dimensional elongation of actuating struts to achieve programmable auxeticity. The directly attached actuating struts exhibit forces onto the passive re-entrant architecture resulting in change of unit cell angle. Via thermal control, the unit cell angle can be precisely programmed from 68° to 107° which results in negative, zero or positive Poisson's ratio under applied tensile strain. This concept of shape morphing hydrogel metamaterials via the addition of actuating struts into otherwise passive architectures extends the toolbox of structural reconfiguration. It can be readily extended to other architectures as well as soft robotic applications where Finite-Element-Method simulation predicts the reconfiguration and response to applied mechanical forces.

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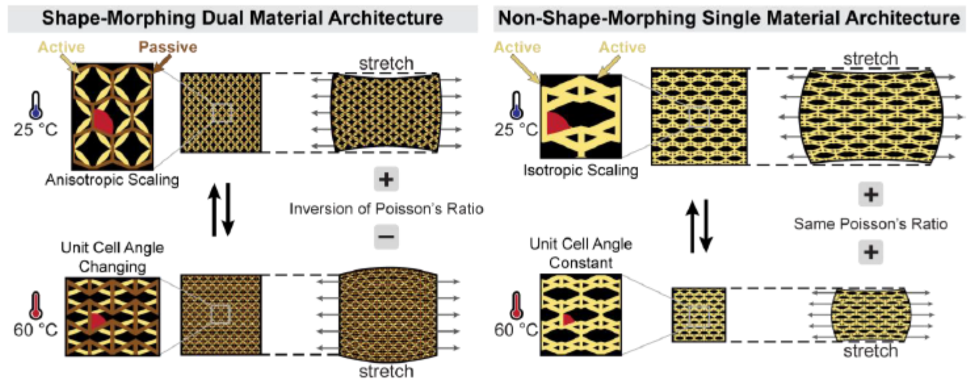
**Keywords**

Programmable Materials | Metamaterials

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**Acknowledgments**

This work was supported by the Carl Zeiss Research Cluster on "Interactive and Programmable Materials" (IPROM). Andreas Walther acknowledges generous support from the Gutenberg Research College.

**Olga Speck** | University of Freiburg, DE — Friday 11:00, R 1010

*Charting the twist-to-bend ratio of plant axes: a matter of geometry, mechanical properties and tissue pattern*

O. Speck[1,2], S. Wolff-Vorbeck[3], M. Langer[1,2], T. Speck[1,2], P. W. Dondl[2,3]

During evolution of land plants a variety of body plans have developed that may serve as inspiration for technical materials systems. Plant axes differ in cross-sectional geometry, tissue pattern and mechanical properties of the tissues involved. These influence the flexural rigidity and torsional rigidity of the entire plant stem and thus the ratio of both rigidities, the so-called twist-to-bend ratio [1,2].

In a comparative analysis [3], we have designed normalized cross-sections (Fig. 1), each with the same area percentage of tissues but differing in tissue pattern and elastic modulus *E* of the tissues: 1% epidermis (50 MPa), 84% parenchyma (20 MPa), and 15% strengthening tissues such as vascular bundles (1 GPa), collenchyma (2.5 GPa) or sclerenchyma (45 GPa).

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[3] *Department for Applied Mathematics, University of Freiburg, 79104 Freiburg, Germany*

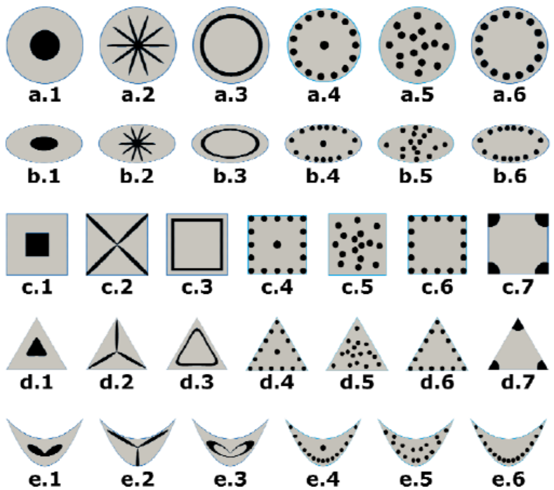


Fig. 1. Artificial cross-sections with various geometries and tissue patterns. Each cross-section consists of an outer epidermis (blue), parenchymatous ground tissue (light grey) and strengthening tissues such as vascular bundles or strands of collenchyma fibers or strands of sclerenchyma fibers (black). (from [3] under license CC BY 4.0)

The torsional modulus G is set to G = *E*/2.7. Our mathematical model enables the calculation of the minimal flexural rigidity ($D_{min}$) and the torsional rigidity ($D_z$) while simultaneously taking the cross sectional geometry and the tissue pattern into account. This allows us to place each individual cross-sectional design in a rigidity landscape (Fig. 2). The respective place in the rigidity landscape provides information about the trade-off between flexural rigidity and torsional rigidity and thus the twist-to-bend ratio. Our main results are: (1) We find clusters based on similar tissue patterns but no clusters in terms of similar geometry. (2) Flexural rigidity increases the more the vascular bundles or fiber strands are placed in the periphery. (3) Torsional rigidity decreases the more the vascular bundles or fiber strands are separated [3].

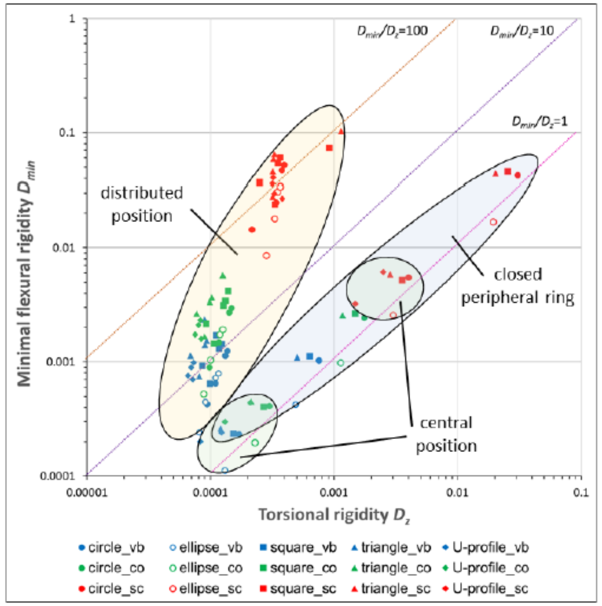


Fig. 2. Rigidity chart of all cross-sections with various geometry and patterns of vascular bundles (vb), strands of collenchyma fibers (co) and strands of sclerenchyma fibers (sc). (from [3] under license CC BY 4.0)

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**Thomas Speck** | University of Freiburg, DE — Wednesday

*Plant bioinspired material systems and structures with life-like properties* — 13:00 | R 1115

T. Speck[1,2,3]

In recent decades, bioinspired material systems and structures have received steadily growing attention in both basic and applied research, as well as in various fields of engineering, building construction and industry. Biomimetics not only has a high potential for innovation, but also offers opportunities for the development of sustainable technical products and production chains that are of increasing importance for greener technology and architecture in the 21st century. Novel sophisticated methods for analysis and simulation at different hierarchical levels of the form-structure-function relationship provide new fascinating insights into the multiscale mechanics and other functions of biological materials systems and surfaces. Of equal importance has been the development of new production methods, such as generative manufacturing processes, which for the first time make it possible to transfer many outstanding properties of biological role models into biomimetic products at reasonable cost.

Like animals, plants are valuable concept generators for many areas of biomimetic research. A selection of plant-inspired materials systems will be shown using examples from current research projects of the Plant Biomechanics Group Freiburg and the Cluster of Excellence *liv*MatS. Selected examples include damping and puncture resistant materials systems inspired by peel citrus fruit peels, branched and unbranched fibre-reinforced light-weight load-bearing systems based on inspiration from cacti and arborescent monocots, as well as adaptive (anti-)attachment surfaces inspired by leaves and motile plant organs, which offer a huge potential for a new generation of materials systems for soft robots, bioinspired architecture and technical applications in general.

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**Keywords**

biomimetics | bioinspiration | soft robotics

**References**

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**Claas-Hendrik Stamp** | University of Freiburg, DE — Thursday

*Smart fluidic devices based on hydrodynamically-coupled elastic elements* — 14:20 | R 1010

C. Stamp, E. Mitropoulos, F. Lang, T. Pfohl

The acellular slime mold „blob" - *Physarum polycephalum* - with its vascular fluid network embedded in a soft matrix is capable of solving complex tasks, such as finding the shortest connections within mazes and adapting its behavior to triggers in the environment [1]. The interactions of the

vascular fluid flow with its surrounding elastic matrix and the impact of penetrating fluids within the matrix of the organism inspired us to develop microfluidic devices that mimic specific parts of the complex network functions of this fascinating natural model. We use the coupling of thin elastomer membranes with bypassing fluids to control material and information transport. In particular, we mainly utilize the sometimes-dramatic swelling-induced changes in the shape of the membranes, which depends on the swelling properties of the fluids and aspect ratio of the membranes. With this method, we are able to spatially change the hydraulic resistance within the microchannel system, in order to regulate and direct pressure-induced flows through the device.
Applying pressure gradients in a specific pressure range along the fluidic membrane systems, buckled membranes show periodic positional movements, which can be described by travelling waves, which show frequencies from sub-Hz to kHz depending on the swelling power of the fluid components and applied pressure gradients. In addition, the travelling waves of the membranes generate peristaltic flows in adjacent environment, which in turn can be hydrodynamically and elastically coupled to fluidic networks. The next step is to use these coupled fluid networks to mimic logic and information processing on smart microdevices.

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**Falk Tauber** | University of Freiburg, DE — Friday, 11:20, R 1115

*Environmental responsive multi-material artificial venus flytrap demonstrators*

F. Tauber, J. Teichmann, F. Scheckenbach, L. Riechert, T. Speck

Biological material systems are adapted to their respective environment and can react to a variety of environmental stimuli. They serve as concept generators for bioinspired material systems that transfer functions of living nature into technical applications. Artificial Venus flytraps are inspired by carnivorous snap trap plants and enable fast, hingeless movements in plant-inspired soft robotic systems.

We present novel bioinspired „artificial Venus flytrap“ systems that technically implement the principles of fast snap trap movement within a 3D printed multilayer. The systems respond to the change in various environmental stimuli such as temperature and humidity with a snapping movement of their trap halves. We will present the new fabrication techniques as well as a kinematic analysis of the systems.
Our project and the presented „artificial Venus fly traps“ serve as feasibility studies for systems with dynamic, life-like and non-equilibrium properties. This is a first step towards the future implementation of novel technologies in industrial products and everyday applications.

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**Keywords**

Biomimetics | Bioinspiration | Demonstrators | 3D/4D printing | Adaptive materials systems | Environmental adaptive actuators | Environmental adaptive soft robots

**Dor Tillinger** | Penn State University, US — Thursday, 13:20 | R 1199

*3D printing of multi-hydrogel extrusion printing*

D. Tillinger[1]

The 3D printing mechanisms of inkjet and extrusion printing are limited in manufacturing complex heterogeneous structures [3]. Inkjet printing provides highefficiency printing with low operating costs, but suffers from the inability to create uniform droplet sizes and is constrained to low viscosity inks [1]. Extrusion printing, specifically direct ink writing, offers a wider variety of inks and greater structural complexity, but has lower resolution, longer production time, and requires more maintenance, especially when printing with various soft materials [1,3]. Here we demonstrate a multi-material microfluidic extrusion 3D printer to combine direct ink writing with precise droplet resolution. The microfluidic chip will generate a multi-material droplet thread assembled by the technique of droplet interface bilayers (DIBs). More specifically, the microfluidic chip will generate various droplet types on demand through pneumatic valve actuation. The continuous oil phase will contain phospholipids which will form a monolayer around droplet interface due to their amphiphilic nature. The droplets will then enter an oil siphoning region in which some oil is removed, slowing the droplets velocity, and bringing them closer together. Upon close proximity, the phospholipid monolayers will form a lipid bilayer between the droplets while maintaining each of the droplets' content compartmentalized. This will form a multi-material droplet thread which will exit the microfluidic chip into the nozzle of the 3D printer. The 3D printer will extrude the thread based on the desired geometry. Once printing is complete, the structure will be cured to disrupt the lipid bilayer and form a continuous multi-material hydrogel structure.

*[1]AIMS Lab, PI/Advisor: Prof. Joseph Najem*

**Keywords**
3D/4D Printing | Integrative multimaterial manufacturing Demonstrators

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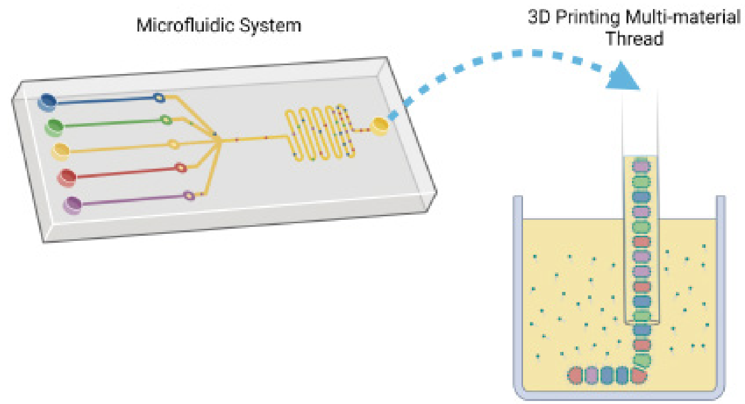


Fig. 1 High level overview of multi-material printing system. The microfluidic chip will generate various droplet types based on desired sequence. The output from the microfluidic chip will feed into the nozzle of the 3D printer as a multi-material thread assembled with phospholipids bilayers to create final structure.

**Kim Ulrich** | University of Freiburg, DE
Friday 12:00 R 1115

## *Material transitions and delamination resilience in pine cones from Pinus nigra and Pinus jeffreyi*

K. Ulrich[1,2], T. Masselter[1], T. Speck[1,2]

Many hygro-sensitive bending actuators are struggling with poor long-term usability due to delamination between the different hygroscopic active layers and the resistance layer. The opening and closing movement of the scales of pine cones has been analyzed for a deepened understanding of how delamination can be prevented, and how the resilience of a multilayered materials system against delamination can be enhanced in bioinspired technical actuators. To this aim, we performed biomechanical measurements and μCT-imaging on pine cones before and after periods of increased mechanical stress. In those 'high stress' periods we closed and opened multiple cones repetitively by submerging them into water and airdrying them afterwards. This method allows for (1) a comparison of the results of μCT-imaging of whole cones, as well as the data of the scale tip displacement and activation force of selected scales before and after the 'high stress' periods, and subsequently (2) insights on tissue distribution, material fatigue and delamination in pine cone scales and the impact on their opening behavior. In future studies, those results will be used to abstract functional structures and principles and implement them into hygro-sensitive demonstrators to help increase the long-term usability of such actuators.

[1]*Plant Biomechanics Group @ Botanic Garden, Faculty of Biology*
[2]*Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies*

**Keywords**
damage prevention | resilience | bioinspiration | demonstrators

**Kadri-Ann Valdur** | University of Tartu, EE | Imperial College London, UK

Friday
11:00
R 1115

*Amoeba-inspired granular rearrangement as an embodied adaptation strategy in unstructured environments*

K. Valdur[1,2], I. Must[1], T. Nanayakkara[2]

Amoeboid cell migration (e.g. white blood cells hunting bacteria) is a constant cycle of disassembly-transportation-reassembly of the building blocks of the cell (i.e. the cytoskeleton and membrane) without any central control [1,2], exhibiting truly embodied intelligence (EI). In unstructured and constantly changing environments such as disaster sites a high passive adaptability in the morphology of the robot can benefit effective locomotion. Movement around and/or over obstacles of similar characteristic dimension as the robot is an ongoing challenge in robotics. Here we show a passively adaptive robot locomotion effector inspired by the constant rearrangement of the ameboid cell's building blocks. We explore configurations of rearranging various sizes of granular matter within the robot's perimeter. Similarly to granular jamming for stiffness variation, we predict that the functional behaviour of granular material in the form of ad hoc formation of force chains during locomotion gives us a good compromise between load bearing and adaptation. The (estimated) results show the smaller granules have a critical role in adapting to the environment and larger granules form the skeleton of the effector enabling locomotion. Leveraging the fluidic adaptability of granular matter in robot locomotion can enable passive morphological computation, giving access to wider range of terrains. Achieving locomotion of midsize robots in unstructured terrains via EI can enable a higher degree of automated monitoring of natural ecosystems and aid search-and-rescue missions.

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[2]*Morph Lab, Dyson School of Design Engineering, Imperial College London*

**Keywords**
Bioinspiration | Soft Robotics | Embodied intelligence | Environmental adaptive soft robots

**References**

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*[2] A. GręObecki, „Membrane and Cytoskeleton Flow in Motile Cells with Emphasis on the Contribution of Free-Living Amoebae," in International Review of Cytology, vol. 148, K. W. Jeon and J. Jarvik Eds.: Academic Press, 1994, pp. 37-80.*

**Elena Vazquez** | UNC Charlotte, US — Wednesday

*Adaptive architecture: elastic instability for kinetic building shades* — 13:00 | R 1098

Building envelopes regulate the energy exchange between inside and outside, managing thermal gains, daylight control, and radiation. Building envelopes are typically designed to be static; however, outdoor temperature and sky conditions can fluctuate throughout the day. In contrast, plants are more complex and respond to various environmental stimuli. These highly adaptive systems have inspired biomimetic facades that adjust their configuration in response to changing outdoor conditions (Lopez et al., 2017). Nevertheless, plant movements are typically slow, measured in hours and days, when they rely exclusively on passive hydraulic actuation (Poppinga et al., 2020). Building envelope designers can turn to elastic instability to achieve fast actuation and more considerable deflections in bioinspired kinetic envelopes. This presentation first provides an overview of strategies for elastic instability in building shades and, second, describes the Bistable Kinetic Skin demonstrator as a case study. The first part of the presentation identifies structural and morphological qualities of elastic kinetic systems found in previous building envelope research. Common design strategies are identified, such as using linear elastic elements like bistable beams. Secondly, the presentation will cover the Bistable Kinetic Skin demonstrator as an example of a kinetic screen that relies on elastic instability for its movements. The Bistable Kinetic Skin comprises bistable laminates with two stable states made with carbon fiber prepregs. To snap the laminates into position, the screen relies on a secondary material-based actuation system with Shape Memory Alloys. The work argues that while elastic instability might not have been a desirable feature of past architectural archetypes, it is a concept that can help design highly adaptive bioinspired kinetic screens.

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*Poppinga, S., Correa, D., Bruchmann, B., Menges, A., & Speck, T. (2020). Plant movements as concept generators for the development of biomimetic compliant mechanisms. Integrative and comparative biology, 60(4), 886-895.*

**Martí Verdaguer Mallorquí** | Heriot-Watt University, UK — Friday

*A morphologically inbuilt sawing safety mechanism in the ovipositors of sawflies* — 11:20 | R 1010

Sawflies are named after their ovipositors which present saw-like features and are used to cut into the soft tissue of plants to lay eggs inside. There is a high level of specificity on the relationship between the different species of sawflies and the plants they target, which hints an untapped large source of knowledge on how to cut or saw different substrates. Working with a scaled up set up, which features the morphological traits of a selected sawfly specie, showed the presence of a safety mechanism built within the morphology and structure of the teeth presented by the ovipositor. This safety mechanism will protect the integrity of both, the plant and the insect, by slipping out the substrate from within the teeth range when it is over a certain material resistance threshold. A mathematical model to predict the threshold has been built and put to a test. A new set up meant to study the performance of the teeth at a smaller scale will also be presented.

**Michael Walter** | University of Freiburg, DE — Wednesday

*Mechanochemistry: a theoretical and experimental interplay* — 13:20 | R 1199

W. Maftuhin, P. Bhat, M. Walter

Mechanochromic polymers are intriguing materials that allow to sense force of specimens under load. The connection between macroscopic stress and the forces acting on the molecular level is still elusive and covalently incorporated molecular mechanochromophors promise to shed light on this. Most mechanochromic systems rely on covalent bond scission with optically distinct “on” and “off” states [1]. There, bond rupture is induced by temperature fluctuations involving force dependent barriers. We show that these barriers are fully determined by the dissociation energy and the maximal force the potential can withstand, which allows for a re-interpretation of the Eyring-Zhurkov-Bell length and the expressions going beyond [2].

We furthermore present and analyse the concept of mechanochromic donor-acceptor (DA) torsional springs that allows for a continuous mapping of molecular forces to photoluminescence wavelengths. The mechanically induced deflection from equilibrium geometry of the DA spring is theoretically predicted and reveals forces of 1 nN on the molecular level before destruction of the specimen [3]. Our theoretical analysis demonstrates a thiophene ring flip as the major part of the overall mechanochromic response within a related ansa-DAD spring at forces as low as 27 pN. Such micromechanical motion gives access to sensing of tiny forces and expands both sensitivity and the force range of conformational mechanochromophores [4].

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**Natalie Walter** | Penn State University, US

Wednesday

*Mycelium-based composites for sustainable architectural acoustics*

13:20 | R 1098

Over the past decade, the field of architecture has begun to show a new emphasis on material-based design. With aims to transition to a more environmentally and socially sustainable model of design, a new movement towards advanced, biological construction materials has taken ground.

This research intends to generate a more holistic understanding of myceliumbased composites, a biomaterial derived from fungus. As a proof-of-concept demonstration, we explore and assess the practicality of using mycelium-based composites as acoustic materials, both in terms of material-based and architectural performance. The research has two main tracks: Material to Performance and Form to Performance. In the Material to Performance track, the objective is to understand how the morphological properties of the material impact its acoustic performance. Myceliumbased composite samples are cultivated and assessed for their acoustic absorption and mechanical properties. In the second track, Form to Performance, the material-specific data generated in the Material to Performance Track is used as an input for acoustic simulations, using ray tracing and image source methods. The goal of these simulations is to investigate how the design of acoustic panels made from mycelium-based composites affects room acoustics.

At the conference, we will present:

- Existing research on the acoustic applications of mycelium-based composites
- Results from acoustic and mechanical experiments of cultivated samples
- Results of computer simulations for acoustic performance
- Full scale acoustic panel prototypes

The broader impacts are to mitigate waste generated and energy consumed due to material manufacturing of acoustic materials.

Fig 1. Mycelium-based composite samples tested in an impedance tube for acoustic absorption.

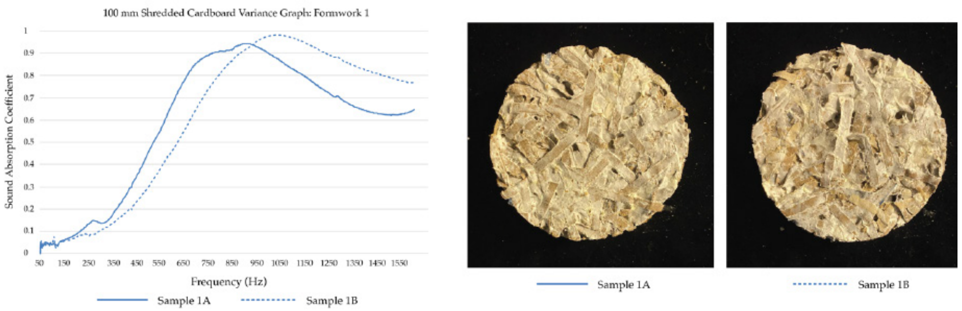


Fig 2. Sound absorption coefficient graph and the corresponding samples tested.

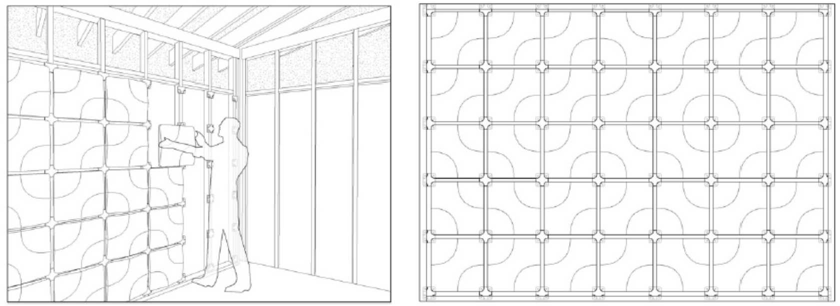

Fig 3. Acoustic panel wall prototype design: (a) Acoustic panel installation illustrated (b) Example wall configuration.

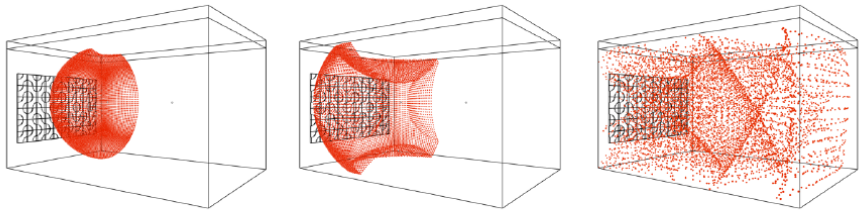

Fig 4. Ray tracing simulation experiment using the material-specific data generated in the Material to Performance Track as an input parameter.

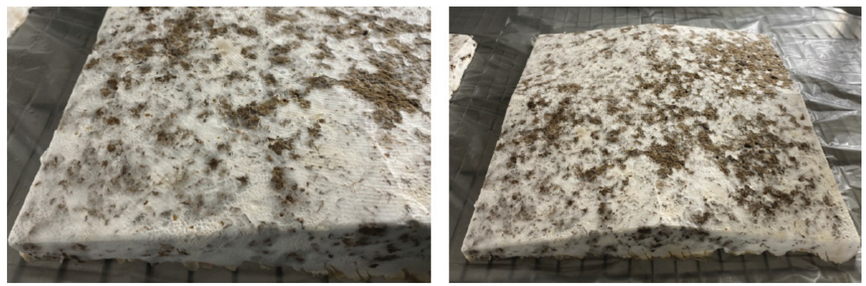

Fig 5. Early prototype for a mycelium-based acoustic panel.

**Wei Wei** | University of Freiburg, DE — Friday 11:40 R 1098

## *Influence of interstitial Li on the electronic properties of $Li_xCsPbI_3$ for photovoltaic and battery applications*

W. Wei[1], J. Gebhardt[1,2], D. F. Urban[2,3], C. Elsässer[1,2,3]

The stability of crystalline $CsPbI_3$ with interstitial Li ions is investigated together with the effect that Li has on the electronic structure of the resulting compound $Li_xCsPbI_3$. We analyze this by two structural models for $CsPbI_3$ at room temperature, the cubic *α* phase and a distorted structure analogous to the *γ* phase (*γ′* structure). The hypothetical *α* phase does thermodynamically not allow Li uptake and is likely to be structurally unstable for x>1/4, while adding Li up to x=1 in the *γ′* structure is possible. In all cases, Li promotes structural distortions, namely tilting of bond angles $\Delta_{Pb\text{-}I\text{-}Pb}$ and Cs off-center displacements $\Delta r_{Cs}$, which are increasing with the Li concentration.

Interstitial Li has the following effects on the electronic structure of $CsPbI_3$: i) the induced structural distortion reduces the band dispersion, which leads to a significant increase of the band gap; ii) depending on the electronic charge (Li being considered as atom or ion), the electronic shielding of additional electrons in the conduction band leads to a small increase of the band gap; iii) although Li 2s states hybridize with I and Pb states, the effect on the band edges and band gap is negligible. Altogether, the change of the band gap is dominated by the $\Delta_{Pb\text{-}I\text{-}Pb}$ angles, i.e., stronger distortion caused by increasing Li content is accompanied by a (linearly) increasing band gap.

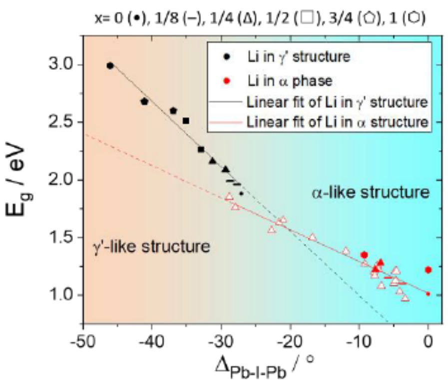


Fig. 1 Relation of band gap Eg and angular disorder $\Delta_{Pb\text{-}I\text{-}Pb}$ caused by Li insertion.

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[2]*Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstraße 11, 79108 Freiburg, Germany and*

[3]*Freiburg Materials Research Center (FMF), Albert-Ludwigs-Universität Freiburg, Stefan-Meier-Straße 21, 79104 Freiburg, Germany*

**Daniel Werz** | University of Freiburg, DE — Tuesday 13:30 | R 1199

## *Superfluorophors by rational design and serendipitous discoveries*

D. B. Werz[1]*

The rich chemistry of the BODIPY motif, together with its beneficial photophysical properties, has markedly boosted the popularity of this user-friendly fluorophore over the last few decades [1]. The diversity of easily incorporated fluorescence modulation modes has set the stage for a variety of sensorically active species. The talk describes which physical-organic rationalisation led to the development of the BOIMPY motif showing a significant red-shift with respect to the parent BODIPY [2]. In addition, a simple synthetic route to oligomerized ethano-linked BODIPYs (up to an octamer) is presented which can be further oxidized to huge completely conjugated systems [3]. Photophysical properties and biological properties are discussed by experimental and theoretical means [4]. It is shown that the suprastructure of the oligomeric dyes plays a significant role for their absorption and emission properties and that the conjugated systems are interesting NIR fluorophores.

[1]*Institute of Organic Chemistry, Albert-Ludwigs-Universität Freiburg, Albertstraße 21, Germany, www.werzlab.de*

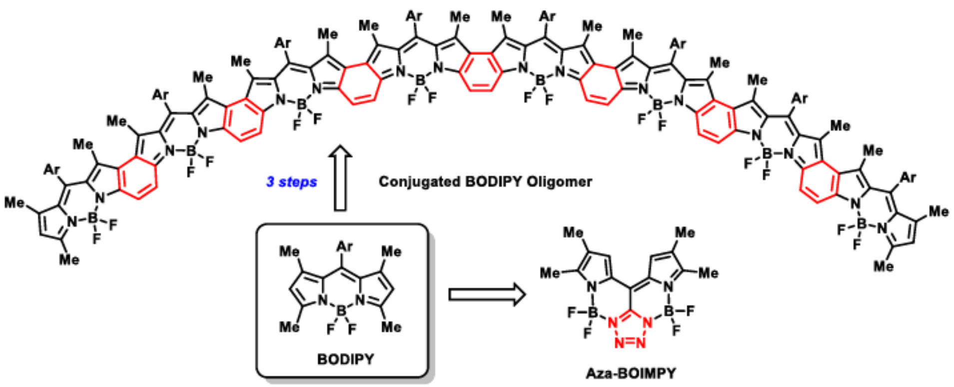


Fig. 1 BODIPY, (Aza-)BOIMPY and highly conjugated BODIPY oligomer.

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**Yingdan Wu** | Max Planck Institute for Intelligent Systems, DE

Tuesday
14:10
R 1115

## *Flow-powered millimeter-scale wheeled tube robot*

C. Hong[1,2,†], Y. Wu[1†], C. Wang[2], W. Hu[1], M. Sitti[1,3]

Wireless millimeter-scale robots show promising applications in complex and precise instruments and in the biomedical field. However, most such robots require an external power supply, limiting the potential to be autonomous; the alternative solutions with onboard control and power units have issues of balancing the size and the functionality. Here, we propose a wireless millimeter-scale wheeled robot utilizing the energy from the environment, such as flow, capable of autonomously traversing complex tubular structures (Fig. 1). We adopt an impeller as an energy module to convert flow energy into kinetic energy and a miniature gearbox as a transmission module to amplify the output torque for locomotion. We analyze the power conversion via the impeller by tuning the impeller design (the length and the amount of fin), the flow rate and loading conditions. Our energy conversion module is functional in different flow media (gases, water, and liquids of different viscosities). Our robot's motion status (move against/with flow, or pause) can be automatically switched by a reciprocating magnet since the impeller is covered by a house with magnetically switchable doors. We develop and characterize the Kirigami wheels for our robot to enable its locomotion in complex tubular structures of different geometries (tube of changing diameter, or S /U /spiral shapes, Fig. 2). We also characterize the robot's ability to carry payloads and demonstrate that our robot can function autonomously with endoscopic cameras, wireless temperature sensors or other functional modules mounted.

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*[3]Institute for Biomedical Engineering, ETH Zürich, 8092 Zürich, Switzerland*
*[†]Equally contributing first authors*

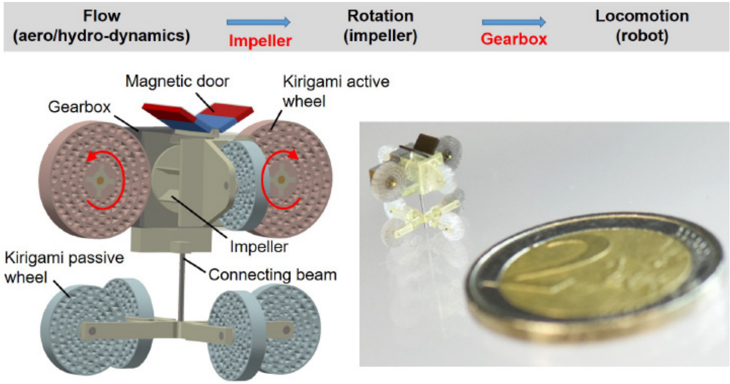


Fig. 1 Design of the flow-powered millimeter-scale wheeled tube robot.

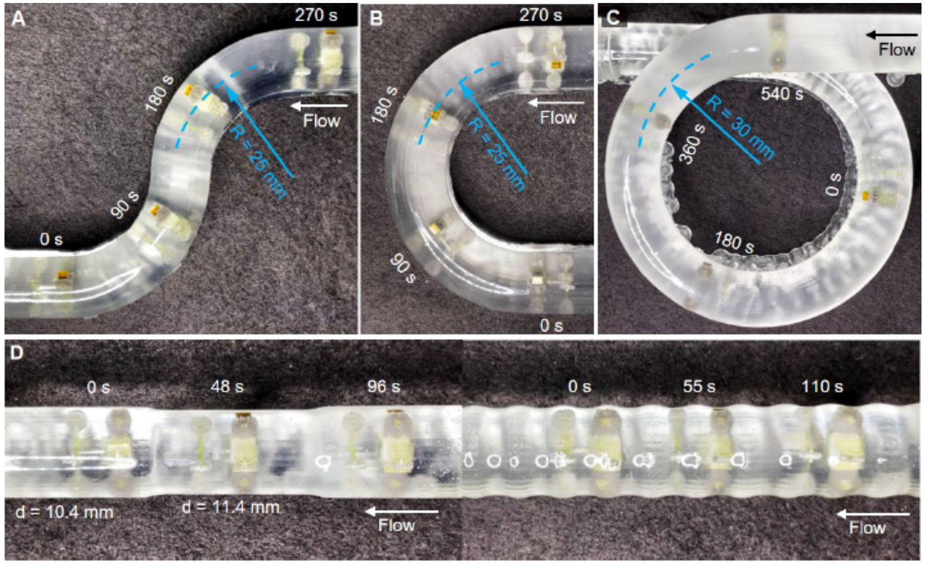


Fig. 2 Locomotion adaptability to pipelines with different geometries. (A) S shape. (B) U shape. (C) Spiral shape. (D) Variable-diameter shape.

**Jingshi Zhang** | Penn State University, US

Thursday

*Building-integrated reversible proton exchange membrane fuel cell (PEMFC) for energy harvesting and storage*

14:20

R 1098

Buildings consume 39% of the total U.S. energy and are responsible for 39% of $CO_2$ emissions. On-site renewable energy generation (i.e., distributed energy) in buildings can be a key contributor to carbon neutralization and is therefore prescribed in national net-zero emission policies to reduce dependency on fossil fuels. The application of electrochemical technologies for renewable energy generation and storage has expanded in recent years, and some of these technologies, such as solid oxide and microbial fuel cells, have even been tested for building applications.

The present ongoing doctoral project aims to integrate photovoltaics and reversible PEM fuel cells (PEMFC) into building envelopes. To evaluate the feasibility and potential of fuel cells for building applications, we constructed a reversible PEMFC-based cladding system prototype. The hydrogen energy output of the system was determined to be 16.01 W/m$^2$ with input radiation of 156.6 W/m$^2$, yielding an energy conversion rate of 10.22%. The traditional PV system's energy conversion rate is 15–20%. While the proposed system cannot compete with commercial PV systems, there is a possibility of improving energy conversion efficiency through future research. The proposed system is promising in terms of introducing hydrogen into buildings. Additionally, oxygen is a byproduct of the proposed system, which can be introduced to HVAC systems in buildings to improve indoor air quality. We envision a future where diverse and clean energy generation and storage technologies are adopted in building skins to help supplement or replace traditional sources of energy.

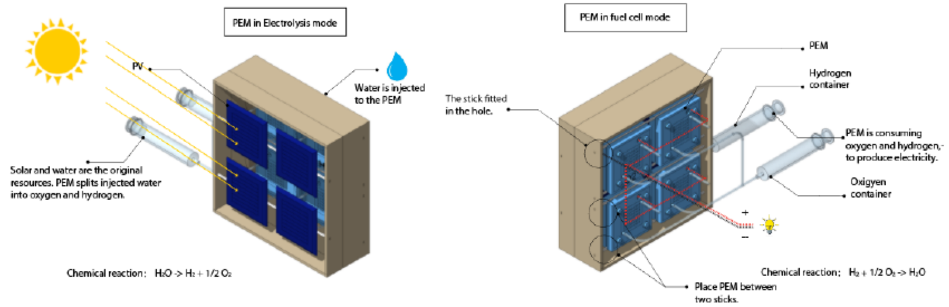


Fig. 1 First PEM fuel cell-based solar harvesting cladding system prototype design

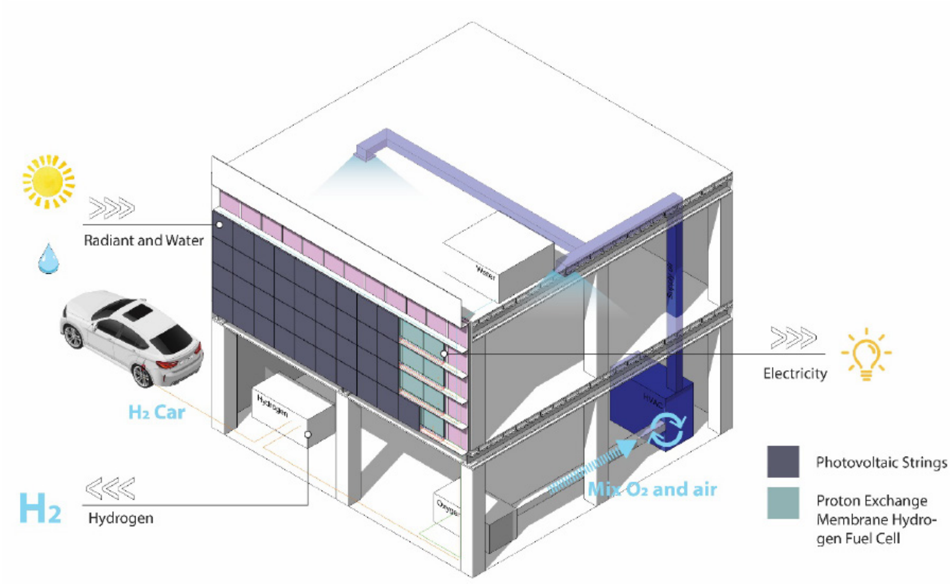


Fig. 2 Building-integrated PEM fuel cell system

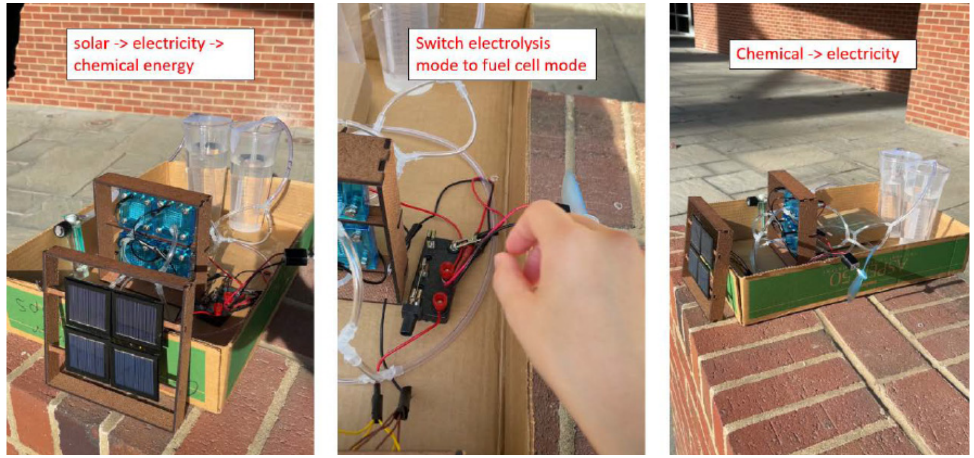


Fig. 3 Prototype chemical energy producing potential test

**Angela Zhou** | University of Freiburg, DE — Thursday 13:20, R 1009

*Social acceptance of photovoltaic installation on buildings: the importance of building appearance, module visibility and aesthetic integration*

A. Zhou[1], A. Wessels[2], S. Glunz[2], T. Speck[3], A. Kiesel[1]

Regarding the expansion of renewable energy, existing buildings provide high technical potential for photovoltaic (PV) systems. However, not every building may be considered as suitable: Social acceptance for installing PV modules on historical or religious buildings might be low. In two explorative studies, we investigated the building-specific acceptance of PV installations.

In an online study (N=109), different buildings of the city Freiburg, Germany, were presented. For each building, participants indicated their acceptance for a PV module. Results show that social acceptance for PV installations on buildings is generally high. Acceptance was rated even higher for aesthetically integrated or invisible PV modules. There were differences between buildings regarding social acceptance, being lower for historical buildings and higher for modern buildings. Interestingly, these acceptance differences between buildings disappeared when the PV module was to be installed in an invisible manner. Further, building appearance was found to be more important to predict acceptance than person variables such as environmental concern, values or political attitude.

The second study (N=76) was conducted in the Botanic Garden of the University of Freiburg in front of the *liv*MatS pavilion. Six different types of PV modules varying in color and angular sensitivity were presented. Participants were asked to rate the modules and match them to presented buildings. Results show that all given module types were relevant and that they were matched to the buildings due to reasons of aesthetic integration.

Taken together, the studies underline the importance of aesthetic integration and (in)visibility for PV installation on buildings.


Fig. 1 Photovoltaic Module Exhibition for Study

*[1]Albert-Ludwigs-Universität Freiburg, Institut für Psychologie*
*[2]Fraunhofer Institut für Solare Energiesysteme ISE*
*[3]Albert-Ludwigs-Universität Freiburg, Institut für Biologie II*

**Note**

The picture on the left displays the six PV module types that were used in Study 2. The presented modules were provided by the Fraunhofer Institute for Solar Energy Systems ISE. The exhibition table, which can be seen on the picture on the right, was situated next to the *liv*MatS pavilion in the Botanic Garden of the University of Freiburg. Study participants were invited to fill out a short questionnaire, rating the module types and matching them to buildings.

**Pang Zhu** | University of Freiburg, DE

Thursday 14:20 R 1199

*Reusable photoresponsive hydrogels for high-resolution polymer replication*

Microstructured molds are essential for fabricating a variety of different components ranging from precision optics and microstructured surfaces to microfluidics. However, conventional fabrication technology such as photolithography requires expensive equipment and a large number of processing steps. Here, we report a facile method to fabricate micromolds based on a reusable photoresponsive hydrogel: Uniform micropatterns are engraved into the hydrogel surface using photo masks under UV irradiation within a few minutes. Patterns are replicated using polydimethylsiloxane with minimum feature size of 40 µm and exceptional smoothness of Rq ~3.4 nm. After replication, the patterns can be fully erased by light thus allowing for reuse as a new mold without loss in performance. Utilizing greyscale lithography, patterns with different height levels can be produced within the same exposure step. We demonstrate the versatility of this method by fabricating a microfluidic device with 100 µm wide channels, a microlens array and diffractive optical devices for imaging application.

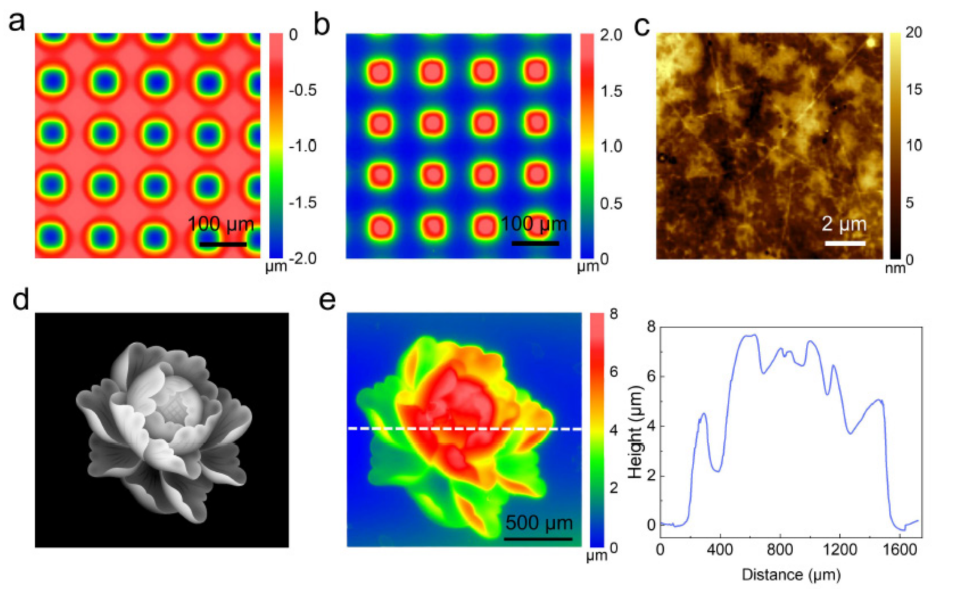


**Fig. 1 Acrylamide/azobenzene-cyclodextrin (AM/AZO-CD) hydrogel based micromold displays for high resolution replication and grayscale lithography.** (a) Surface profile of the micromold, i.e., the structured hydrogel after 1 min of structured UV irradiation, (b) PDMS component replicated from the micromold; (e) the PDMS surface characterization shows high smoothness with a Rq ~3.4 nm; (d) A grayscale flower mask and (e) replicated flower on PDMS with different height based on the varied transparency of the mask.

# POSTERS

**Bizan Nicolas Balzer** | University of Freiburg, DE — Poster

*Triboelectric energy harvesting by redox active molecules* — Prometheus Hall

R. Sharma[1,2], Q. Hu[1,3], M. Brzoska[3], P. Gaiser[2], C. Schmidt[2], N. Ranjan[1,3], B. N. Balzer[1,3,4], B. Esser[1,2,5]

For thousands of years, the triboelectric effect has been present in our daily life. It describes a charge separation process, when two, different or same, materials are contacted or are in motion against each other. While the physical origins of the triboelectric effect are still not well understood, triboelectric nanogenerators (TENG) have been already developed as prospective energy sources [1].

Here, the capability of redox active molecules for an efficient triboelectric charge transfer is investigated, serving as a novel route for the development of TENGs with enhanced performance. In particular, redox active molecules with opposite electronic character (electron donors and acceptors) are synthesized, namely Tetrathiafulvalene (TTF) and Tetracyanoanthraquinodimethane (TCAQ) [2]. Then, Au based test samples are functionalized with those redox active molecules and then contacted. Surface sensitive techniques, such as X-ray Photoelectron Spectroscopy and Kelvin Probe Force Microscopy [3] are used to probe the functionalization quality and to obtain the surface potentials before and after contacting experiments to understand the extent and the mechanisms of charge transfer.

These experiments enable us to probe the impact of surface functionalized redox active molecules on triboelectrification and provide a new approach for efficient energy harvesting.

[1] Cluster of Excellence livMatS @ FIT – Freiburg Center for Interactive Materials and Bioinspired Technologies, University of Freiburg, Germany

[2] Institute for Organic Chemistry, University of Freiburg, Germany

[3] Institute of Physical Chemistry, University of Freiburg, Germany

[4] Freiburg Materials Research Center (FMF), University of Freiburg, Germany

[5] Institute of Organic Chemistry II and Advanced Materials, Ulm University, Germany

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## **Niamh Bayliss** | University of Glasgow, UK — Poster P13

*Aqueous multi-phase systems and polymerisation* — Prometheus Hall

N. Bayliss[1], A. Belluati[2], N. Bruns[2], B. V. K. J. Schmidta[1]

Liquid-liquid phase separation is an important feature in biological systems and the synthetic reproduction of these systems has been the focus of many branches of research [1,2]. A particular target is the mimicry of membrane-less organelles for the formation of artificial cells or applications like catalysis. Developing methods utilising controlled polymerisations can be the starting point to closely mimic these biological systems [3]. For example, polymerisation techniques such as reversible deactivation radical polymerisation in multi-phase systems can be used to help develop a mimic for these biological systems, as the polymerisation induced aggregation of poly(acrylamide) can occur in the presence of a multi-phase forming polysaccharide. Polymerisation induced liquid-liquid phase separation can also help mimic the phase separation that occurs in biological systems by forming membrane-less coacervates. Correlation between conversions of polymerisation reactions whilst also using confocal laser scanning microscopy allows to follow the phase separation process and investigate the nature of the aggregation and coacervates formed. This will allow to compare polymerisation in multi-phase systems with that of standard polymerisation techniques and relate polymerisation kinetics with the state of the multi-phase environment.

The investigated polymerisation techniques in aqueous multi-phase systems might not only be of use to understand liquid-liquid phase separation in better detail, but also serve as innovative bio-inspired materials platform for a range of applications. The unique properties of liquid-liquid phase separation have been used in many applications such as for drug delivery, purification of biological macromolecules and catalysis.

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### Keywords

Biomimetics | Bioinspiration

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## **Pooja Bhat Mulki** | University of Freiburg, DE — Poster P10

*Predicting forces needed for bond breaking in molecules* — Prometheus Hall

P. Bhat, W. Maftuhin, M. Walter

Smart functional materials that respond on external forces are extremely useful for purposes such as: internal stress indicators, enabling certain reactions or releasing therapeutical agents. There are precision Single Molecular Force Spectroscopy experiments for several bond opening reactions in polymer chains. The ability to predict the corresponding bond rupture force computationally can help us advance our molecular level understanding and lead the design of related materials.

Instant pulling of a molecule results in it experiencing a maximum force before one of the bond ruptures. This maximal force can be obtained easily by Constrained Geometry (CoGEF) calculation, but the force obtained is much larger than what is observed in the experiment. The reason for this discrepancy is the lack of consideration of temperature in CoGEF.

We extend the CoGEF description by following the force dependent deterministic energy path with activation barrier to give out desirable product state. This transition barrier be predicted using force independent Nudged elastic Band method.

By employing the experimental loading rate, temperature and computed maximum force and activation barrier, the bond rupture force for any given molecule can be predicted. Excellent agreement to available experimental results is demonstrated. Additionally, the experiments can be tailored to have a completely different reaction paths and product state or a desired rupture force.

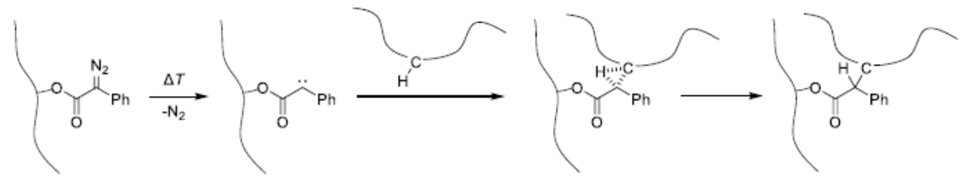
**Alexander Bleiziffer** | University of Freiburg, DE Poster P15

*Thermal structuring of surface-attached polymer networks by C,H insertion reactions*

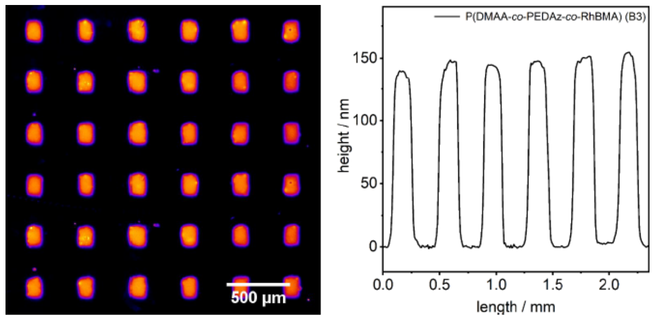
Prometheus Hall

A. Bleiziffer, J. Rühe

Photolithography is an important process in semiconductor technology to create structured surfaces, but often requires specific substrate materials that have to be pre-treated. Using a novel, fast, robust, and simple process based on thermal activation, we were able to produce spatially controlled surface-bound polymer networks on a variety of different common materials that exhibit high longevity [1]. In this process, which is similar to branding livestock or wood with a hot branding iron, a hot stamp is brought into direct contact with a diazo groupcontaining copolymer applied to a substrate to map the profile of the stamp into the polymer film. Crosslinking and covalent surface attachment to the substrate are achieved as a result of thermal activation of the diazo groups, leading to carbene formation, which induces C,Hinsertion crosslinking (CHic). After dissolving the uncrosslinked material, the shape of the stamp is transferred into the polymer film [1,2].




The polymer systems used here allow activation of the diazo function at mild temperatures of below 150°C, so that relatively fast processing of a few seconds allows step-and-repeat processes. By re-coating and then repeating the process on already structured surfaces, the physical and chemical material properties of structures can be tailored, and structure-onstructure features become easily possible [1].




Thermal scanning probe lithography can be used to realize structures in the nanometer range, with the polymer system presented here acting as a novel negative resist and thus enabling completely new structuring possibilities in contrast to conventional positive resists [3].

**Keywords**

Damage resistance | Robustness | Environmental responsive materials

**References**

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**Patrick Huber** | University of Freiburg, DE Poster P16

## *Single- and two-photon absorption based C-H-insertion crosslinking (CHic) of anthraquinone containing copolymers*

Prometheus Hall

P. Huber, J. Rühe

Polymer networks can be generated and modified by various methods, either during die polymerization by adding multifunctional monomers or after the polymerization by incorporation of dormant crosslinker molecules. Both methods have drawbacks like removing the residual monomer or that the reactive groups have to come in contact to perform the crosslinking. We use crosslinker molecules that can be activated on demand by thermal or photochemical stimulation and do not require a specific reaction partner for the crosslinking reaction, it only needs a C-H-bond in vicinity. Examples for the crosslinker molecules are diazo-compounds, benzophenones or anthraquinones. For all of them the crosslinking occurs through a C-H insertion based crosslinking (CHic), which makes it a powerful and universal method [1]. The reaction mechanism is shown for an anthraquinone based crosslinker in Fig 1.

The activation parameters of the Chic process can be tuned with functional groups on the crosslinker molecule. So can antraquinones with electron-donor substituents be used for effective photocrosslinking with UV-C (250 nm) or UV-A irradiation (365 nm) and additionally have an increased probability for two-photon absorption (2PA) which enables the use for a process called two-photon crosslinking (2PC), which is a 3D-printing technique to generate free standing microstructures with a resolution of <1 µm [2,3].

Our goal is to synthesize novel crosslinker molecules, characterize their crosslinking behavior and therefore improve the 2PC process and the resolution of the printed microstructures as well as the single-photon crosslinking for the generation of macroscopic structures e.g. with photomasks.

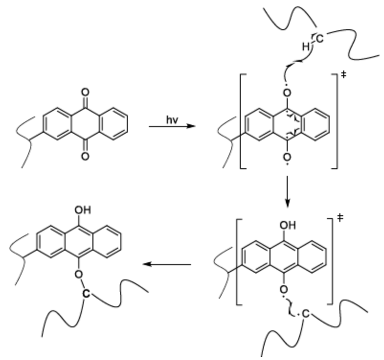


Fig. 1 Mechanism of the photochemical induced CHic-reaction of an anthraquinone.
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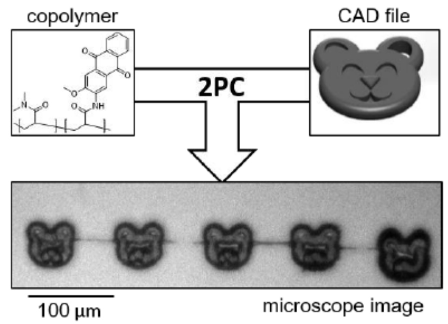


Fig. 2 2PC process with the anthraquinone based copolymer P(DMAA-co-AAMAQ$_{5\%}$) to generate free standing 3D-microstructures (microscope images).
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**Ershuai Jiang** | University of Freiburg, DE Poster A2

*Organic solar modules with side-point-connection for indoor light energy harvesting* R 1115

E. Jiang[1,2,4]*, B. Zimmermann[2], U. Würfel[1,2,3], S. Glunz[1,2,4]

Recently, the dynamic development of organic photovoltaics (OPV) attracted more and more attention. It is well known that OPV devices have tuneable absorption range and excellent weak light response. What is more, the materials used are usually non-toxic and the films can be processed at room temperature on flexible substrates with green solvent. These merits make OPV one of the most suitable candidate among the different PV technologies for indoor light energy harvesting. Up to now, the power conversion efficiency of small area organic solar cells can be as high as 30 % under indoor light. On the other hand, the development of OPV modules for indoor light lags behind. One important reason is that the connection method of sub cells in a module is still the conventional type, in which the connection lines are always parallel to the separation lines, and the lengths are equal. By this way the series resistance is the lowest. However, the risk for shunting is high with this approach, since shunts always have high probability to be formed along the connection lines.

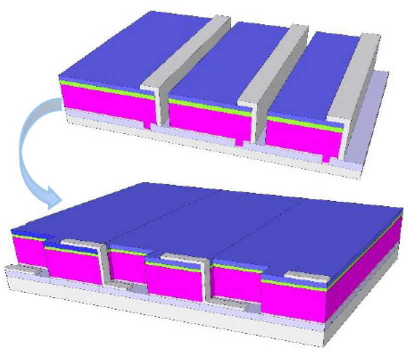

Fig. 1 Schematic images of conventional connection (upper) and side-point connection (bottom) modules

Compared to outdoor PV, the requirement for a low series resistance is decreased by several orders of magnitude under indoor illumination, whereas the requirement of maintaining a large parallel resistance is increased by several orders of magnitude. Therefore, the limitation of the current transporting length is much longer. Thus, it is advisable to improve the conventional geometric layout of the connection pads by reducing their area as much as possible. Here we propose a novel connection method that is particularly useful for indoor light energy harvesting, which can be called side-point-connection. By this way, the connection pads are set on the side as small points. Because the connection area is dramatically reduced this way and there is no necessity of another separation line of the top electrode, the shunt probability is significantly decreased while simultaneously the geometric fill factor is increased. In addition, the side-point connection is also beneficial for modules with irregular shape and ITO-free substrates. Generally, this novel design provides a promising new approach to improve the performance of solar modules under indoor light.

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**Esther Jimenez** | Rice University, US Poster P2

*Controlling the mechanical properties of macroscopic living materials by altering their matrix* Prometheus Hall

E. M. Jimenez[1],C. M. Ajo-Franklin[1]

Living cells assemble into hierarchical structures, forming complex materials with remarkable mechanical properties. Inspired by nature, the emerging field of Engineered Living Materials (ELMs) aims to predictively design cells to grow into materials with tailored properties. Contributing to this goal, our lab has recently reported the first **B**ottom-**U**p **D***e novo* **E**ngineered **L**iving **M**aterials (**BUD-ELMs**) using the bacterium *Caulobacter crescentus*. BUD-ELMs are comprised of a secreted protein matrix that assembles cells into centimeter-scale materials and defines their mechanical and physical characteristics [1]. Thus, to achieve predictive design for targeted mechanical properties, we require insight into how genetic modifications affect bulk material characteristics. Therefore, to elucidate sequence-property relationships of BUD-ELMs, we developed strains expressing elastin-like polypeptides (ELPs) with different mechanical properties, grew the strains to form BUD-ELMs, and characterized each material's viscoelastic behavior. We hypothesized that the mechanical properties of the purified ELPs would be mimicked in BUD-ELMs. Our results show that shortening the ELP increases the storage and loss moduli of the material while lengthening the ELP decreases both moduli. Moreover, when transglutaminase, an enzymatic crosslinker, is incubated with the original BUD-ELM, the storage modulus increases two times higher indicating stiffer materials. Additionally, when the original BUD-ELM is incubated at 37°C post-growth without transglutaminase the storage modulus becomes almost four times greater. Thus, this exploration into the genetic and environmental tunability of BUD-ELMs leads us toward establishing design rules for ELMs with programmable mechanical properties.

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**Keywords**

Bioinspired materials | adaptive materials | programmable materials

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**Nung Lee** | University of Freiburg, DE — Poster P7

*Icephobic mechanisms and anti-icing strategies of superhydrophobic surfaces*

Prometheus Hall

N. Lee[1], J. Rühe[1,2]

Condensation and icing on surfaces are inevitable in the environment, excessive ice accumulation can lead to severe damage from personal injuries to large fatal accidents and may cause poor mechanical performance in various machines and power supply facilities [1].

Conventional de-icing methods consume energy to melt the ice and may cause environmental pollution due to the use of chemicals. Therefore, the investigation for a low-energy consuming and sustainable anti-icing material is essential.

In nature, superhydrophobicity can be observed on the surfaces of plants and animals, such as the well-known lotus leaf and the legs of water striders. These exceptional properties are attributed to the low surface energy and textured microstructure surface [2]. Inspired by nature, a structured material with superhydrophobicity was used in this work for anti-icing instead of the traditional de-icing methods.

This work aims to investigate the icephobic mechanism on surfaces under different environmental conditions and to introduce corresponding anti-icing strategies for novel nanostructured material. The morphology of condensed water droplets and ice crystals within the nanostructures was investigated by theoretical and experimental methods. As well as the mechanical behavior of the nanostructure when the external weight from ice is added.

In addition, an innovative method based on quartz crystal microbalance has been developed to evaluate anti-icing properties by monitoring the global condensation freezing behavior of the surface. This method not only improves the inaccuracies in image analysis due to the limitation of the observation area but also provides a way to quantitatively define anti-icing.

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**Keywords**

Anti-icing | Superhydrophobic surface | Nanostructure | Condensation freezing | Quartz crystal microbalance

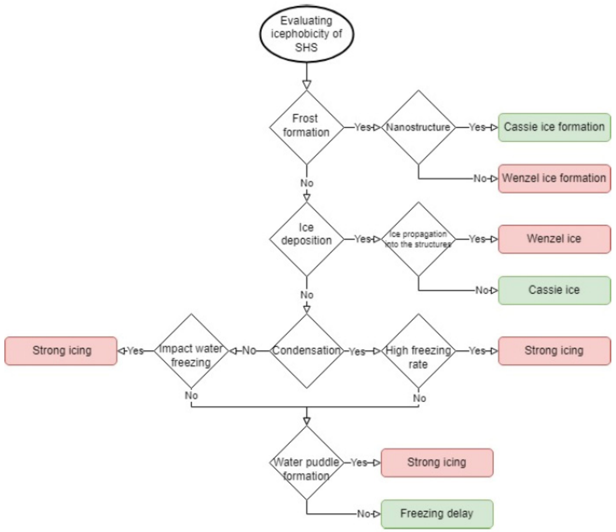


Fig. 1 The figure illustrates the different icing mechanisms on superhydrophobic surfaces under the various conditions. The main challenge with anti-icing is that there is no one-size-fits-all strategy that applies to all situations. Therefore, the goal of this work is to define anti-icing performance of superhydrophobic surfaces under different circumstances and discuss the mechanisms of icing on the surfaces.

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**Mohammad Ali Maghsoudlourad** | University of Freiburg, DE Poster P1

*Bio-inspired topologically transformable mechanical metamaterials* Prometheus Hall

M. A. Maghsoudlourad[1], C. Eberl[1,2]

Nature is the best reference for researchers to obtain inspiration by which they can improvise materials with specific geometries or properties that cannot be found in the existent materials. For instance, there is a reproductive mechanism in plants called fern sporangium dispersal that plants use to mechanically disperse contained spores into the air. Surface tension force out of wetting and then drying is implemented in this mechanism as the stimuli to open microstructures called sporangia. Therefore, there is a capability to extract work from surface tension force while drying. This work can lead to shape morphology since surface tension becomes dominant among other types of forces at submillimeter scale.

With this notion in mind, we are focusing on applying this phenomenon in mechanical metamaterials as the fundamental body of this research. In this work, we present a novel design of sporangium-inspired unit cell with the rib-like structures. After wetting the unit cell, water seeks to minimize the surface energy between the ribs which causes micro transformation in the morphology. This hierarchical surface-tension-driven micro deformation can lead to bulk deformation, thereby shape morphing in the lattice of metamaterial at macroscale. For doing so, we will derive and optimize the parameters which play pivotal roles in achieving the stable positions before and after wetting with the consideration of limitation in 3D-printing fabrication process. Then, proof of the concept will be presented by the aid of microfluidic simulation platforms. Hence, the correlation between the simulation and printed sample will be analyzed.

**Keywords**

mechanical metamaterial | shape morphing | surface tension | capillary force

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**Renato Maraula** | University of Freiburg, DE Poster A8

## *Synovial joint as a model for the development of super-lubricated surface-attached hydrogels*

R 1115

R. Maraula[1,2], J. Rühe[1,2]

Tribological contacts account for about 23% of worldwide energy consumption. While 20% of this energy is used to overcome friction, 3% repair wear failures. Consequently, friction and wear cause costs of 250 billion euros every year and they are responsible for the emission of 8120 Mt of $CO_2$ [1].

This problem can be solved by creating materials that exhibit low friction, preventing wear phenomena and minimizing energy loss.

Despite using oil-based lubricants, whose recycling is only partially possible, natural systems can be an inspiration for developing technical systems because of their high efficiency, durability, and ability to adapt themselves to new environmental situations. The evolutionary process has led to specialized surfaces where friction is adjusted to meet the requirement of the living organism for different purposes, for example, the synovial joint of mammals, in which the synovial fluid plays a crucial role as a water-based lubricant [2]. In this context, hydrogels are promising materials because they consist of a solid matrix, can recover their initial shape after stress release, and have a high-water content, similar to biological tissues.

This work aims to investigate the impressive frictional properties of bio-inspired hydrogels covalently attached to a rigid substrate by C,H-Insertion Crosslinking (CHic) via UV radiation. CHic is a method in which crosslinking and covalent attachment to the substrate occur simultaneously, as reactive groups are incorporated into polymer chains by a copolymerization reaction [3].

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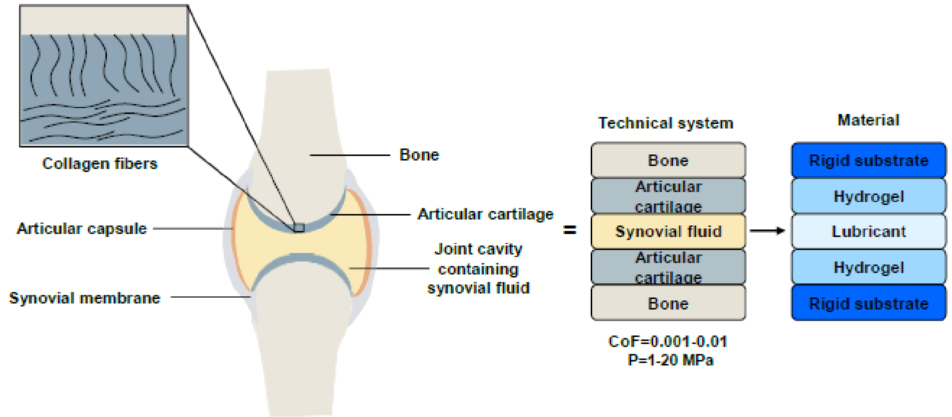
**Keywords**

Super-lubricity | Bioinspiration | Hydrogels | Surface modification | CHic reaction



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**Yannick Meurer** | University of Freiburg, DE Poster P8

## *Generation of hairy surfaces on polymer substrates via a hot drawing process*

Prometheus Hall

Y. Meurer, R. Konradi, J. Rühe

The surfaces of many biological organisms (mainly plants and animals) are at least partially covered with hairs. Those hairy structures (i.e. high-aspect-ratio, fibrous nano- or microstructures anchored to the surface) serve different purposes crucial for the organism's survival, such as water repellency, enhancement of friction and adhesion, or thermal insulation. One of the most prominent examples of a hairy, highly hydrophobic surface (Contact angle: $\theta > 150°$; roll-off angle: $\Delta\theta < 10°$) is the leaf of the Lady's Mantle (*Alchemilla vulgaris*), which exhibits a dense layer of microhairs [1,2].

Although it is very desirable to fabricate artificial hair-like features from polymer materials, the commonly used methods based on photolithography or molding techniques are either rather complex or, in the case of the latter, often fail during the demolding step. Recently, template-based cold drawing processes showed great success in producing high-aspect-ratio structures [2,3]. These processes use porous (polymer) templates that are first pressed onto molten polymer surfaces, and are then delaminated to generate highly elongated features (Fig. 1 a).

This work aims to establish a novel process based on hot polymer drawing using stainless steel meshes as templates to generate hair-like structures at elevated temperatures exploiting the temperature-dependent tensile properties of polymers to easily adjust hair formation by varying the process parameters. The fabricated surfaces are capable of repelling water mimicking the wetting behavior of superhydrophobic plant surfaces.

**Keywords**

Biomimetics | Metamaterials | Superhydrophobicity | Polymer Drawing

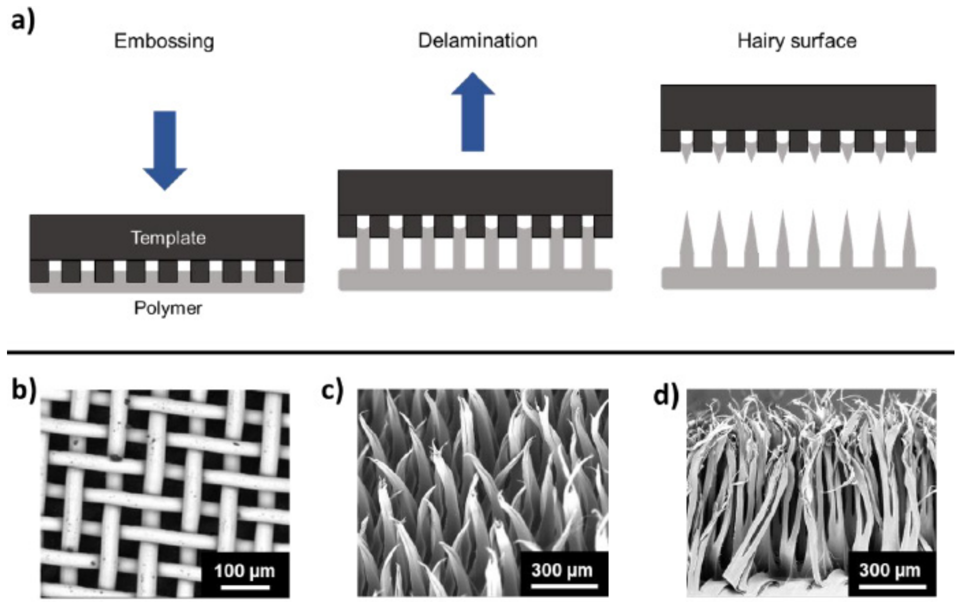


Fig. 1 a) Simplified scheme of a two-step template-based polymer drawing process for the fabrication of a hairy surface. b) SEM image of a stainless-steel mesh used as template. Exemplary SEM images of fabricated hairy surfaces from HDPE from a top view (c) and side view (d).

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**Fernanda Lucía Narváez Chicaiza** | University of Freiburg, DE Poster A6

## *Kirigami-inspired stretchable ECoG for electrophysiological recording in developing brain*

R 1115

F. Narváez[1], M. Asplund[1]

The stretchability and flexibility of bioelectronics devices are key factors for good integration with deformable biological tissue such as the heart, muscle, limbs, and brain. Studies of the activity of the brain during development require a high spatiotemporal resolution of signals, but also a device that can expand with the tissue during growth. One of the most interesting approaches is a top-down patterning of a non-stretchable substrate to generate cuts allowing the structure to expand. This is the case of kirigami Japanese art which has been developed for numerous applications. For instance, with kirigami it has been demonstrated that a paper can reach up to 840% expansion. Although this technique can reach such astonishing expansion, for neurotechnological applications there is a trade-off between the number of cuts and the number of electrodes integrated. Furthermore, the out-of-plane rotation of the kirigami structure, when it expands, results in insufficient contact between electrode and tissue surface.

Here we designed a rectangular grid of 2.5 × 3.4 $mm^2$ with 64 electrodes based on polyimide of thickness 5 µm. According to the theoretical beam bending model we expect a linear region of the strain of 60% in the elastic regime. The grids were mechanically tested using a bond tester so analyse their strain/stress curves and point of failure. In addition, two design variations were tested to demonstrate how the insufficient electric contact due to the out-of-plane rotation could be overcome by strategical cutting patterns. The first one (A) introduces an extra slit around the electrode which releases the electrode from the plane and allows it to disentangle from the rotation of the surface. The second approach (B) leaves strings of polyimide free of any cutting pattern connected with expandable kirigami structures. By using agar to mimic the brain tissue, the grid was stretched while electrochemical spectroscopy was evaluated. Finally, an inflated spherical balloon was used to simulate the growth of the tissue and test the kirigami-inspired stretchable ECoG.

For structure A, the mechanical pull tests showed that an initial force of 9 mN is required to expand the grid and that mechanical failure occurs at 100% strain for a force of 92mN. . Electrochemical impedance spectroscopy (EIS) was first performed during stretching while the electrodes were in contact with a flat agarose surface to verify the loss of electrical contact, and in PBS solution to separate the effects of the stretching due to micro-cracks in the Pt traces. This way we could investigate impedance changes during expansion and could confirm that within the linear range of expansion the variation was acceptable (below 10%). When stretched on the surface of the agarose, the impedance increases to twice its initial value during expansion, which is related to the reduced contact to the surface. To address this problem, we developed a second structure (structure B), that maintains i's contact with the agarose (i.e. model tissue) which should reduce the change in impedance. Using the ballon model we could validate that there was no significant rotation of the electrodes due to out-of-plane deformation of the kirigami cuts using pattern B. Thus we demonstrate that by strategic design of the cutting pattern we could successfully tackle the problem of contact loss, and allow expansion of a flexible grid.

*[1]University of Freiburg, Germany*

**Guido Panzarasa** | ETH Zürich, CH Poster P12

*Design and applications of chemical clocks for controlling self-assembly in time* Prometheus Hall

G. Panzarasa[1]

The astounding ability of living organisms to make materials of high complexity arises from the ability to control self-assembly in time, which they achieve through biochemical networks. Understanding and modeling such processes with artificial reaction networks holds the promise to develop novel far-from-equilibrium materials.

In this context, chemical clocks appear as versatile tools for programming in time the autonomous and transient self-assembly of organic as well as inorganic building blocks.

Here I will showcase examples of how to program chemical systems to give rise to stable or transient structures, from colloidal particles to macroscale gel assemblies, eliminating the need for external control [1-3]: chemical clocks resulting in the production of transient pH changes (especially the methylene glycol-sulfite-propanesultone (MGS-PrS) system) and iodine clocks for controlling sol-gel transition in time.

[1]*Wood Materials Science, Institute for Building Materials, Department of Civil, Environmental and Geomatic Engineering, ETH Zürich, Laura-Hezner-Weg 7, 8093 Switzerland*

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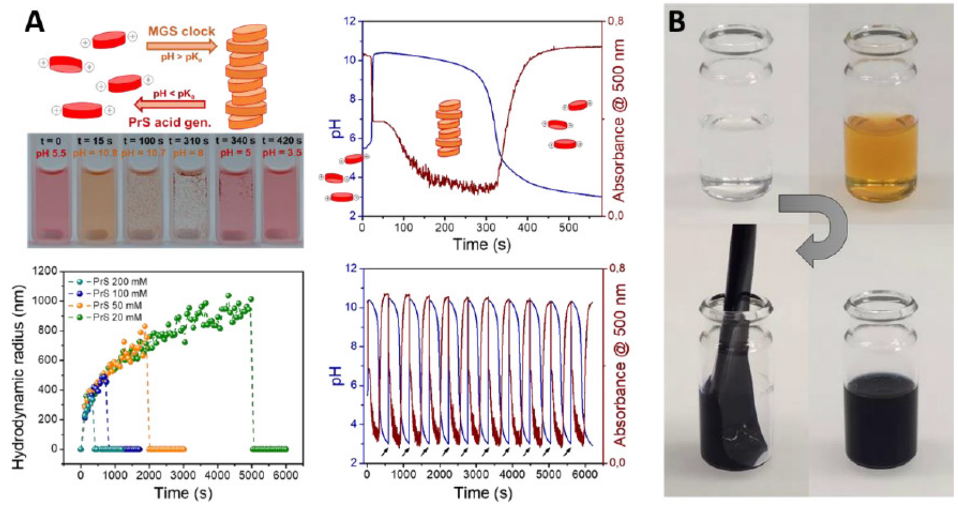
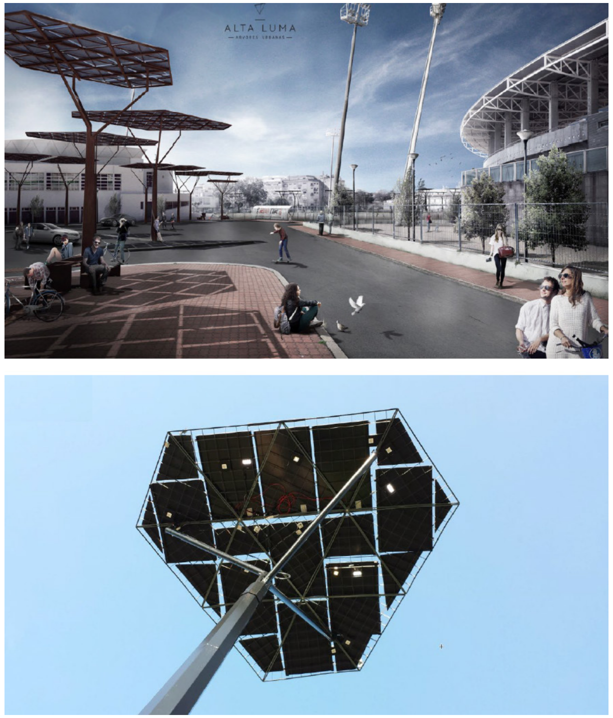



Fig. 1. (a) The MGS-PrS system used to control the self-assembly in time of a pH-responsive perylenediimide [3]. (b) An iodine clock used to control the sol-gel transition of poly(vinyl alcohol) [2].

**José Pinto Duarte** | Penn State Univesity, US Poster A3

*Solar trees: energy and information in urban settings* R 1115

Cities are the main energy consumers. However, energy is produced in power plants located in the countryside. Transporting energy to city requires an infrastructure that is costly, hard to maintain, and has a negative visual impact on the landscape. In addition, there is a growing World interest in the use of renewable energy sources to produce electricity, particularly using photovoltaic technology. Current solutions rely on the use of solar power plants that have the disadvantages referred to above, or on the placement of photovoltaic panels in buildings, which also has a negative visual impact and is not very efficient. We propose an alternative solution called "solar trees." These are parametric structures that resemble the function and shape of trees. These structures can be placed along roads, streets or in other public spaces like squares and parking lots. They blend into the landscape, optimize the harvest of sunlight, and may provide additional features, such as artificial light, shade, information, and may enhance public space. In its simpler form they are simple structures, affordable, easy to build and to maintain. In its more complex format they are 3D printed and use algorithms and smart materials to optimize the harvest of sunlight.




Figur1. Solar trees: simulation in urban context (top) and physical working prototype (bottom).

**Mahesh Pol** | University of Freiburg, DE — Poster P9

*Abiotic phosphate fuels* — Prometheus Hall

**Lina Manuela Rojas Gonzalez** | University of Freiburg, DE — Poster P4

*Bioinspired functionally graded materials for damage resistant connection of two materials with different mechanical properties* — Prometheus Hall

L. M. Rojas Gonzalez[1,2], M. D. Mylo[1,2], N. Ghavidelnia[1,2], C. Eberl[1,2]

The European mistletoe (*Viscum album*) is a hemiparasitic plant that grows on host trees, depriving them from water and dissolved nutrients. This physiological connection is provided by the formation of a so-called haustorium, which also mechanically anchors the mistletoe inside the host branch. Despite the occurring loads (own weight of the mistletoe, wind, snow...) and the different mechanical properties of the parenchymatous mistletoe and the lignified host, the connection was found to be very damage resistant over the entire lifetime of the mistletoe (Mylo et al., 2022). This is facilitated through lignin and cell wall gradients along the interface that smoothens the mechanical transition and minimize crack initiation, together with redundant anchoring structures that prevent total failure in case of localized defects (Mylo et al., 2021).The aim of the present study is to transfer these underlying functional principles into functionally graded materials (FGMs) systems, and thus increase their longevity potential. Polymer blends, consisting of two or more polymers with different properties that are brought together to tailor the mechanical, physical, and/or chemical properties of the final material (Utracki & Wilkie, 2014), will be used for this purpose. Two thermoplastics will be compatibilized and extruded at varying ratios and with various interface shapes to produce a FGM, aiming to transfer and further characterize the functional mechanisms of the mistletoe-host interface. Mechanical testing will be used to comparatively analyze the behavior of the molded FGMs under load and to correlate them with simulation approaches.

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**Dennis Rusitov** | University of Freiburg, DE — Poster P14

## *Tunable thermal and photochemical crosslinking of CHic-able diazo-groups containing polymers*

Prometheus Hall

D. Rusitov[1,2], J. Rühe[1,2*]

The work presented here focuses on the formation of (surface attached) polymer networks. Covalently bound networks have increased stability over physically adsorbed linear polymers and can therefore be a tool for enhancing the longevity of a material function. They are prepared from prepolymers containing a few phenyl diazo ester based dormant molecules per chain, forming reactive intermediate carbenes upon UV or thermal activation, which crosslink via C,H insertion reactions (C,H insertion based crosslinking: CHic, Fig. 1). Conventional crosslinking methods are done in bulk where no post-processing is possible, need additives, or a high density of functional groups to trigger the crosslinking reaction. The CHic reaction requires only a low amount of functional groups since the reaction partner, a C,H-group, is abundant, does not require any additives, is processable before activation and can be carried out under atmospheric conditions. In addition to that, it is possible to attach the polymer network to a surface, as long as the surface contains C,H groups. The carbene formation from diazo groups, and therefore the crosslinking behaviour, is controllable to a certain extend through the chemical environment of the diazo group. This study focuses on the influence of donor/acceptor groups on the aromatic ring, to tune and improve the thermal and photochemical activation of diazo containing polymers to form surface attached polymer networks.

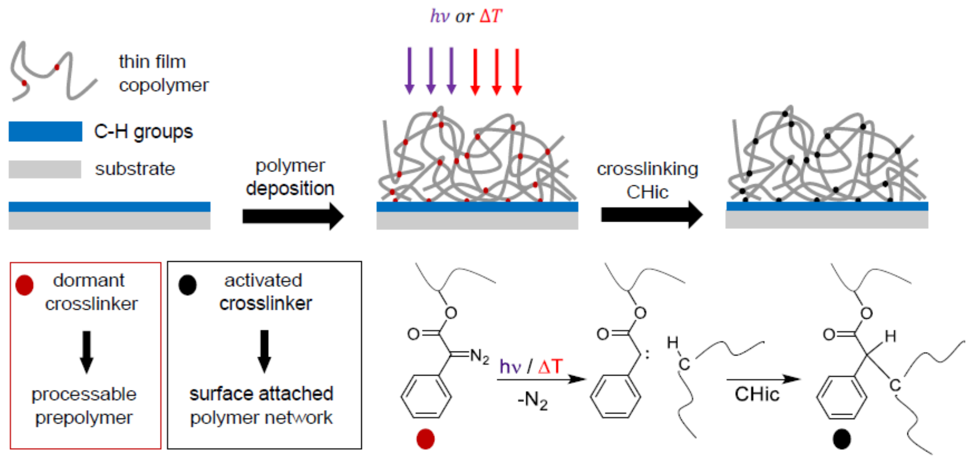


Fig. 1 Schematic description of the C,H insertion based crosslinking of phenyl diazo ester containing polymers, to generate surface attached polymer networks upon thermal or photochemical activation.

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### Keywords

polymer networks | crosslinking | diazo-chemistry | longevity

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**Seyedali Sabzpoushan** | University of Freiburg, DE Poster A4

## *Adaptivity of a leaf-inspired wind energy harvester with respect to wind speed*

R 1115

S. Sabzpoushan[1,2], P. Woias[1,2]

In small-scale energy harvesting, sporadic ambient wind is a source that has been always in great attraction. Among different conversion methods, electrostatic harvesters sometimes implement bio-inspired remedies to capture the mechanical energy of the wind stream. In this regard, efficient conversion as well as durable operation (life time) of the harvester matter. For achieving both, one solution would be referring to the natural responses of green leaves in windy conditions or even the body movements of aquatic animals. For instance, deformation and vibration of a Platanus acerifolia leaf at different wind speeds has been studied [1]. Moreover, bending of the blades of a maple or triplaris seed during its fall from the tree to the ground surface has been analyzed and the possible applications in design of wind turbine blades has been addressed [2]. Investigation of the flow control role of the scales on a shark's body [3] is another example of such referrals. In this paper, we aim to add some adaptivity to the target wind energy harvester which mainly consists of a leaf-mimetic structure. Since a real ambient wind source may be so variable in both speed and direction, the aero-structural configuration of the leaf should be variable and self-adaptive, as well. One way for doing so is spontaneous implementation of structure flexibility and passive aerodynamic actuation. Using retractable micro spoilers, flexible tail and high aspect ratio shutters are the major remedies which will be examined in the present study.

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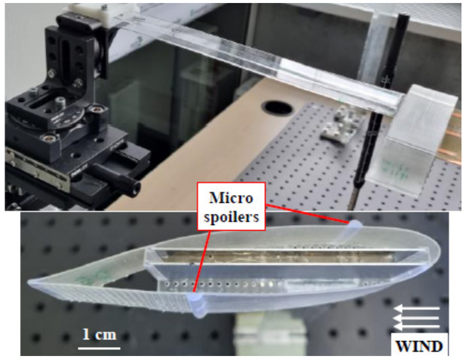


Fig. 1 Leaf structure of the harvester and the micro spoilers in a cross-sectional view.

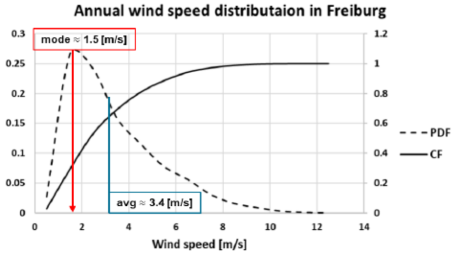


Fig. 2 Probability Density Function and Cumulative Frequency of annual distribution of wind speed in Freiburg.

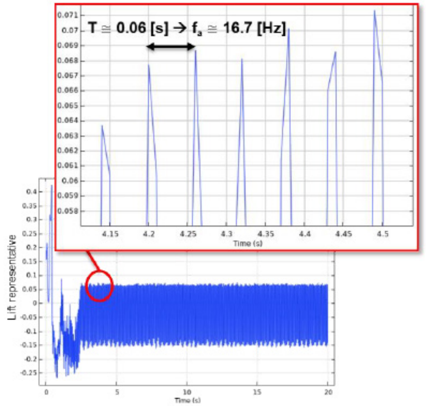


Fig. 3 Temporal behavior of aerodynamic lift on the leaf shell at wind speed of 3 m/s.

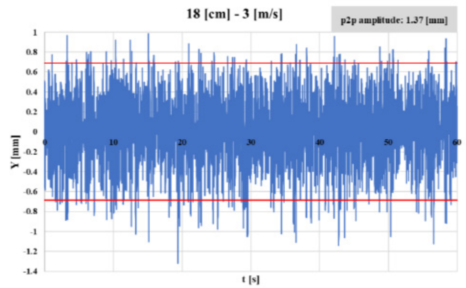


Fig. 4 Vertical position of the leaf shell (with respect to an initial position) at wind speed of 3 m/s and using a 18 cm-long wind stalk.

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**Karima Saddedine** | University of Freiburg, DE Poster A7

## *Bi-O-ACTUATOR: bio-based and -inspired stimuli-responsive system made out of printed wood*

R 1115

The research project Bi-O-ACTUATOR is investigating the suitability of a 3D-printable bio-based polymer for nature-inspired stimuli-responsive structures. The wood-based composite ink made of cellulose and lignin can be used to print at room temperature using *direct ink writing*. Due to the shear force induced alignment of the cellulose fibrils, the printed filaments exhibit anisotropic properties, which can be exploited to locally "program" the printed material. We aim to identify material and process technologies to hierarchically structure printed wood. The local "programming" of the elastic modulus and the swelling or shrinkage coefficient allow an intelligent integration of sensory and actuator properties in the material. Inspired by the passively driven, hydromorphic motion of a pine cone scale, we aim to engineer a moisture induced curvature of a printed bi-component assembly. The 4D-printed Bi-O-ACTUATOR could become a resource-effective way to enable high-tech functions with a fully bio-based and potentially biodegradable material system. Furthermore, ultrasonic welding will be investigated for its compatibility with the bio-polymer, in order to make printing scalable and multi-material composites possible, without introducing other materials, in the sake of recyclability.

**Abanounb S. Sedeky** | University of Freiburg, DE Poster P18

## *Fabrication of bead-based polymeric systems for biomedical applications*

Prometheus Hall

L. Alpsoy[1], A. S. Sedeky[1], T. Brandstetter[1], J. Rühe[1]

Polymers are the main materials used to produce beads especially for biomedical applications including drug delivery, bead-based multiplex analysis and biosensors. The production of hydrogel beads and sponge particles from polymers is achieved by using different strategies such as polymerization, gelation, freezing and ionic crosslinking. Moreover, different applications require different features of the platform and for this reason, having different bead's characteristic can be remarkably useful. Depends on the type and concentration of polymer and fabrication methods, beads can have different pore size, surface area, density, and water absorption capacity [1]. Additionally, microfluidics facilitates the generation of beads in an easy and controllable way.

In this work, three strategies of the bead fabrication will be presented. The hydrogel beads are produced either by using droplet-based microfluidics in combination with photo-chemically induced C–H insertion reactions or by using a chemical crosslinking reagent. Photo-crosslinking could be performed at room temperature for hydrogel beads or after freezing step for sponge particles [2,3]. To produce the hydrogel beads by chemical crosslinking, beads could be incubated in a water bath at 70°C. These bead-based platforms can be easily generated, functionalized and even barcoded in a single step. By manipulating the polymer concentration, carrier / plug flow rate ratio and tubing system dimensions, the bead's size and shape can be controlled. Moreover, using multiple dyes with different concentrations is allowing the expansion of the barcoding map. The production, barcoding and bio-functionalization of polymeric beads for medical applications could be achieved in one single step.

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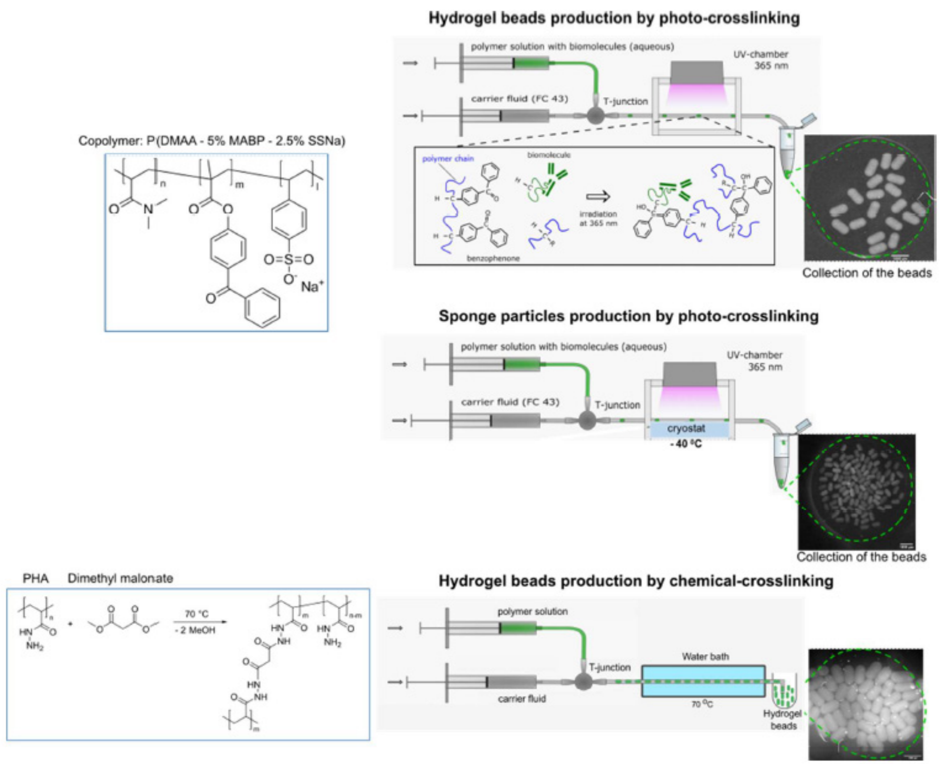


**Keywords**

Hydrogel beads | Sponge particles | Chemical and Photo-crosslinking | contribute to Adaptive Materials Systems

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**Dan Song** | University of Freiburg, DE Poster P17

## *Functional and stable actuators generated by multi-material 2D and 3D printing*

Prometheus Hall

D. Song[1,2,3], M. Gastearena[1,2,3], B. Rapp[1,2,3], J. Rühe[1,2,3]

Over the past decades, photolithography and photoinduced 3D printing have attracted increasing interest in both industrial and scientific fields. However, conventional polymerization-based systems have several limitations such as delamination and insufficient long-term stability due to the only physical interaction between the fabricated struc-tures and the substrate surfaces. In our work, we report on a novel prepolymer system based on photoinduced C,H-insertion crosslinking (CHic) as a new photoresin to generate complex 2D patterns and 3D structures on arbitrary surfaces (Fig. 1(a)) [1,2]. As shown in Fig. 1(b), a grayscale pattern with complex topographies was generated via one-photon absorption in the UV region by digital light processing [2]. Fig. 1(c) shows a complex 3D hydrogel in high reso-lution fabricated via two-photon absorption in the near-infrared region by two-photon lithography.

Compared to other strategies that need two functional groups for forming a covalent bond, CHic only requires ali-phatic C,H units, which are ubiquitous, as reaction partners. Thus, numerous covalent bonds are established at the interface, rendering a stable system. Moreover, CHicable prepolymers can be designed to various properties via co-polymerization conveniently and generated together to combine their properties in one object. In Fig. 1(d) and Fig. 1(e), multi-material 2D patterns [2] and 3D structures are demonstrated as examples. By this approach, actuators com-posed of multi-materials, which have different behaviours upon actuation, can be generated easily. This opens up possibilities to fabricate a broad spectrum of functional patterns and microstructures in a very simple way (Fig. 1(f)).

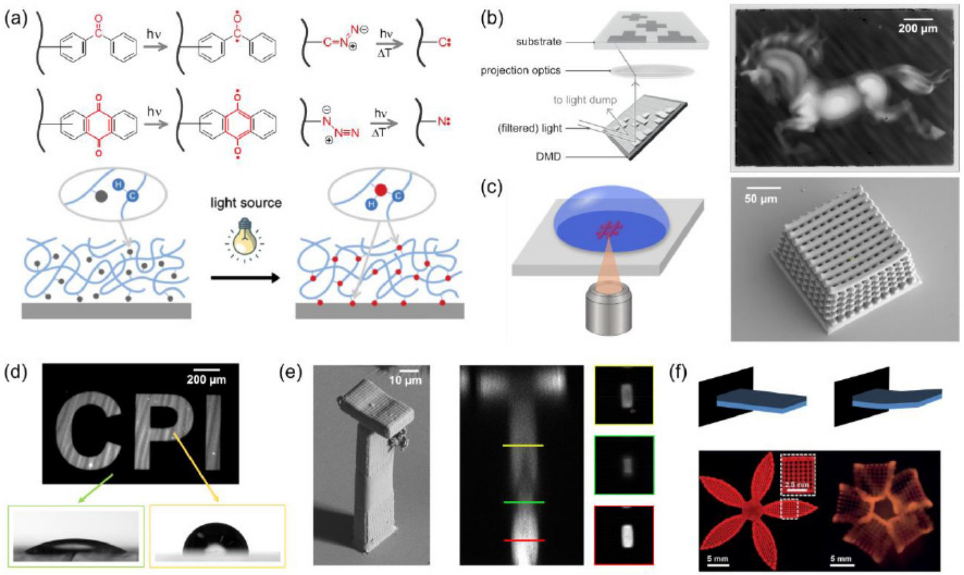


Fig. 1. (a) Variety of CHicable systems and the schematic description of photochemical CHic reaction.[1] (b) A grayscale image fabricated from CHicable pre-polymer by digital light processing at 365 nm.[2] (c) A 3D hydrogel scaffold fabricated from CHicable pre-polymer by two-photon lithography at 780 nm. (d) A bi-property 2D pattern showing different protein absorption on different regions after incubation.[2] (e) A multi-layered 3D structure composed of hydrophobic and hydrophilic components. (f) Approach and outlook of generating microactuators[3] via CHic.

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**Anaclara Visconti** | University of Freiburg, DE — Poster P5

## *Finding design inspirations in the tropics: can marantochloa inspire engineered fiber reinforced components?*

Prometheus Hall

A. Visconti[1], L. Hesse[1,2]

The monocot *Marantochloa leucantha* grows in an upright self-supporting manner within moist lowland forest in tropical Africa or islands in the Indian ocean. As typical for monocots, their growth is limited by primary growth processes and the stem vasculature is characterized by a scattered arrangement of individual fibrous vascular bundles embedded within a viscoelastic ground tissue. This interior architecture is comparable to the design of technical fiber-reinforced components. We aim to understand the development and 3D arrangement of mechanically rigid and fibrous vascular bundles particularly through complex node of the aerial stem in *M. leucantha*. For this, we use light microscopy, µCT and biomechanical experiments (bending and torsion) to visualize and quantify structural changes along the ontogenetic gradient of aerial stems. Our findings will be compared to results of other Marantaceae and they will be abstracted and used as design principle for engineered fiber composites with load-optimized fiber placement and nodal fiber connectivity.

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## Christiane Wenzel | University of Freiburg, DE — Poster P11

*AFM imaging of fueled assembly processes of peptide-based molecular building blocks*

Prometheus Hall

C. Wenzel[1,2], J. L. Trefs[1,2], M. Pol[2], K. Dai[2], C. Pappas[2], B. N. Balzer[1,2,3], T. Hugel[1,2]

In living systems, autonomous assembly of building blocks into structures is a common process. Often this (self-)assembly is controlled by the concentration of the building blocks (continuous turnover) and chemical fuels like ATP, such as for microtubules. The aim of this study is to mimic such an out-of-equilibrium assembly in an artificial peptide-based system.

Therefore, aminoacyl phosphates are used as high energy building blocks in phosphate fueled systems. The out-of-equilibrium assembly process is investigated via atomic force microscopy (AFM) imaging in a time-resolved manner. We obtain sub-nanometer spatial resolution and sub-minutes time resolution, which allows us to monitor and understand assembly pathways. This knowledge is important to optimize the use of (self-)assembly for the synthesis of novel materials in adaptive and sustainable materials systems.

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**Keywords**

Fueled systems | autonomous response

## Kaiyang Yin | University of Freiburg, DE — Poster P3

*Programmable mechanical metamaterials in metals: optimization from materials to structural design*

Prometheus Hall

K. Yin[1,2], B. Cao[1,2], J. Todt[4], F. Gutmann[3,6], H. F. Tunçay[3], A. Roth[3], F. Fischer[3], N. Grübel[1,2], A. Pfaff[6], G. C. Ganzenmüller[3,6], J. Keckes[4], S. Hiermaier[3,6], C. Eberl[1,2,5], N. Ghavidelnia[2]

Programmable mechanical metamaterials (PMMs) have unique and dynamically changing mechanical properties, such as highly nonlinear stiffness, strength, Poisson's ratio, and the functionalities built upon, such as if-then-else logic and memory. Current PMMs are predominantly made with soft elastomers due to their capability to sustain large elastic deformation. However, polymer PMM cannot achieve the high stress and temperature, which are frequently required for industrial applications. A simple translation of the proven PMM unit cells made of polymers into metals is proven unsuccessful because most metals have magnitudes lower elastic strain limit than polymers, leading to very different functionalities and early failure even. Without a complete structural redesign of the unit cells, the required strain amplitude would be extremely challenging to achieve in metals. Although additive manufacturing (AM) offers the potential to fabricate complex geometry for metamaterials applications, there are numerous challenges during AM process. The small dimension and complex geometry required to achieve functionality in PMMs have reached the resolution limit of AM technique. Also the residual stress and porosity developed during fabrication of these small structures (such as struts) significantly degrade the structural and mechanical stability (such as fatigue resistance) of PMMs. Hence, there is an urgent need to proceed both from the structural design and AM processing to achieve desirable small features predictable mechanical behavior in metallic PMMs (MPMMs). Presented is first the optimization of a bistable structure, as the element of memory function in PMMs, to decrease the maximum strain by introducing curliness along a bistable, sinusoidal beam. A systematic study of the porosities and defects, microstructure and the resulting mechanical properties of selected laser melted Ti-

6Al-4V structure at submillimeter scale is then presented, to show the crystal growth phenomena and the structure-property-processing correlation in small AM structures. Overall, the presented studies highlight the necessary approaches to implement PMMs in metals.


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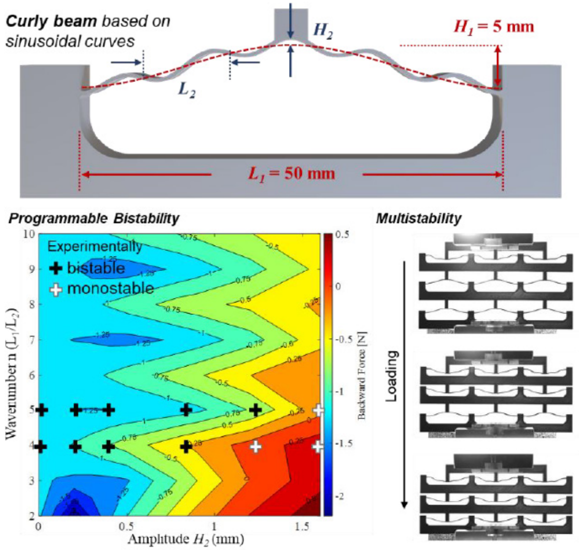



Fig. 1. Structural design of curly beams



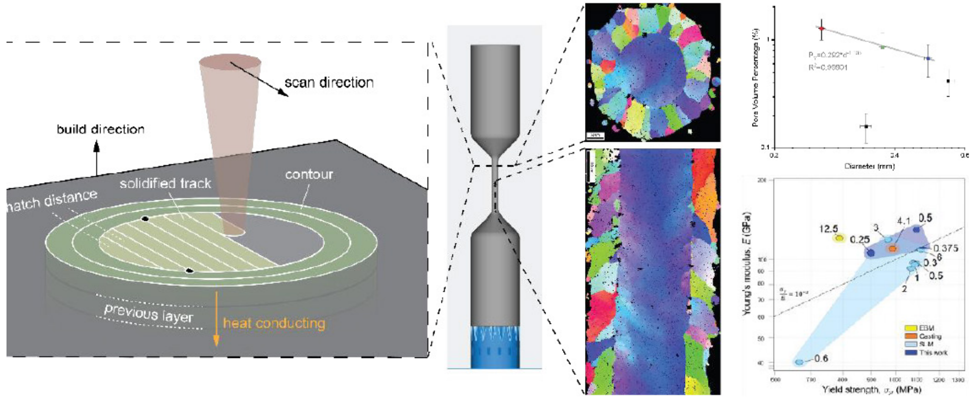



Fig. 2. Manufacturing size effect in Ti-6Al-4V microbeams

**Steve Wolff-Vorbeck** | University of Freiburg, DE — Poster P6

*Phase field methods for shape and and topology optimization in plant morphology*

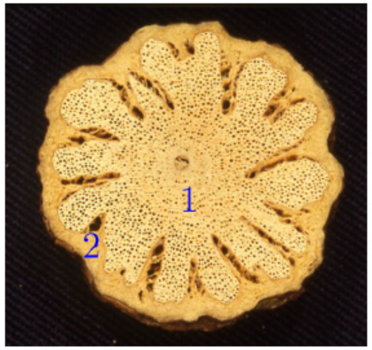
Prometheus Hall

S. Wolff-Vorbeck[3], O. Speck[1,2], M. Langer[1,2], T. Speck[1,2], A. Maione[3], P. W. Dondl[2,3]

Due to their flexibility with respect to geometries and their dimension independence, phase field models have emerged as a comprehensive and useful tool for the optimization of shapes and structures with applications in several fields of engineering and biosciences [1,2,3,4]. Especially, when describing the development of plant stems morphology, where tailoring resistance to twisting and bending under mechanical loading is a necessary evolutionary response, phase field models can be used to address a shape optimization problem which considers the distribution of different strengthening tissues inside plant stems cross-sections [1].

Here, the arrangement and shape of the tissue pattern influence the flexural rigidity and torsional rigidity of the entire plant stem and thus the ratio of both rigidities, the so-called twist-to-bend ratio [3,4,5]. In particular, increasing the "twist-to-bend ratio" it is often advantageous if this can be achieved by small changes to the geometry of the plant stems cross-section or the arrangement of structural material inside the cross-section.

Based on a phase field model we, therefore develop a shape optimization problem that treats the torsional and bending rigidity as objectives. Using gradient descent methods and sensitivity analysis we can finally analyse this problem and compare numerically optimized shapes to plant specimens.



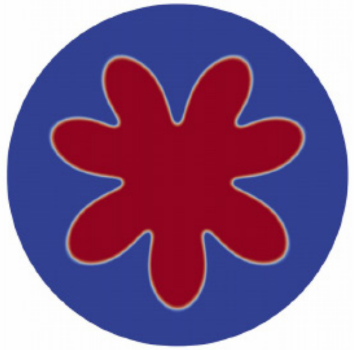



Fig. 1. Left: cross-section of liana Condylocarponguianense in the non-self-supporting old ontogenetic stage after attachment to a support.~The secondary xylem is marked with (1) where the cortex is marked with (2).

© Plant Biomechanics Group Freiburg, annotated and used with permission. Right: optimal distribution of two materials resulting from shape optimization unsing a phase model.

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Funded by

DFG Deutsche Forschungsgemeinschaft

German Research Foundation

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