

# IACM

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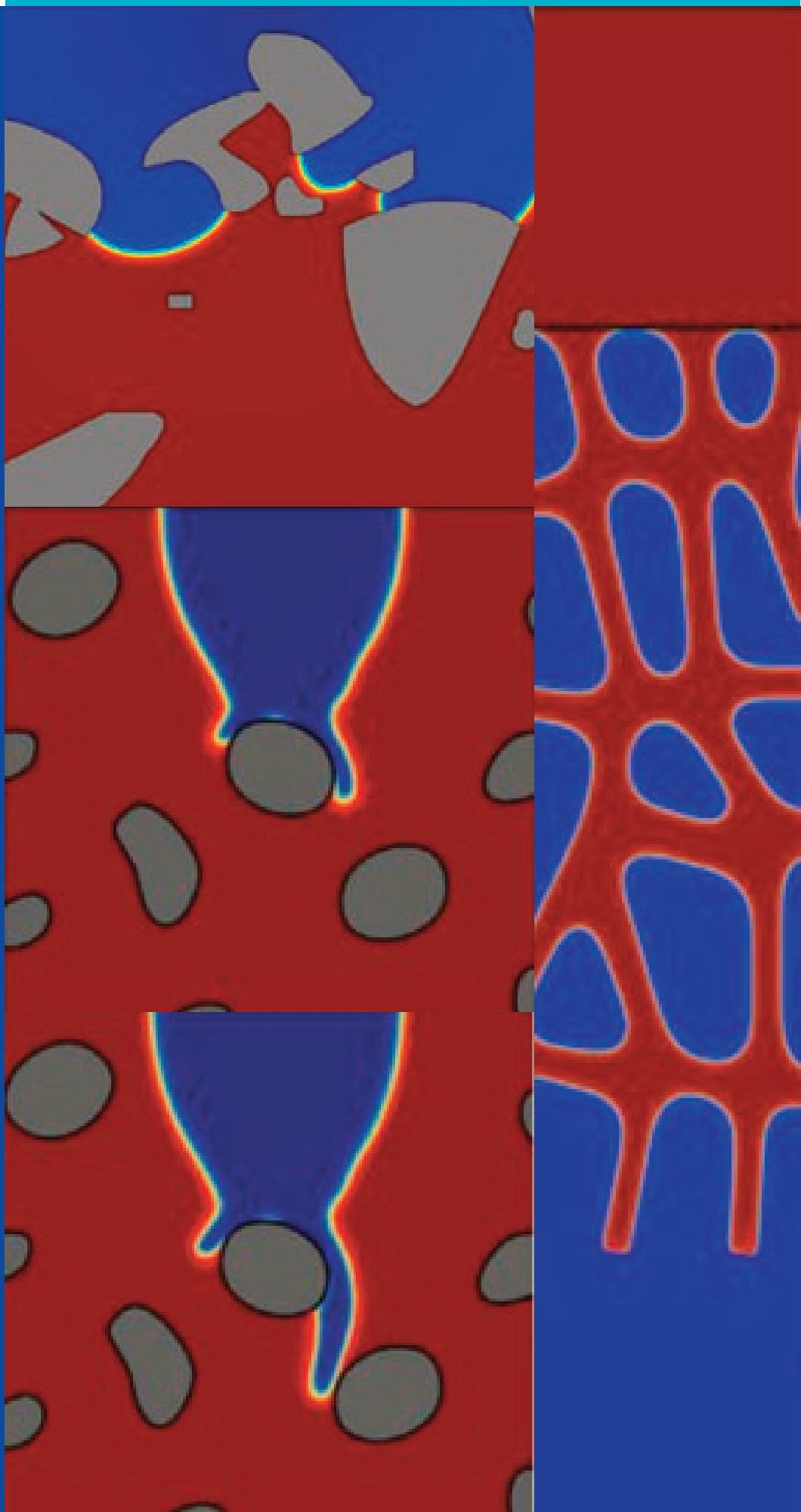
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*I am pleased to extend my warm greetings and wish you continued success and prosperity.*

*Nearly four years have passed since the end of the COVID-19 pandemic, and the period that once felt almost apocalyptic now seems almost unreal. Since then, the international conferences organized or sponsored by IACM have resumed in-person format and have been held successfully, as if nothing had happened. We are now approaching the 17th World Congress on Computational Mechanics and the 10th ECCOMAS Congress (WCCM-ECCOMAS 2026), which will take place in Munich, Germany, from July 19 to 24, 2026. More than 5,200 abstracts have been submitted, and the event is expected to become the largest WCCM in the history of our community. At the time of writing this message, the conference is still a few months away, but I am convinced that this remarkable international gathering in computational mechanics will undoubtedly go down in history. I would like to express my heartfelt appreciation to the organizers for their tireless efforts and dedicated work.*

*As already announced, the 4th IACM Digital Twins in Engineering Conference (DTE 2027) will be held from March 8 to 12, 2027, and the 24th IACM Computational Fluids Conference (CFC 2027) from March 12 to 15, 2027, both in Yokohama, Japan. As you may have noticed, the final day of DTE overlaps with the opening day of CFC, and the two conferences will be held consecutively at the*

*same venue. In a sense, this may also be viewed as a “revenge” edition of the 15th World Congress on Computational Mechanics and the 8th Asian Pacific Congress on Computational Mechanics (WCCM–APCOM 2022), which unfortunately could not be held in person at the same venue in 2022.*

*Until recently, the conferences organized directly by IACM, namely the IACM Conferences, consisted of three major series: WCCM, CFC, and DTE. However, as you may already know from the recent call for letters of intention or proposals, the International Conference on Computational Engineering and Science for Safety and Environmental Problems (COMPSAFE), originally organized by the Asian Pacific Association for Computational Mechanics (APACM), will be reborn starting from its fourth edition as the fourth international conference series organized by IACM.*

*While the Olympic and Paralympic Games, symbols of peace, have been held successfully, wars and conflicts continue to occur in many parts of the world, and the global situation remains highly unstable. Nevertheless, through these conferences and our daily research activities, IACM will continue to contribute steadily to the advancement of human prosperity as well as to safety and security for society.*

**Kenjiro Terada**  
President of IACM

# Unlocking the Challenge of Simulating Corrosion through a New Phase Field Revolution

by  
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“ For the first time, computational models can be developed that can resolve the complex underlying physics governing corrosion, ... ”

Predicting corrosion failures is a long-standing challenge for scientists and engineers. However, our community is getting closer to achieving this elusive breakthrough. For the first time, computational models can be developed that can resolve the complex underlying physics governing corrosion, from the transport of ionic species in an electrolyte to the interplay between mechanical fields and chemical reactions. Importantly, phase field models have enabled us to computationally track the evolution of the corrosion front, which is often described by a complex morphology involving pits, cracks and other localised defects. This not only lays the ground for another ‘phase field revolution’, akin to the ones that we have seen in microstructural evolution and fracture mechanics, but enables simulating corrosion from ‘meso-scale first principles’ (i.e., without strong assumptions and fitting parameters, resolving explicitly the underlying physical processes as they happen in reality). With a focus on the author’s contributions, the present article overviews recent progress in this emergent field and highlights opportunities for computational mechanicians.

## Introduction

Corrosion, the degradation of materials due to their reaction with the environment, is arguably one of the most longstanding challenges in engineering. Despite centuries of empirical knowledge and decades of sophisticated experimentation, predicting when and how a metallic component will fail due to corrosion remains an elusive challenge. From energy infrastructure and transportation to biomedical implants, corrosion-driven failures continue to impose enormous economic costs and safety risks. At the heart of the problem lies complexity: corrosion is not governed by a single mechanism, but by the interaction of chemistry, mechanics, transport phenomena, microstructure, and an evolving geometry.

At its core, corrosion involves the dissolution of a metal into an electrolyte.

In practice, however, this deceptively simple description hides a wealth of coupled phenomena. As a metal corrodes, its surface evolves into complex morphologies - pits, grooves, and cracks - that concentrate stresses and alter local chemical conditions. Inside a narrow pit or crack, the chemistry can be radically different from that of the surrounding environment: pH drops, ion concentrations rise, and electrostatic fields develop. These local changes, in turn, accelerate corrosion and interact with mechanical loading, potentially leading to catastrophic failure.

Traditional corrosion models, such as those used in the nuclear industry, have had to rely on heavy assumptions and simplifications, embedding the complex physics of corrosion into multiple fitting parameters, often with no clear physical connection. The aim was to compensate for the lack of computational resources with heavy experimental calibration. This proved to be challenging due to the different timescales involved: corrosion is accelerated in lab experiments, which last for hours or days, but the corrosion of engineering components can take place over decades. Simple extrapolation of empirical models failed to deliver accurate predictions, as it would be expected; simplification came at the cost of predictive abilities. However, there is an opportunity now to develop mechanistic, computational models for corrosion that can explicitly resolve the underlying physical mechanisms, eliminating assumptions and delivering predictions based purely on physical parameters, which can be independently measured in the lab. This is possible thanks to recent developments in two areas:

*Multi-physics modelling.* Increased computer power and coupled algorithms now enable direct numerical simulations of coupled electro-chemo-mechanical processes. As schematically illustrated in *Figure 1*, models are now available capable of solving for the electrochemical behaviour of electrolytes, surface reactions,

absorption of pernicious species and their bulk transport, mechanical straining, and defect evolution [1].

*Phase field modelling*, which offers a conceptually elegant solution to the interface problem. Instead of representing the metal–electrolyte boundary as a sharp surface, the interface is described as a thin but finite transition zone. An auxiliary field variable—the phase field—smoothly interpolates between intact metal and electrolyte.

The exact location of the interface no longer needs to be tracked explicitly; it emerges automatically from the solution of the governing equations. This concept will feel familiar to many – phase field methods have already proven successful in fracture and microstructural evolution. Their extension to corrosion allows the dissolution front to evolve freely, capturing pit initiation, growth, coalescence, and crack-like features without ad hoc criteria. Just as importantly, the diffuse-interface description makes it straightforward to couple corrosion to other physical fields, enabling genuinely multi-physics simulations. The reader is referred to Ref. [2] for a technical overview.

These developments have enabled the emergence of the field of phase field corrosion, which is already experiencing notable growth, in its very early days. Examples of phase field corrosion simulations are shown in *Figures 2 and 3*.

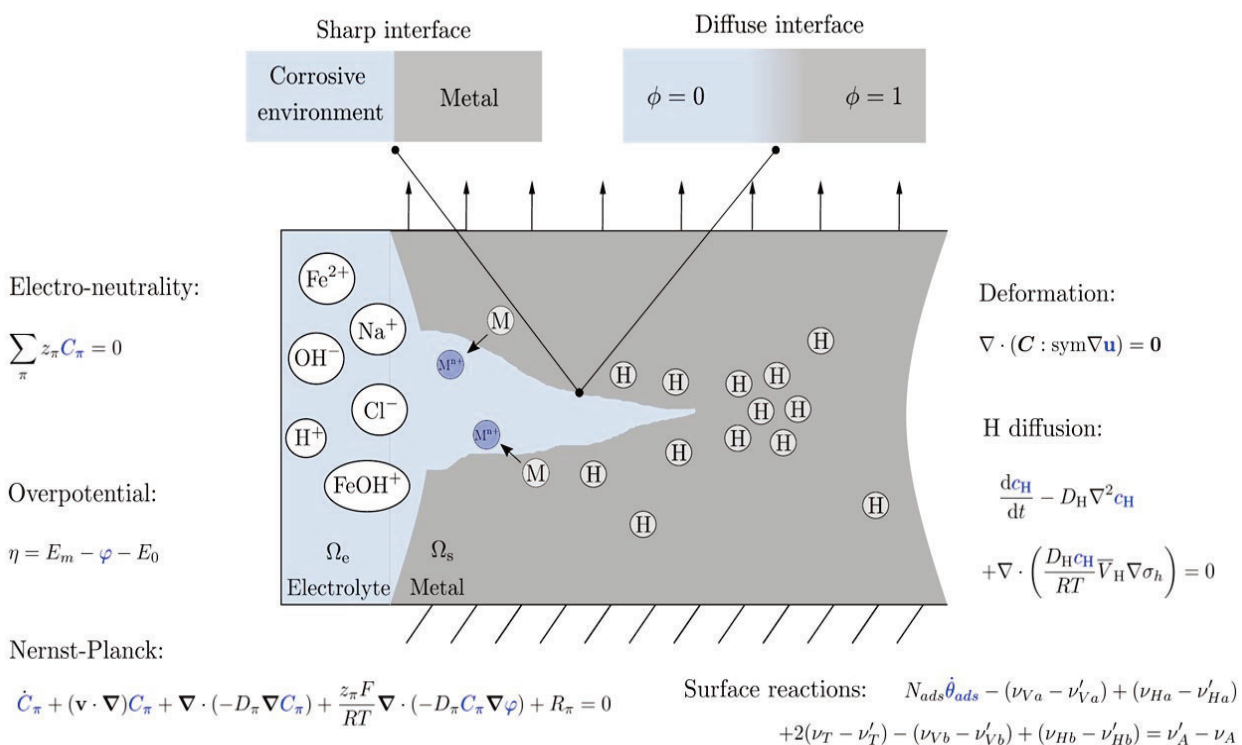
### Early Successes

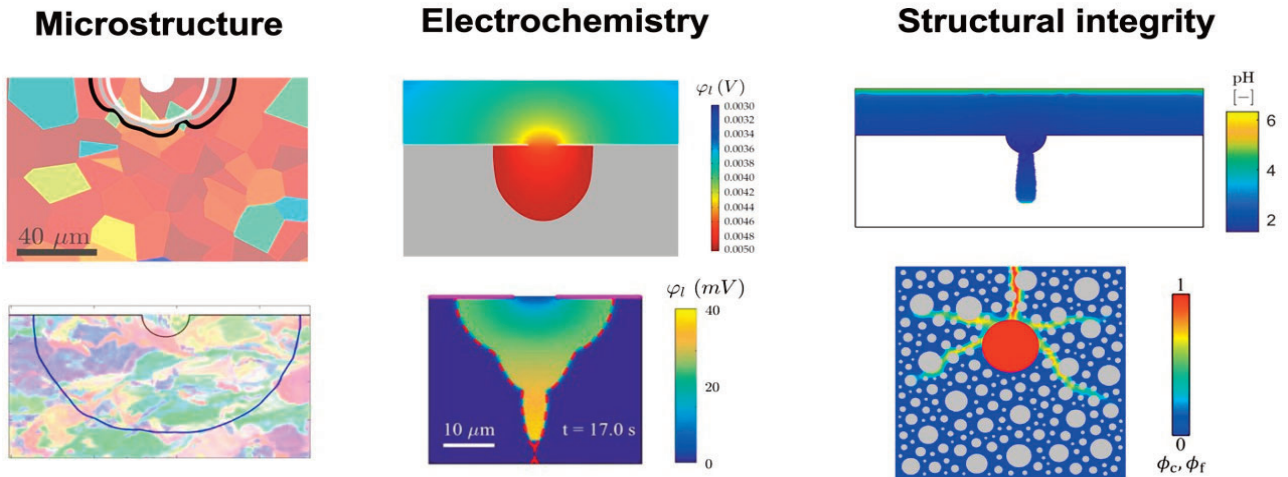
*From dissolution kinetics to transport-limited corrosion*

One of the earliest successes of phase field corrosion models was their ability to capture different corrosion regimes within a single framework. At low corrosion rates, material dissolution is controlled by surface reaction kinetics (so-called activation-controlled corrosion). At higher rates, dissolution becomes limited by the diffusion of metal ions away from the interface into the electrolyte. Phase field models naturally reproduce this transition. The rate at which the phase field evolves can be directly related to the corrosion current density, while ion transport in the electrolyte governs how quickly reaction products are removed. Without switching equations or introducing empirical thresholds, the model predicts when corrosion shifts from reaction-controlled to diffusion-controlled behaviour. This capability already represents a major step beyond classical approaches and provides a physically grounded basis for predicting corrosion rates across a wide range of conditions.

**Figure 1:**

*The challenge of predicting corrosion failures. Typical phenomena involved in localised corrosion damage, with the variables that correspond to nodal degrees of freedom highlighted in blue: transport of ions due to fluid flow, diffusion and electromigration, the deformation of the metal, the absorption of hydrogen by the metal, and its transport within the crystal lattice. Material dissolution and the electrolyte–metal interface are described using phase field. Adapted from [2]*





**Figure 2:** Examples of applications: unravelling the role of microstructural anisotropy, resolving the electrochemistry–corrosion interplay and predicting corrosion-induced cracking. Adapted from [2]

### Adding mechanics: when stress accelerates corrosion

Corrosion rarely acts alone. In many engineering applications, components are subjected to mechanical loading while exposed to aggressive environments, and mechanical fields impact corrosion in typically two ways: (i) accelerating corrosion kinetics, and (ii) rupturing the passivation layer that is formed in corrosion-resistant alloys. Both have been encapsulated in phase field corrosion modelling [3,4], enabling for the first time to understand the interplay between corrosion and straining kinetics and predicting (naturally, without ad hoc criteria), the pit-to-crack transition – a ‘holy grail’ of corrosion research.

### Electrochemistry without simplification

Electrochemical effects are central to corrosion, yet they are often treated in a simplified manner. Corrosion depends sensitively on local electrostatic potential, ion concentrations, and electrolyte conductivity—all of which evolve as corrosion progresses. Phase field corrosion models address this by explicitly resolving electrochemistry in the electrolyte. The transport of multiple ionic species, driven by diffusion, fluid flow and electromigration, can be simulated alongside the evolution of the corrosion front. The electrolyte potential responds to both charge transport and metal dissolution, creating a tightly coupled system.

This capability has enabled new insights into long-standing questions [1,5]. Simulations reveal how pits acidify, how corrosion can become self-sustaining even in oxygen-poor environments, and how hydrogen and oxygen evolution reactions interact with metal dissolution.

### Microstructure matters

Corrosion is not only sensitive to the environment and mechanical fields, but also to microstructure. Grain orientation, phase distribution, and manufacturing route can all influence corrosion behaviour. Phase field models have been extended to account for microstructural anisotropy, allowing corrosion kinetics and mechanical properties to depend on crystallographic orientation [6].

These models can be directly informed by experimental characterisation techniques such as electron backscatter diffraction (EBSD), enabling microstructure-resolved corrosion simulations. Results show that crystallographic effects often dominate pit morphology and growth rates, sometimes outweighing the influence of grain size or elastic anisotropy. *Figures 2 & 3* showcase relevant results, including corrosion in 3D printed additively manufactured alloys and intergranular corrosion.

### Beyond traditional corrosion: biodegradation & complex environments

The scope of phase-field corrosion modelling extends beyond conventional structural materials. A notable example is the biodegradation of magnesium alloys for medical implants. These materials are designed to corrode safely inside the human body, eliminating the need for implant removal. However, controlling degradation rates remains a major challenge.

Electro-chemo-mechanical phase-field models recently developed enable virtual testing of biodegradable implants, capturing geometry evolution, mechanical integrity, and interaction with physiological environments [7,8]. Validated against in-vitro experiments, such models open the door to predictive “in-vivo” simulations and accelerated design cycles.

## Conclusions

While the present contribution showcases some of the authors' recent work in the area of phase field corrosion, many corrosion-related problems remain unaddressed. Moreover, to enable virtual testing in engineering problems, there is a need to develop robust computational schemes – there are many opportunities for computational mechanicians keen to contribute to this growing area.

To facilitate this, all the codes developed have been openly released (see <https://mechmat.web.ox.ac.uk/codes>). These include easy-to-use codes in commercial FE packages like COMSOL [9] or ABAQUS, but also in-house codes in Matlab or C++ and implementations carried out in open-source platforms such as FEniCS.

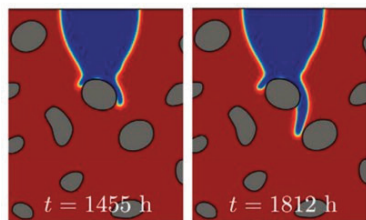
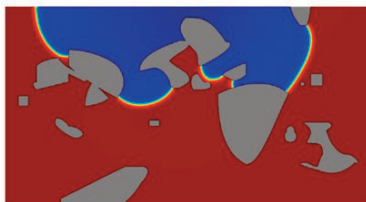
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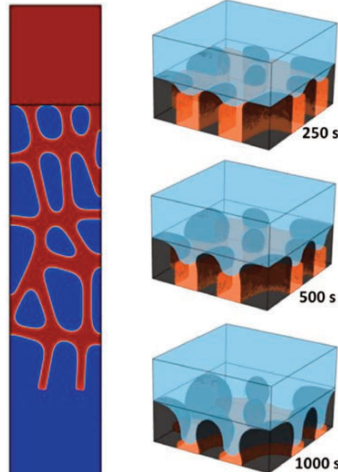
### Figure 3:

*Examples of applications: shedding light on the interplay between corrosion and secondary phases, understanding the preferential path of corrosion along grain boundaries (intergranular corrosion [IG]), and predicting “in vivo” the biodegradation of Mg alloys. Adapted from [2].*

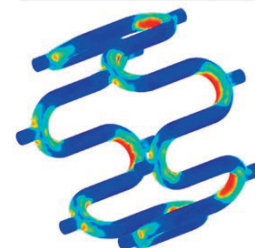
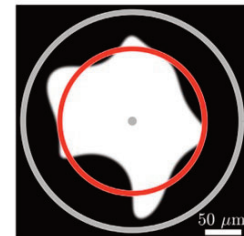
### Insoluble phases



### IG corrosion



### Biodegradation



## References

- [1] T. Hageman, E. Martínez-Pañeda. **A phase field-based framework for electro-chemo-mechanical fracture: crack-contained electrolytes, chemical reactions and stabilisation.** *Computer Methods in Applied Mechanics and Engineering* 415, 116235 (2023)
- [2] E. Martínez-Pañeda. **Phase-field simulations opening new horizons in corrosion research.** *MRS Bulletin* 49, 603–612 (2024)
- [3] C. Cui, R. Ma, E. Martínez-Pañeda. **A phase field formulation for dissolution-driven stress corrosion cracking.** *Journal of the Mechanics and Physics of Solids* 147, 104254 (2021)
- [4] Cui, R. Ma, E. Martínez-Pañeda. **A generalised, multi-phase-field theory for dissolution-driven stress corrosion cracking and hydrogen embrittlement.** *Journal of the Mechanics and Physics of Solids* 166, 104951 (2022)
- [5] T. Hageman, C. Andrade, E. Martínez-Pañeda. **Corrosion of metal reinforcements within concrete and localisation of supporting reactions under natural conditions.** *Electrochimica Acta* 527, 146203 (2025)
- [6] M. Makuch, S. Kovacevic, M.R. Wenman, E. Martínez-Pañeda. **A microstructure-sensitive electro-chemo-mechanical phase-field model of pitting and stress corrosion cracking.** *Corrosion Science* 232, 112031 (2024)
- [7] S. Kovacevic, W. Ali, E. Martínez-Pañeda, J. LLorca. **Phase-field modeling of pitting and mechanically-assisted corrosion of Mg alloys for biomedical applications.** *Acta Biomaterialia* 164, 641-658 (2023)
- [8] S. Kovacevic, W. Ali, E. Martínez-Pañeda, J. LLorca. **on the biodegradation of magnesium alloys for medical implants: An in vitro and phase-field study.** *Acta Biomaterialia* 198, 546-565 (2025)
- [9] C. Cui, R. Ma, E. Martínez-Pañeda. **Electro-chemo-mechanical phase field modeling of localized corrosion: theory and COMSOL implementation.** *Engineering with Computers* 39, 3877–3894 (2023)

# Current Trends and Challenges in Ice Shelf Modelling

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The Antarctic Ice Sheet covering 98% of the Antarctic continent and comprising 70% of the world's fresh water plays a pivotal role in regulating global sea level, yet it is increasingly affected by anthropogenic climate change. Rising atmospheric and oceanic temperatures in the polar regions have intensified the melting and structural weakening of ice shelves - vast floating extensions of the continental ice sheet that act as mechanical buttresses restraining the flow of ice streams, glaciers, from the continent into the surrounding Southern Ocean (SO).

Figure 1 illustrates a small iceberg breakout from the Fimbul Ice Shelf at Penguin Bukta. Thinning and gradual disintegration of ice shelves weaken their buttressing effect, reducing resistance to glacier discharge and promoting increased outflow of grounded ice into the SO. The complete collapse of ice shelves removes most of this buttressing, often leading to further ice flow acceleration and contributing to global sea-level rise [2]. At present, ice shelf mass loss is driven in nearly equal measure by basal melting and ice break-off. Although the Antarctic ice sheet shows weak sensitivity to different global warming scenarios - because increased ice discharge into the ocean is largely compensated by enhanced snowfall, in particular in East Antarctica [37] - there is now clear evidence of a recent regime shift in Antarctic sea-ice extent. This shift is characterised by self-perpetuating processes of sea-ice reduction, with implications not only for Antarctic ice

discharge but also for ocean circulation, climate and ecosystems [1]. Ice discharge through iceberg calving, in particular, is highly sensitive to early climate-change. Global warming reduces basal resistance at grounding lines, where glaciers enter the ocean, initiating a positive feedback loop of enhanced calving, upstream thinning, and accelerated ice flow as illustrated in Figure 2. However, fracture mechanics and failure processes at calving fronts and shear margins remain poorly understood, leading to large biases in calving-rate estimates and hampering predictive modelling of ice shelf and ice sheet dynamics [44].

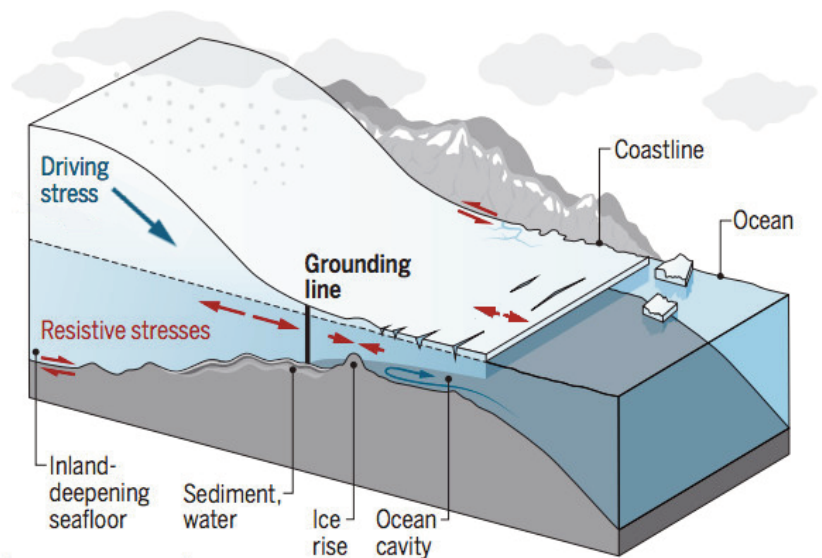
Recent advances in computational mechanics provide powerful tools for quantifying these processes more accurately. Thermo-mechanically coupled models based on viscoelastic constitutive laws, fracture mechanics, and damage evolution are increasingly used to simulate the progressive weakening of ice shelves under combined thermal and mechanical forcing (e.g. [7, 19, 46]). Such models allow researchers to link local changes in material properties to system-scale responses such as flow acceleration, loss of buttressing capacity, and instability thresholds. When integrated with satellite remote sensing, field measurements, oceanographic and atmospheric observations, and climate projections, these computational models offer predictive capability for assessing future Antarctic ice mass loss and its global consequences [28, 37].

## Figure 1:

Onshore view of iceberg breakout from the Fimbul Ice Shelf at Penguin Bukta at the end of an ice flow-parallel crevasse formed by splaying in December 2024.



Antarctic ice sheet and ice shelf dynamics is a gravity-driven flow problem as shown in *Figure 2*. Ice flow from the continent is primarily governed by ice rheology and basal sliding over the underlying bedrock up to the grounding lines, where glaciers enter the ocean, as well as by shear along embayment margins and coastal floor elevations - so-called ice rises - where ice shelves are locally anchored. Grounding lines therefore play a critical moderating role in ice flow, not only for the ice shelves themselves but also for the upstream glaciers feeding them. Sea ice provides additional buttressing at the ice shelf front. Any reduction in sea-ice extent and seasonal cover negatively impacts ice shelves mechanically through reduced buttressing and increased swell-induced flexure, while also enhancing ocean heat uptake, increasing warm-water inflow into the ice shelf cavity, and accelerating basal melting [25].



**Figure 2:** Schematics of ice sheet and ice shelf dynamics illustrating the different stress regimes adopted from [18].

The governing equations describing ice shelf dynamics comprise the conservation of mass, momentum, and energy (enthalpy), together with appropriate boundary conditions. Ice shelf geometry evolves according to kinematic boundary conditions at the surface and base, driven by snowfall accumulation, basal melting, and volume flux. The typical aspect ratio of vertical to horizontal spatial scales  $[H]/[L] = 10^3/10^6 = 10^{-3}$  motivates approximations of the momentum balance, ranging from shallow ice approximation regarding only vertical shear, shallow-shelf and shelfy stream approximation with membrane stresses to so-called higher-order approximations of the Stokes problem, that assume that vertical normal stress equals the overburden pressure in the momentum balance in vertical direction. The latter can be considered valid over the majority of the Antarctic ice sheet and ice shelves, while balancing computational costs [34].

The viscous rheology of ice is treated either with Glen’s flow law, or more advanced constitutive models that account for ice fabric evolution, including grain size, crystallographic orientation, impurities, interstitial water, and accumulated damage [8, 15].

*“ Grounding lines therefore play a critical moderating role in ice flow, not only for the ice shelves themselves but also for the upstream glaciers feeding them ”*



*“ Fracture phase-field models combine the strengths of fracture mechanics and damage mechanics by introducing a continuous damage field governed by an additional partial differential equation. ”*

However, such detailed representations are rarely included in large-scale ice sheet simulations due to computational constraints. Ice sheet and ice shelf modelling presents several challenges:

- (i) simulations require physically consistent initial states obtained through spin-up integrations over 10,000–100,000 years;
- (ii) basal friction coefficients of grounded ice are usually inferred using inverse methods;
- (iii) effective pressure at the ice sheet base depends on subglacial hydrology and water pressure; and
- (iv) the rheology of the non-Newtonian material is highly rate and temperature-sensitive leading to a ratio of viscosities in the vertical dimension of  $10^3$  [15].

Given the long simulation time scale of hundreds of years and the treatment of ice as a fluid problem, glaciological models mostly conduct simulations in the Eulerian frame. The lateral evolution of the ice shelf's calving front is commonly tracked by solving a level set problem, where a calving rate is parameterised to approximate fracture-driven ice loss due to iceberg calving using criteria such as stress thresholds based on the von Mises stress [3].

Over the last decades, glaciological models have improved substantially through systematic benchmark experiments designed to evaluate their predictive capability, including studies on the approximations of the Stokes system [29], grounding migration [30, 10], ice shelf loss scenarios [22, 40], and sensitivity to initial conditions [36]. Sliding over bedrock remains one of the key uncertainties in glaciological modelling. Sliding laws typically relate basal shear stress to basal velocity and effective normal stress, which accounts for lubrication due to subglacial water pressure. Inverse modelling techniques are widely used to constrain the basal friction coefficient and the rate parameter of the ice rheology using observed surface velocities, and the inclusion of subglacial hydrology models further enhances physical realism [17].

The continuous flow of ice is accompanied by transient deformation, resulting in evolving stress and strain fields that may eventually lead to material failure. The modelling of such failure events is very complex, due to the different phenomena involved and the wide range of time scales at which they evolve. Long-term processes include the gradual erosion of ice shelves at calving fronts and the slow propagation of crevasses driven by cyclic loading from

tides, especially in the hinge zone of ice shelves, and seasonal environmental variations. In contrast, short-term processes, occurring over days to weeks, include the calving of large tabular icebergs, ice cliff collapse, or the break-up of entire ice shelf regions fragmented by crevasses and rifts. Most currently used calving laws are semi-empirical and lack general applicability across the full range of observed failure mechanisms [44]. A key limitation, besides the identification of proper failure criteria, is that short-term failure processes are governed primarily by elastic deformation, whereas most glaciological models neglect elasticity and focus on long-term viscous flow on regional and continental scale. Furthermore, damage processes occur at spatial scales that are difficult to observe directly, resulting in limited validation data and significant uncertainty in model predictions, e.g. crevasse depths and crevasse advection [14].

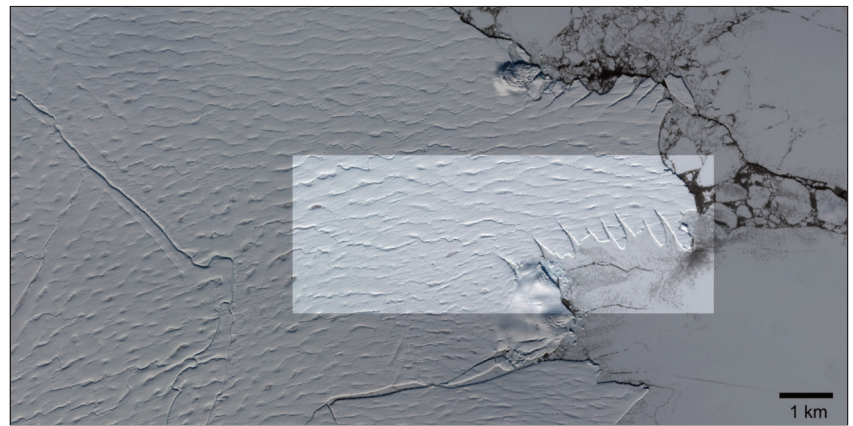
Four main modelling approaches can be distinguished for representing ice damage and failure:

- (a) Classical stress- or strain-based failure approaches employ criteria such as the Hayhurst effective stress [16, 26], von Mises stress [13], or principal stress criterion [9]. The Hayhurst and von Mises criteria are associated with inelastic creep deformation, whereas the principal stress criterion is linked to brittle failure and crack propagation consistent with linear elastic fracture mechanics [12]. This distinction highlights the importance of time-scale considerations when modelling ice failure [5, 6]. For completely embayed ice shelves, where transverse spreading strain rates are relatively small, strain-based approaches have proven particularly useful [23, 42].
- (b) Fracture mechanics approaches use classical fracture criteria such as stress intensity factors, energy release rates, J-integrals, or configurational forces [32, 31, 33]. While physically rigorous, these approaches require pre-existing cracks and knowledge of fracture-mechanical material parameters, which are often unavailable for glacier ice.
- (c) Continuum damage mechanics approaches overcome some of these limitations of fracture mechanics, by introducing an internal state variable representing the progressive degradation of material stiffness and load-carrying capacity [45, 20]. The evolution of this damage variable is governed by

**Figure 3:**  
Fracture phase field simulation of cracks in  
the Nioghalvfjærdsbræ  
(79° North Glacier, 79NG),

**Top:**  
satellite image with simulation  
region highlighted.

**Bottom:**  
viscoelastic 3D finite element  
simulation of subregion  
with superimposed satellite image,  
mesh, and starting crack propagation



- thermodynamically consistent laws, but requires calibration using experimental or observational data, which remains a major challenge.
- (d) Fracture phase-field models combine the strengths of fracture mechanics and continuum damage mechanics by introducing a continuous damage field governed by an additional partial differential equation. A characteristic length-scale parameter defines the transition zone between intact and fully fractured material.

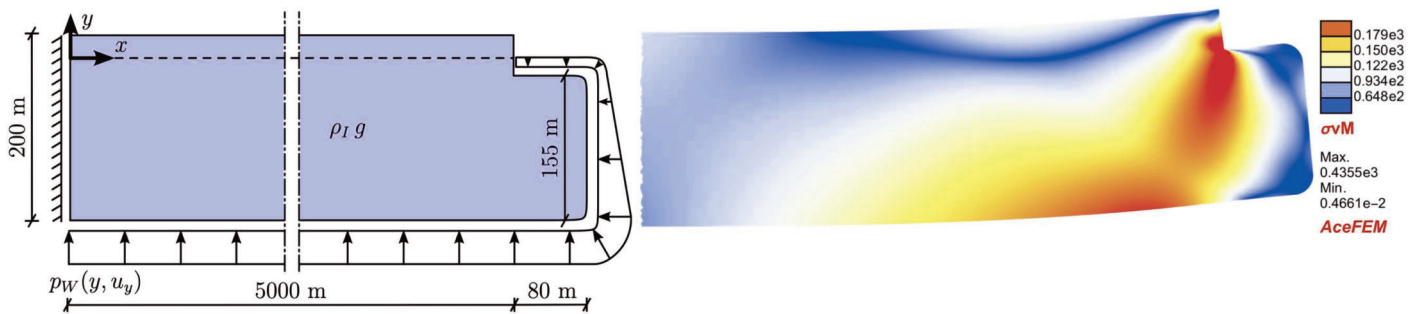
Phase-field models enable fracture initiation, propagation, branching, and coalescence to be simulated without explicitly prescribing crack geometry [27]. They provide a physically consistent and computationally robust framework for modelling fracture in complex materials such as glacier ice [9, 41, 39]. The simulation of cracks in the Nioghalvfjærdsbræ glacier part of the Greenland Ice Sheet is illustrated in Figure 3 [38].

The main focus of research to date has been on events on regional and continental scale such as large tabular iceberg calving, catastrophic ice shelf collapse and retreat of grounded glaciers, as these phenomena can be readily observed using satellite data. The runaway process of marine ice cliff instability (MICI) hypothesis attempts to explain underlying mechanisms and relevancy of influencing parameters, such as freeboard, bedrock slope, and conditions at the bedrock, pre-existing damage or cracks with regards to a potentially self-perpetuating failure and retreat of tall grounded glacier fronts, which, however, may not be a likely factor in the 21st century [28]. In contrast, small-scale

phenomena involving the continuous ice loss at the calving front driven by a combination of frontal ablation due to warm surface water currents and wave-caused erosion [24], or flexural stresses including fatigue due to tide and wave-induced vertical motion remain poorly quantified [21, 25], despite their potential importance as ice shelves thin and accumulate damage [2].

Smaller scale modelling of damage evolution and failure requires a more accurate ice rheology description and parameterization of its depth-varying physical properties for which only very limited field observations exist [8]. Near ice shelf termini, prolonged upward flexure associated with the footloose rampart effect may occur due to the vertically variable ice viscosity or preceding freeboard cliff failure with subsequent changes in buoyancy equilibrium [4, 43].

The latter has been observed at Penguin Bukta after partial calving at the ice shelf freeboard and is investigated in an academic example in Figure 4 using a finite strain viscoelastic Maxwell model [35] and a nonlinear stress-driven viscosity governed by Glen's flow law [11]. Hydrostatic pressure  $p_w$  is applied as a follower load, acting only on submerged portions of the ice shelf subject to its own weight to ensure buoyancy equilibrium. After one year of simulation time, the von Mises stress plot reveals pronounced uplift at the front, with a



**Figure 4:**

Left: boundary value problem regarding the footloose rampart effect under consideration of hydrostatic pressure  $p_w$  induced by the water. Right: von Mises stresses within the deformed and uplifted ice shelf after a simulation time of one year for  $x \geq 4400$  m.

stress concentration at the cut-out corner branching diagonally down to the basal plane which may lead to break-off of the underwater protrusion.

In conclusion, computational mechanics provides a rigorous quantitative framework for understanding Antarctic ice sheet and ice shelf dynamics and the coupling between

climate forcing, ice deformation, damage evolution, and fracture. To address critical knowledge gaps, in particular regarding field observations, the Polar Engineering Research Group at the University of Cape Town is leading an international research project focused on monitoring and modelling the evolving stability of the Fimbul Ice Shelf under climate forcing. Funded by the National Research Foundation's South African National Antarctic Programme, the project combines satellite observations, airborne surveys, in-situ field measurements, and advanced computational modelling. ●

#### References:

- [1] Nerilie J Abram, Ariaan Purich, Matthew H England, Felicity S McCormack, Jan M Strugnell, Dana M Bergstrom, Tessa R Vance, Tobias Stål, Barbara Wienecke, Petra Heil, et al. **Emerging evidence of abrupt changes in the antarctic environment.** *Nature*, 644(8077):621–633, 2025.
- [2] Jeremy N Bassis, Anna Crawford, Samuel B Kachuck, Douglas I Benn, Catherine Walker, Joanna Millstein, Ravindra Duddu, Jan Åström, Helen A Fricker, and Adrian Luckman. **Stability of ice shelves and ice cliffs in a changing climate.** *Annual Review of Earth and Planetary Sciences*, 52(1):221–247, 2024.
- [3] J. H. Bondzio, H. Seroussi, M. Morlighem, T. Kleiner, M. Rückamp, A. Humbert, and E. Y. Larour. **Modelling calving front dynamics using a level-set method: application to jakobshavn isbræ, west greenland.** *The Cryosphere*, 10(2):497–510, 2016. doi: 10.5194/tc-10-497-2016. URL <https://tc.copernicus.org/articles/10/497/2016/>.
- [4] W Roger Buck. **The effect of ice shelf rheology on shelf edge bending.** *The Cryosphere*, 18 (9):4165–4176, 2024.
- [5] Julia Christmann, Carolin Plate, Ralf Müller, and Angelika Humbert. **Viscous and viscoelastic stress states at the calving front of antarctic ice shelves.** *Annals of Glaciology*, 57(73):10–18, 2016.
- [6] Julia Christmann, Veit Helm, Shfaqat Abbas Khan, Thomas Kleiner, Ralf Müller, Mathieu Morlighem, Niklas Neckel, Martin Rückamp, Daniel Steinhage, Ole Zeising, et al. **Elastic deformation plays a non-negligible role in greenland's outlet glacier flow.** *Communications Earth & Environment*, 2(1):232, 2021.
- [7] Theo Clayton, Ravindra Duddu, Martin Siegert, and Emilio Martínez-Paneda. **A stress-based poro-damage phase field model for hydrofracturing of creeping glaciers and ice shelves.** *Engineering Fracture Mechanics*, 272:108693, 2022.
- [8] Theo Clayton, Ravindra Duddu, Tim Hageman, and Emilio Martínez-Paneda. **The influence of firn layer material properties on surface crevasse propagation in glaciers and ice shelves.** *The Cryosphere*, 18(12):5573–5593, 2024.
- [9] Theo Clayton, Ravindra Duddu, Tim Hageman, and Emilio Martínez-Paneda. **Modeling ice cliff stability using a new mohr–coulomb-based phase field fracture model.** *Journal of Glaciology*, 71:e70, 2025.
- [10] Stephen L Comford, Helene Seroussi, Xylar S Asay-Davis, G Hilmar Gudmundsson, Rob Arthem, Chris Borstad, Julia Christmann, Thiago Dias dos Santos, Johannes Feldmann, Daniel Goldberg, et al. **Results of the third marine ice sheet model intercomparison project (mismip+).** *The Cryosphere Discussions*, 2020:1–26, 2020.
- [11] Kurt Cuffey and William Stanley Bryce Paterson. **The Physics of Glaciers.** Elsevier, 4 edition, 2010.
- [12] Jan De Rydt, Gudmundur Hilmar Gudmundsson, Thomas Nagler, and Jan Wuite. **Calving cycle of the brunt ice shelf, antarctica, driven by changes in ice shelf geometry.** *The Cryosphere*, 13(10):2771–2787, 2019.
- [13] Veronika Emetc, Paul Tregoning, Mathieu Morlighem, Chris Borstad, and Malcolm Sambridge. **A statistical fracture model for antarctic ice shelves and glaciers.** *The Cryosphere*, 12 (10):3187–3213, 2018.
- [14] Ellyn M Enderlin and Timothy C Bartholomaus. **Poor performance of a common crevasse model at marine-terminating glaciers.** *The Cryosphere Discussions*, 2019:1–19, 2019.
- [15] Sheng Fan, Ting Wang, David J Prior, Thomas Breithaupt, Travis F Hager, and David Wallis. **Flow laws for ice constrained by 70 years of laboratory experiments.** *Nature geoscience*, 18 (4):296–304, 2025.
- [16] DR Hayhurst. **Creep rupture under multi-axial states of stress.** *Journal of the Mechanics and Physics of Solids*, 20(6):381–382, 1972.
- [17] L.-S. Hojns, T. Kleiner, A. Rademacher, M. Rückamp, M. Wolovick, and A. Humbert. **Improved basal drag of the west antarctic ice sheet from l-curve analysis of inverse models utilizing subglacial hydrology simulations.** *The Cryosphere*, 19(6):2133–2158, 2025. doi: 10.5194/tc-19-2133-2025. URL <https://tc.copernicus.org/articles/19/2133/2025/>.
- [18] Christina Hulbe. **Is ice sheet collapse in west antarctica unstoppable?** *Science*, 356(6341): 910–911, 2017.

- [19] Alex Huth, Ravindra Duddu, Benjamin Smith, and Olga Sergienko. **Simulating the processes controlling ice-shelf rift paths using damage mechanics.** *Journal of Glaciology*, 69(278):1915–1928, 2023.
- [20] Samuel B Kachuck, Morgan Whitcomb, Jeremy N Bassis, Daniel F Martin, and Stephen F Price. **Simulating ice-shelf extent using damage mechanics.** *Journal of Glaciology*, 68(271): 987–998, 2022.
- [21] L Lescarmontier, Benoit Legresy, NW Young, Richard Coleman, L Testut, C Mayet, and Pascal Lacroix. **Rifting processes and ice-flow modulation observed on mertz glacier, east antarctica.** *Journal of Glaciology*, 61(230):1183–1193, 2015.
- [22] A. Levermann, R. Winkelmann, T. Albrecht, H. Goelzer, N. R. Golledge, R. Greve, P. Huybrechts, J. Jordan, G. Leguy, D. Martin, M. Morlighem, F. Pattyn, D. Pollard, A. Quiquet, C. Rodehacke, H. Seroussi, J. Sutter, T. Zhang, J. Van Breedam, R. Calov, R. DeConto, C. Dumas, J. Garbe, G. H. Gudmundsson, M. J. Hoffman, A. Humbert, T. Kleiner, W. H. Lipscomb, M. Meinshausen, E. Ng, S. M. J. Nowicki, M. Perego, S. F. Price, F. Saito, N.-J. Schlegel, S. Sun, and R. S. W. van de Wal. **Projecting antarctica’s contribution to future sea level rise from basal ice shelf melt using linear response functions of 16 ice sheet models (Iarmip-2).** *Earth System Dynamics*, 11(1):35–76, 2020. doi: 10.5194/esd-11-35-2020. URL <https://esd.copernicus.org/articles/11/35/2020/>.
- [23] Anders Levermann, T Albrecht, Ricarda Winkelmann, MA Martin, M Haseloff, and I Joughin. **Kinematic first-order calving law implies potential for abrupt ice-shelf retreat.** *The Cryosphere*, 6(2):273–286, 2012.
- [24] Yue Ma and Jeremy N Bassis. **The effect of submarine melting on calving from marine terminating glaciers.** *Journal of Geophysical Research: Earth Surface*, 124(2):334–346, 2019.
- [25] Robert A Massom, Theodore A Scambos, Luke G Bennetts, Phillip Reid, Vernon A Squire, and Sharon E Stammerjohn. **Antarctic ice shelf disintegration triggered by sea ice loss and ocean swell.** *Nature*, 558(7710):383–389, 2018.
- [26] Rémy Mercenier, Martin P Lüthi, and Andreas Vieli. **Calving relation for tidewater glaciers based on detailed stress field analysis.** *The Cryosphere*, 12(2):721–739, 2018.
- [27] Christian Miehe, Fabian Welschinger, and Martina Hofacker. **Thermodynamically consistent phase-field models of fracture: Variational principles and multi-field fe implementations.** *International journal for numerical methods in engineering*, 83(10):1273–1311, 2010.
- [28] Mathieu Morlighem, Daniel Goldberg, Jowan M Barnes, Jeremy N Bassis, Douglas I Benn, Anna J Crawford, G Hilmar Gudmundsson, and H el ene Seroussi. **The west antarctic ice sheet may not be vulnerable to arine ice cliff instability during the 21st century.** *Science Advances*, 10(34):eado7794, 2024.
- [29] Frank Pattyn, Laura Perichon, Andy Aschwanden, Beate Breuer, Brigitte De Smedt, Olivier Gagliardini, G Hilmar Gudmundsson, Richard CA Hindmarsh, Alun Hubbard, Jesse V Johnson, et al. **Benchmark experiments for higher-order and full-stokes ice sheet models (ismip-hom).** *The Cryosphere*, 2(2):95–108, 2008.
- [30] Frank Pattyn, Laura Perichon, Ga el Durand, Lionel Favier, Olivier Gagliardini, Richard CA Hindmarsh, Thomas Zwinger, Torsten Albrecht, Stephen Cornford, David Docquier, et al. **Grounding-line migration in plan-view marine ice-sheet models: results of the ice2sea mis-mip3d intercomparison.** *Journal of Glaciology*, 59(215):410–422, 2013.
- [31] Carolin Plate, Ralf M uller, Angelika Humbert, and Dietmar Gross. **Evaluation of the criticality of cracks in ice shelves using finite element simulations.** *The Cryosphere*, 6(5):973–984, 2012.
- [32] Niels Reeh. **On the calving of ice from floating glaciers and ice shelves.** *Journal of Glaciology*, 7(50):215–232, 1968.
- [33] MA Rist, PR Sammonds, SAF Murrell, PG Meredith, CSM Doake, Hans Oerter, and K Mat-uki. **Experimental and theoretical fracture mechanics applied to antarctic ice fracture and surface crevassing.** *Journal of Geophysical Research: Solid Earth*, 104(B2):2973–2987, 1999.
- [34] M. R uckamp, T. Kleiner, and A. Humbert. **Comparison of ice dynamics using full-stokes and blatter-pattyn approximation: application to the northeast greenland ice stream.** *The Cryosphere*, 16(5):1675–1696, 2022. doi: 10.5194/tc-16-1675-2022. URL <https://tc.copernicus.org/articles/16/1675/2022/>.
- [35] J. Schr oder, M. Ko bler, R. M uller, and A. Humbert. **A multiplicative finite viscoelastic model for ice using an exponential update formulation.** *Computer Methods in Applied Mechanics and Engineering*, 453:118840, 2026.
- [36] H el ene Seroussi, Sophie Nowicki, Erika Simon, Ayako Abe-Ouchi, Torsten Albrecht, Julien Brondex, Stephen Cornford, Christophe Dumas, Fabien Gillet-Chaulet, Heiko Goelzer, et al. **Initmip-antarctica: an ice sheet model initialization experiment of ismip6.** *The Cryosphere*, 13(5):1441–1471, 2019.
- [37] H el ene Seroussi, Vincent Verjans, Sophie Nowicki, Antony J Payne, Heiko Goelzer, William H Lipscomb, Ayako Abe-Ouchi, C ecile Agosta, Torsten Albrecht, Xylar Asay-Davis, et al. **In-sights into the vulnerability of antarctic glaciers from the ismip6 ice sheet model ensemble and associated uncertainty.** *The Cryosphere*, 17(12):5197–5217, 2023.
- [38] Rabea Sondershaus, Ralf M uller, Dietmar Gross, and Angelika Humbert. **Phase field modeling of cracks in ice.** In *Progress in Structural Mechanics*, pages 281–304. Springer, 2024.
- [39] RS Sondershaus and RM M uller. **Phase field model for simulating fracture of ice.** In *ECCOMAS Congress 2022 - 8th European Congress on Computational Methods in Applied Sciences and Engineering*, 2022.
- [40] Sainan Sun, Frank Pattyn, Erika G Simon, Torsten Albrecht, Stephen Cornford, Reinhard Calov, Christophe Dumas, Fabien Gillet-Chaulet, Heiko Goelzer, Nicholas R Golledge, et al. **Antarctic ice sheet response to sudden and sustained ice-shelf collapse (abumip).** *Journal of Glaciology*, 66(260):891–904, 2020.
- [41] Xiangming Sun, Ravindra Duddu, et al. **A poro-damage phase field model for hydrofracturing of glacier crevasses.** *Extreme Mechanics Letters*, 45:101277, 2021.
- [42] David G Vaughan. **Relating the occurrence of crevasses to surface strain rates.** *Journal of Glaciology*, 39(132):255–266, 1993.
- [43] Till JW Wagner, Peter Wadhams, Richard Bates, Pedro Elosegui, Alon Stern, Dominic Vella, E Povl Abrahamsen, Anna Crawford, and Keith W Nicholls. **The “footloose” mechanism: Iceberg decay from hydrostatic stresses.** *Geophysical Research Letters*, 41(15):5522–5529, 2014.
- [44] Joel A Wilner, Mathieu Morlighem, and Gong Cheng. **Evaluation of four calving laws for antarctic ice shelves.** *The Cryosphere*, 17(11):4889–4901, 2023.
- [45] J Xiao and IJ Jordaan. **Application of damage mechanics to ice failure in compression.** *Cold Regions science and Technology*, 24(3):305–322, 1996.
- [46] Hongju Yu, Eric Rignot, Mathieu Morlighem, and Helene Seroussi. **Iceberg calving of thwaites glacier, west antarctica: full-stokes modeling combined with linear elastic fracture mechanics.** *The Cryosphere*, 11(3):1283–1296, 2017.

# The Method of Multiscale Virtual Power: A General Multiscale Modelling Tool

by

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Multiscale modelling of materials and structures is a topic that has gained significant popularity within the computational mechanics community over the past two to three decades. Stemming from the rather commonsensical idea that the observed (large- or macro-scale) behaviour of a system is the result of the interaction among its (small- or micro-scale) constituents, multiscale approaches have been applied very successfully in the modelling of a wide range of physical phenomena, from classical elasticity and inelasticity to more challenging problems involving higher order strain effects, fracturing, micro-scale dynamics, contact and electromagnetism, among others. Despite the idea being explored since at least the 1940s [1], it was not until the seminal work of Hill [2] and Mandel [3] that its popularity began to rise sharply in applied mechanics circles. With the availability of increasing computing power, the maturity of associated computational methods and its potential to predict complex constitutive behaviour and help the design of new materials, the topic was eventually embraced by the computational mechanics community in the 1990s [4–13], and has since been attracting ever growing interest.

At the heart of any successful computational multiscale methodology lies its ability to yield useful numerical predictions of the large-scale behaviour of a physical system by taking into account the underlying micro-scale phenomena that give rise to it – and this, ideally, at a much lower computational cost than if the entire system were to be modelled at finer (micro-scale) levels of detail. To achieve this, an effective approach must not only model the smaller scales with sufficient accuracy, including the establishment of appropriate equilibrium conditions, but also be able to transfer the relevant system variables up and down the different scales by means of suitable averaging relations in a physically meaningful and consistent manner.

“ *it allows not only for the systematic development of multiscale models ..., but its variational structure provides a platform where further useful insights can be naturally gained, pointing to possible directions of model refinement and improvements.* ”

## The Method of Multiscale Virtual Power

Under quasi-static conditions in the classical purely mechanical case, the RVE-based approach stemming from the original Hill-Mandel Principle of Macro-homogeneity [2,3] provides the basis for the operations of variable transfer across the scales – here relying on the simple (and rather intuitive) volume averaging of strains and stresses. The resulting, now classical, theory is well established and has been used widely in the computational context to model elastic and inelastic behaviours, including finite hyperelasticity [14], crystal plasticity [8,15], as well as more complex phenomena, such as phase transformation plasticity [16,17].

The quest for more refined multiscale models, capable of capturing interactions among different micro-scale physics and emerging non-standard macro-scale constitutive responses, such as macro-fracturing and higher-order strain effects, soon led to the development of new models in non-classical settings. It was in this context that the *Method of Multiscale Virtual Power* – having a variational generalisation of the Hill-Mandel Principle of Macrohomogeneity as one of its pillars – was established, aiming at providing a robust theoretical framework to help the development of general RVE-based multi-scale theories with minimal room for inconsistencies and maximised clarity in the distinction between the modeller's fundamental assumptions and their consequences. Initially used in the modelling of macro-scale failure resulting from micro-localisation of strains [18], the methodology was rigorously formalised by Blanco et al. [19,20] and subsequently applied with success to multi-scale dynamics in [21]. The method rests on three fundamental axioms:

1. *Kinematical Admissibility*, where consistent, conserving operations of kinematical transfer between scales must be postulated by the modeller, comprising the macro-to-micro kinematical insertion and micro-to-macro homogenisation operators. It is at this stage that the freedom of the modeller can be exercised in full, by hypothesising how the observed macro-scale kinematics relates to its originating micro-scale mechanisms.

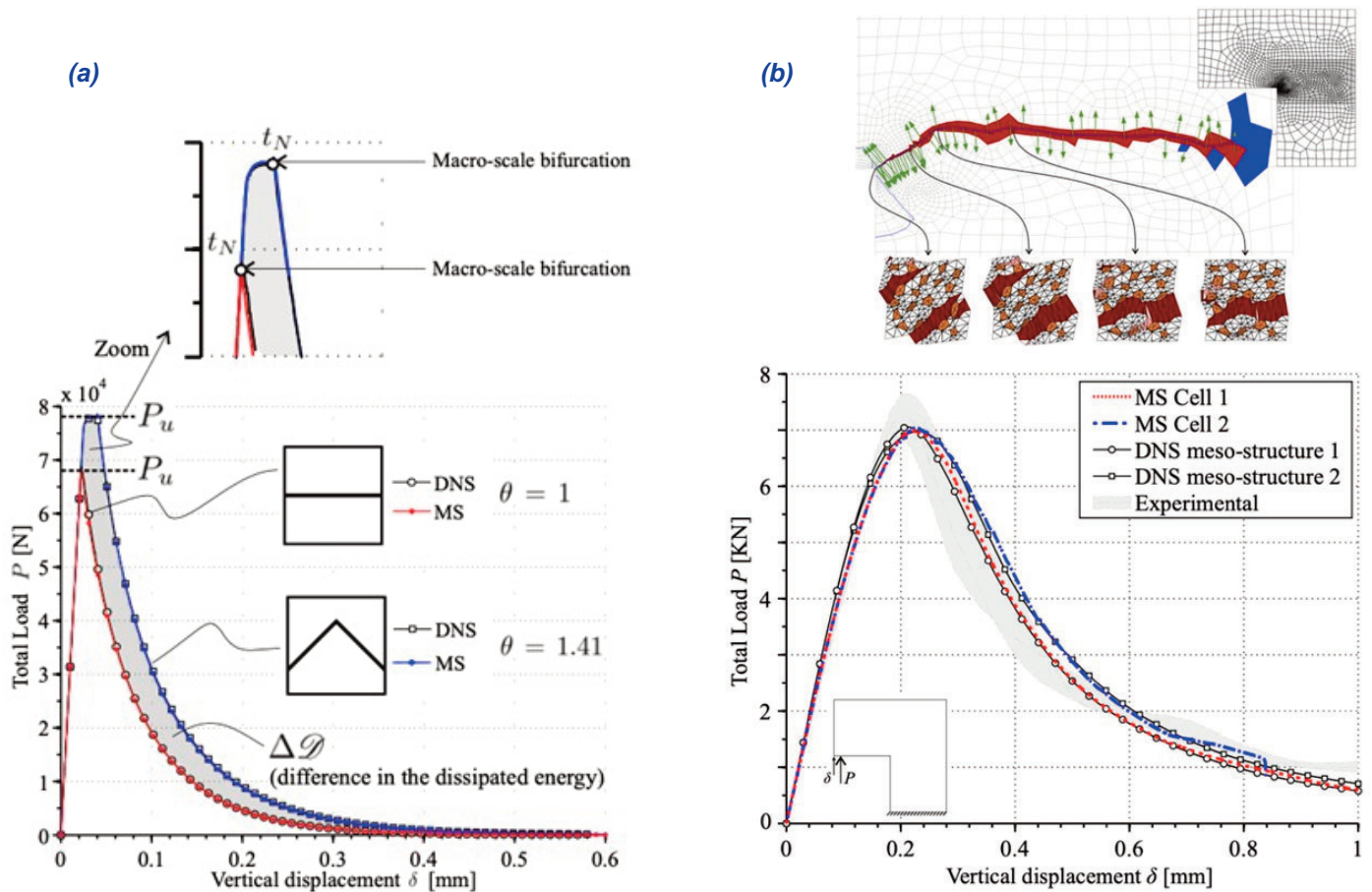
2. *Mathematical Duality*, whereby the macro- and micro-scale power-conjugate variables, such as forces and stresses, are univocally identified based on duality with their kinematical counterparts already postulated in (1).
3. *The Principle of Multiscale Virtual Power*. This is a variational generalisation of the classical Hill-Mandel Principle that enforces the virtual power consistency between the scales. It allows, through simple variational arguments, the univocal derivation of the micro-scale equilibrium equations and the micro-to-macro transfer (homogenisation) of the flux (or dual) variables. Very importantly, the homogenisation of the fluxes here is not postulated a priori (as in many existing multi-scale theories); rather, it is a mere variational consequence of the postulated kinematical transfer operators.

Since the establishment of the methodology, its robustness has been confirmed by successful applications over a wide range of problems. In particular, it allows not only for the systematic development of multiscale models following recipe-like steps, but its

variational structure provides a platform where further useful insights can be naturally gained, pointing to possible directions of model refinement and improvements.

### Multiscale modelling in non-conventional settings

The use of the Method of Multiscale Virtual Power in the modelling of fracturing [22] has naturally produced a homogenised macro-scale cohesive crack response featuring an objective macro-scale fracture energy that is inherently sensitive (as physically expected) to the tortuosity index,  $\theta$ , of the micro-scale crack path. The definition of physically meaningful (and rather non-standard) kinematical transfer operators played a particularly crucial role in achieving this. In addition, the multiscale model is able produce numerical results in remarkable agreement with direct numerical simulations (DNS) – the discretised full-resolution model. This is illustrated for a model problem consisting of a strip under axial loading in *Figure 1(a)* and the classical L-Panel fracturing test in *Figure 1(b)*.

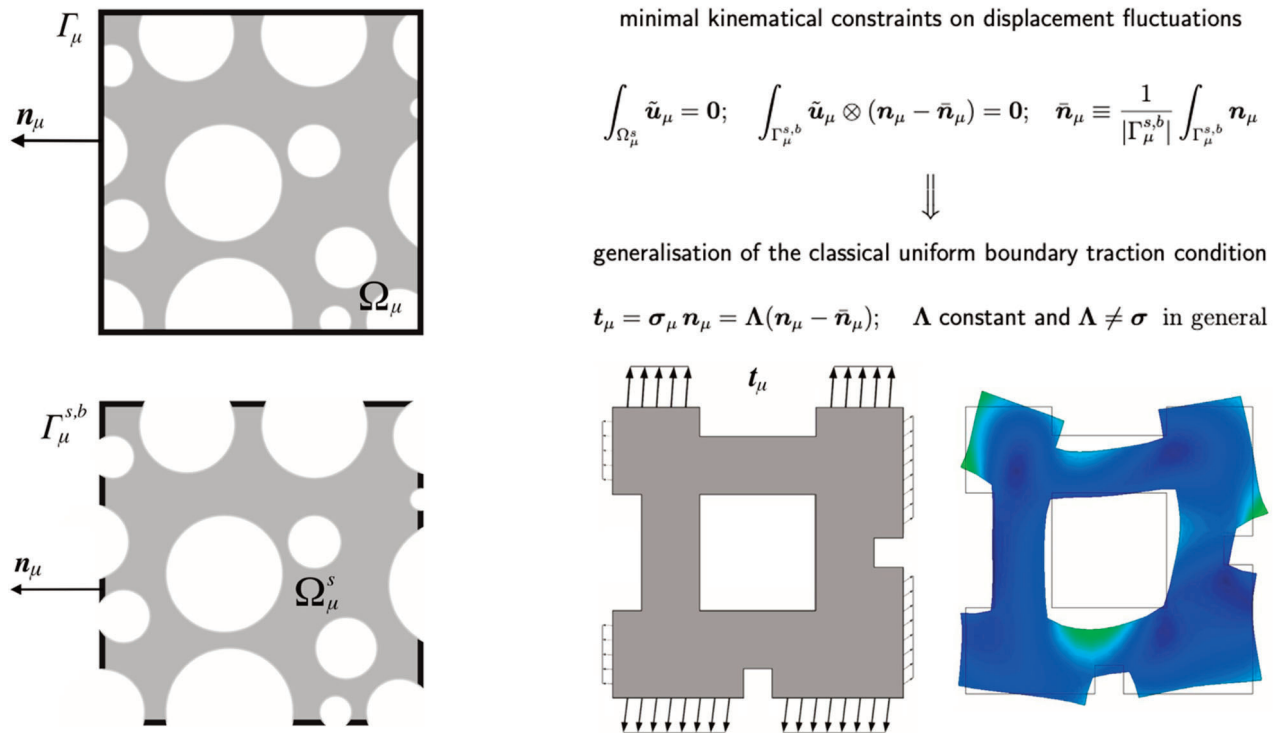


**Figure 1:** Multiscale fracturing. Coupled multiscale (MS) vs direct numerical simulation (DNS) results. (a) Strip under axial loading. Tortuous ( $\theta = 1.41$ ) and non-tortuous ( $\theta = 1$ ) micro-crack path; (b) L-panel test. Macro-scale mesh, RVEs and results

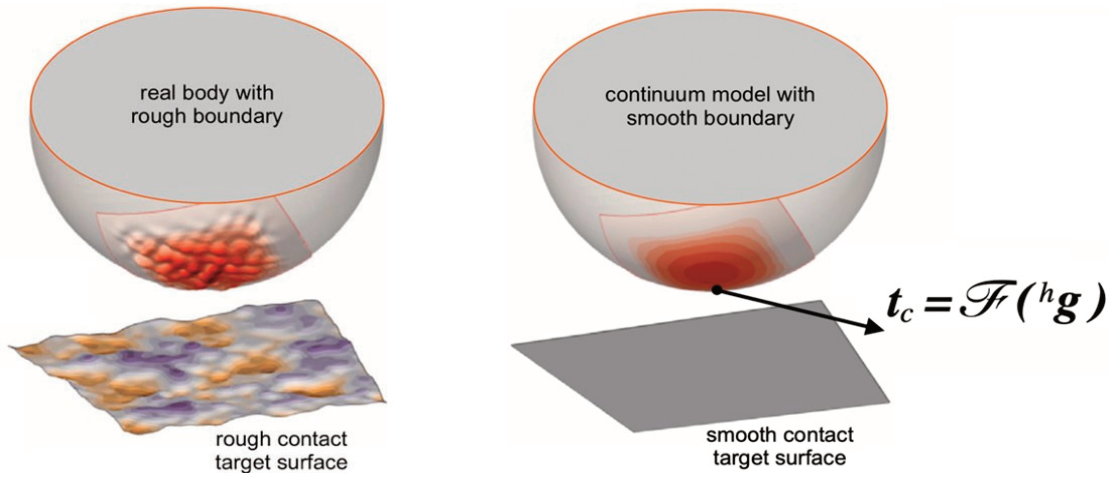
This application, where the discontinuous kinematics presents a significant challenge, cannot be treated within the classical setting of the original Hill-Mandel Principle. The success of the proposed model here was the result of a careful, consistent definition of the kinematical transfer operators, with the homogenised macro-scale cohesive law obtained as a direct consequence of the enforcement of the Principle of Multiscale Virtual Power.

Fast forward to more recent applications, another fundamental development was reported in [23,24]: homogenisation rules for cells containing voids that intersect their boundary. While RVEs containing voids strictly within their interior are easily treated consistently, a general random distribution of voids – where voids may intersect the cell boundary – does not fit within the classical framework. It is rigorously demonstrated in [23] that a well-rounded family of multiscale models that extends the classical theory to the general case of cells with randomly distributed voids can be elegantly devised by following the “recipe-like” steps established by the variational framework of the Method of Multiscale Virtual Power. This can be accomplished, again, by careful consideration of the *Kinematical Admissibility* requirement, here with particular attention needed in the

postulation of a kinematically-consistent/ kinematically-preserving homogenisation operator for the displacement gradient that accounts for the (possibly void-intersecting) topology of the cell boundary. With  $\mathbf{n}_\mu$  denoting the unit outward normal to the boundary  $\Gamma_\mu$  of the (void-containing) cell domain  $\Omega_\mu$  (see *Figure 2*) the minimal boundary integral constraint imposed on the displacement fluctuation field  $\tilde{\mathbf{u}}_\mu$  in the present case generalises the classical constraint, with the solid boundary averaged unit normal  $\bar{\mathbf{n}}_\mu$  playing a crucial role. The resulting model obeys the fundamental properties of the classical case. For example, under the minimal kinematical constraint (lower bound) assumption, the model generalises the uniform boundary traction condition of the classical theory – here, along the solid portion  $\Gamma_\mu^{s,b}$  of the cell boundary, as illustrated in *Figure 2*. The boundary traction in this case reads  $\mathbf{t}_\mu = \Lambda(\mathbf{n}_\mu - \bar{\mathbf{n}}_\mu)$ , with the constant tensor  $\Lambda$  the Lagrange multiplier associated with the minimal kinematical constraint and, in general, unlike the classical case,  $\Lambda$  is unsymmetric and does not coincide with the homogenised stress tensor  $\boldsymbol{\sigma}$ . Models with further kinematical constraints (including the linear boundary fluctuations upper bound) can be defined likewise and are discussed in detail in [23].



**Figure 2:** Cells with boundary-intersecting voids. (left) General cell definitions; (right) Minimal kinematical constraint, resulting generalised uniform boundary tractions and amplified displacement fluctuations with contours on a percolated panel cell subjected to infinitesimal shear and vertical stretching.

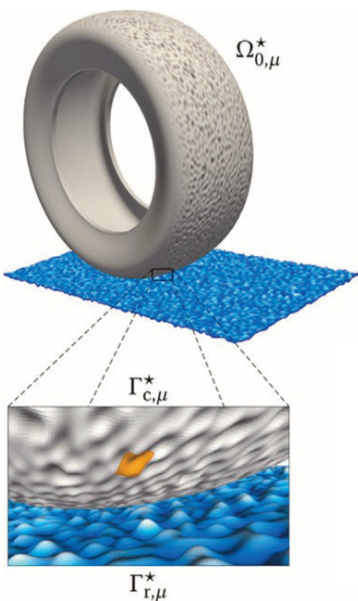


The methodology has recently proven very useful in the modelling of contact too [25,26]. The multiscale modelling of this class of problems is especially challenging since in their classical continuum (macroscale) description they are modelled as surface phenomena. That is, they are formulated as interactions between idealised smooth material surfaces on the boundary of continuum bodies (see *Figure 3*) when, in fact, the interactions between contacting bodies are crucially dependent upon the roughness of their real non-smooth boundary surfaces (that becomes apparent only at smaller spatial scales) and, very importantly, on the constitutive response of the solid material in the immediate vicinity of the contacting surfaces. In the classical phenomenological continuum model, the surface traction  $t_c$  arising from the contact interaction at a point of the boundary is assumed a functional of the history  ${}^h\mathbf{g}$  of

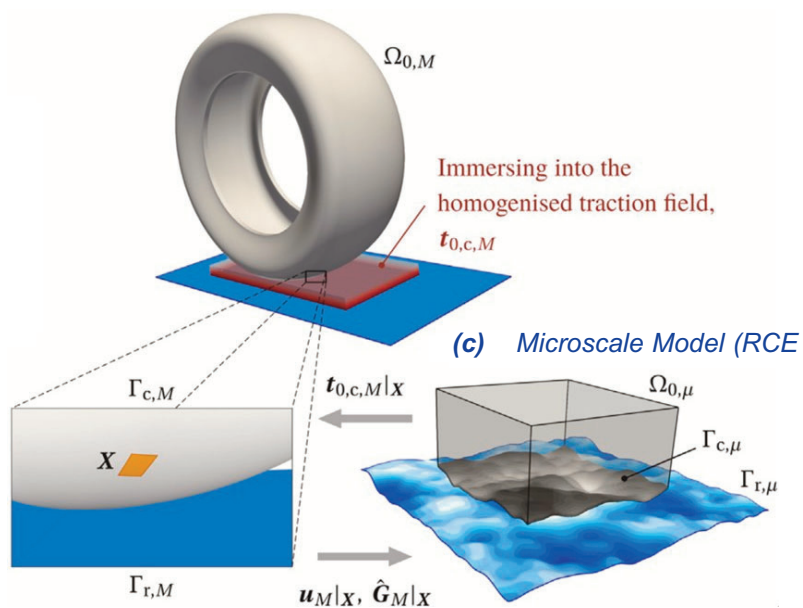
**Figure 3:** *Real contact problem and the continuum model with smooth contact surfaces. The contact traction  $t_c$  expressed as some functional of the history  ${}^h\mathbf{g}$  of the relative displacement  $\mathbf{g}$  between the contact boundary and the target surface*

the relative displacement between the point and the target surface,  $t_c = \mathcal{F}({}^h\mathbf{g})$  – typically a Coulomb-type frictional contact law. In general, assumed macroscopic contact constitutive laws will lose predictive capability, for example, when the deformation of surface asperities caused by longer sliding distances, high contact pressures or finite straining of the solid substrate causes significant changes in the contact interface. To tackle the issue computationally, one possible approach is to use refined full-resolution models in direct numerical simulations. This is illustrated in *Figure 4(a)*. The full-resolution

**(a) Full-resolution continuum model for DNS simulations**

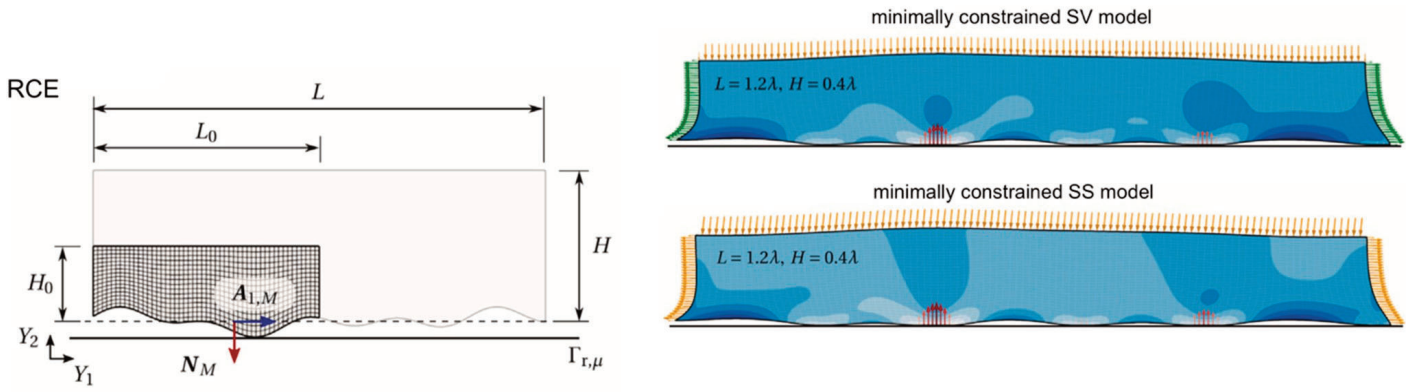


**(b) Homogenised macroscale model**



**(c) Microscale Model (RCE)**

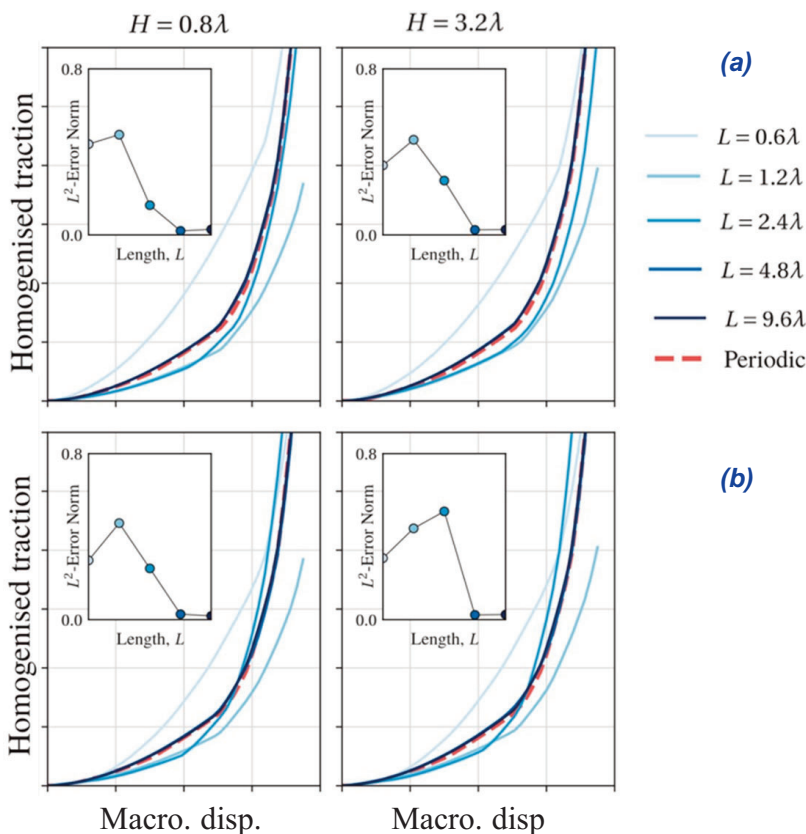
**Figure 4:** *Multiscale contact. (a) Full-resolution model for DNS computations; (b) Homogenised continuum (macroscale) model; (c) Microscale model – the Representative Contact Element (RCE).*



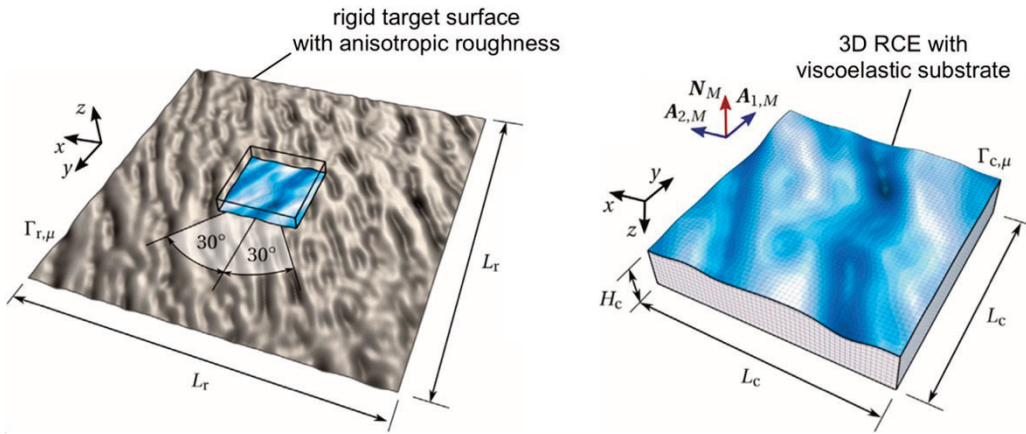
**Figure 5:** Homogenised normal contact stiffness test. RCE set-up and contact tractions on deformed configurations for the minimally-constrained SV and SS models

model must describe the asperities of the contacting surfaces with sufficient level of detail which, for realistic engineering problems, remains computationally prohibitive. An alternative in this case is to resort to multiscale modelling. The macroscale in this case is a continuum (Figure 4(b)), but its contact traction constitutive functional is defined by the homogenisation of a Representative Contact Element (RCE), as illustrated in Figure 4(c). A number of key contributions to multiscale modelling of contact have been made, for example, in [27–30]. In [25,26], by casting the problem within the framework of the MMVP, two families of models have been derived and analysed in detail: the surface-surface (SS) and surface-volume (SV) models. For the

SS family, the kinematical transfer between the scales – a crucial component of the modelling process through the MMVP – is postulated involving only kinematical quantities defined over the macro- and micro-scale contacting surfaces. Exceptionally, in this case, the micro-scale equilibrium must be postulated a posteriori to define a well-posed problem. For the SV family, on the other hand, the kinematical transfer operations are defined between a macro-scale surface point and a micro-scale volume, leading naturally to a well-defined micro-scale equilibrium problem (similarly to volume-to-point homogenisation approaches in conventional solid mechanics). For both families, minimal micro-scale kinematical constraints follow as a direct consequence of the postulated kinematical transfer operators and, like in the conventional multiscale analysis of solids, sub-models may be conveniently created by enforcing more stringent kinematical constraints such as, for example, periodicity of displacement fluctuations. Figure 5 shows the adopted RCE and deformed configurations obtained on a test to determine the homogenised normal stiffness of an interface between a deformable solid, modelled as a neo-Hookean material with a rough periodic boundary, and a rigid flat target. The graphs plotting the macro-scale normal displacement against the normal traction depicted in Figure 6 show that both the SV and SS minimally-constrained models converge with increasing



**Figure 6:** Homogenised normal stiffness. Normal macro-displacement vs homogenised normal traction. (a) Minimally-constrained SV model; (b) Minimally-constrained SS model

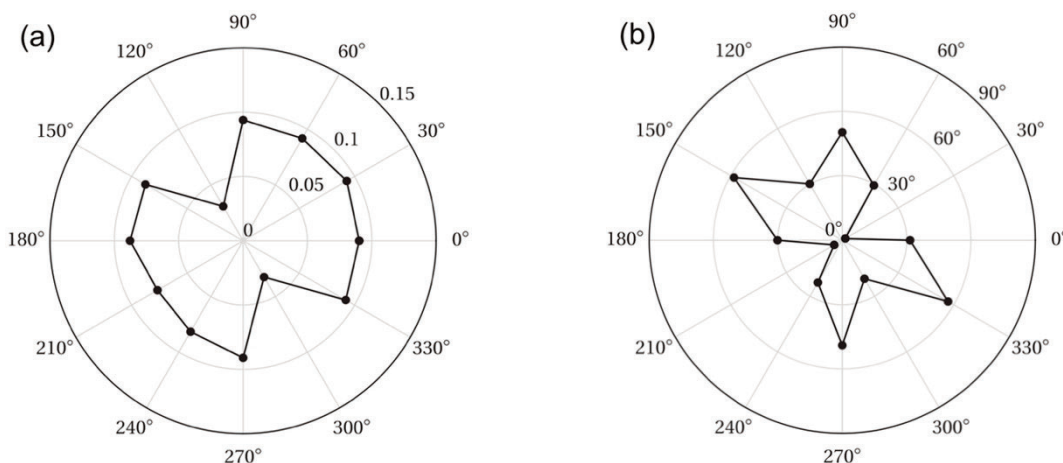


**Figure 7:** Anisotropic friction. Three-dimensional model. Rigid rough target and viscoelastic RCE. RCE discretised with 24336 8-noded hexahedral F-bar elements arranged in 9 layers

RCE size (ratio  $H/L$ ) to the results predicted by their periodically-constrained sub-models (a well-known property of conventional multiscale solid constitutive models). The parameter  $\lambda$  alluded to in Figure 6 defines the periodicity of the deformable surface roughness, constructed as the superposition of three sinusoidal waves with wave lengths  $\lambda$ ,  $\lambda/2$  and  $\lambda/4$ . Figures 7 and Figure 8 illustrate the use of the MMVP-based theory in the simulation of anisotropic friction – where a three-dimensional model is needed. The microscale model in this case, depicted in Figure 7, consists of a rigid target surface with anisotropic roughness and a three-dimensional RCE modelled as an isotropic viscoelastic body with the potential contact portion,  $\Gamma_{c,\mu}$ , of its boundary also featuring an anisotropic roughness. The rough rigid target surface and the RCE contact boundary surface are generated with identical spectral properties, but with principal roughness

directions differing by an angle of  $60^\circ$  ( $\pm 30^\circ$  relative to the  $y$ -axis shown in Figure 7). The simulations here consist in pressing the RCE against the fixed rigid target surface and then sliding it in different directions. The microscale contact is modelled as frictionless, so that only the viscoelastic dissipation resulting from the deforming asperities during sliding gives rise to macroscale dissipation in the form of friction. The predicted anisotropic macroscale frictional response is illustrated in Figure 8(a), that shows the computed average homogenised friction coefficient for different sliding directions. The frictional forces peak over a range of sliding directions approximately between  $-30^\circ$  and  $+90^\circ$  and find a minimum around  $+120^\circ$  and  $-60^\circ$ . The computed mismatch between the sliding direction and the direction of the frictional traction – a key feature of anisotropic frictional contact – is illustrated in the polar plot of Figure 8(b).

**Figure 8:** Anisotropic friction simulation results. Polar plots. (a) Average macroscopic friction coefficient as a function of the macroscopic sliding direction; (b) Average macroscopic tangential traction direction as a function of the macroscopic relative sliding direction



Other interesting applications of the MMVP in the context of non-conventional mechanical problems include the coupling between macro-scale solid continua and micro-scale discrete mechanics. In [31], for instance, the MMVP was applied to model a continuum characterised as a network of interacting fibres at the micro-scale. The approach has successfully captured the impact of fibre damage on the macro-scale constitutive behaviour. In [32], the homogenised continuum-level behaviour of graphene and boron nitride was modelled, aiming the estimation of their ultimate strength, having an atomic-level micro-scale description as the starting point. Stepping away from solid mechanics applications, the flexibility of the MMVP as a general multiscale modelling tool was further confirmed in [33], where fluid flow phenomena in permeable media was modelled, leading to the derivation of consistent continuum-level models based on the Navier-Stokes governing equations at the micro-scale.

General multiscale modelling has found important fields of application outside the purely mechanical realm (see, for instance, [34] for the modelling of magneto-electric media). The usefulness of the MMVP has also been proven in such more general settings. In a recent application [35], the methodology successfully produced a sound multiscale model for structured electromagnetic media. In this case, the micro-to-macro kinematical transfer between scales takes the form of postulated homogenisation operators for the macroscopic electric field and its curl defined by simple volume averaging relations. Following the MMVP recipe, like in the conventional purely mechanical setting, the dual homogenisation formulae, here expressing the macroscale point values of the displacement and magnetising fields as functionals of the microscale electric and magnetic fields over the microscale cell, follow as direct consequences of the Principle of Multiscale Virtual Power. The permeability and permittivity of the homogenised medium, in turn, are derived by a standard linearisation procedure. Interestingly, non-conventional macroscopic properties emerge naturally in this process, coupling the macroscale magnetising field with the electric field and the displacement with the magnetic field – a feature that would be associated with higher-order theories. This MMVP-based theory has been recently used in [36] in conjunction with the topological derivative method to automatically design broadband epsilon-near-zero metamaterials.

## Concluding remarks

A brief account of the Method of Multiscale Virtual Power has been provided. Since its formalisation in [19,20], its successful use in a wide range of applications has shown the methodology to be a robust tool to guide the development of new multiscale models through well-defined, recipe-like steps. Some developments have been highlighted in this paper. They show that the MMVP becomes particularly useful in non-conventional settings, where its three fundamental principles – Kinematical Admissibility, Duality, and Multiscale Virtual Power – provide a safe framework where potentially inconsistent ad-hoc assumptions are largely fenced off throughout the model development steps. A recent application in the modelling of frictional contact [25, 26] provides particularly strong evidence to that effect. It should be remarked, however, that the adoption of the MMVP is not an absolute necessity in the development of new multiscale theories. In fact, a large number of perfectly sound, consistent models have been devised without reference to the MMVP – some of which have been referred to in this article. However, for well over a decade now, the authors' experience has confirmed that the methodology can be a very helpful tool, not only avoiding potential inconsistencies but also providing significant insights into the impact of the modeller's assumptions, for example, on the scale transfer operations involving the primary and dual physical variables of the problem. Finally, it should be added that, within this framework, a comprehensive analysis of the full-resolution solution of the mechanical problem for a generic solid with microstructure, with particular reference to its link with associated coarser-scale solutions, has been conducted recently in [24]. Variational arguments have revealed some fundamental properties of coarse solutions, leading to the construction of new RVE-based minimally-constrained models where either displacements or tractions may be prescribed over complementary portions of the RVE boundary. This allows interactions among neighbouring cells to be accounted for in a consistent manner, paving the way for the design of iterative algorithms whereby the full-resolution solution may be asymptotically approached at a lower computational cost. This is work in progress, and new developments in this direction will be the subject of forthcoming publications. ●

## References

- [1] Kirkwood J (1946) **The statistical mechanical theory of transport processes**. I. General theory. *J. Chem. Phys.* 14,180–201.
- [2] Hill R (1972) **On constitutive macro-variables for heterogeneous solids at finite strain**. *Proc. R. Soc. Lond. A* 326,131–147.
- [3] Mandel J (1971) **Plasticité Classique et Viscoplasticité**. CISM Lecture Notes No. 97. Springer, Udine.
- [4] Fish J, Wagiman A (1993) **Multiscale finite element method for a locally nonperiodic heterogeneous medium**. *Computational Mechanics* 12(3), 164–180.
- [5] Terada K, Kikuchi N (1995) **Nonlinear homogenization method for practical applications**. Proceedings of the ASME International Mechanical Engineering Congress and Exposition, San Francisco, California.
- [6] Terada K, Ito T, Kikuchi N (1998) **Characterization of the mechanical behaviors of solid-fluid mixture by the homogenization method**. *Comp. Meth. Appl. Mech. Eng.* 153(3-4), 223-257.
- [7] Michel J, Moulinec H, Suquet P (1999) **Effective properties of composite materials with periodic microstructure: a computational approach**. *Comp. Meth. Appl. Mech. Eng.* 172,109–143.
- [8] Miehe C, Schröder J, Schotte J (1999) **Computational homogenization analysis in finite plasticity simulation of texture development in polycrystalline materials**. *Comp. Meth. Appl. Mech. Eng.* 171(3-4), 387-418.
- [9] Feyel F, Chaboche JL (2000) **FE2 multiscale approach for modelling the elastoviscoplastic behaviour of long fibre SiC/Ti composite materials**. *Comp. Meth. Appl. Mech. Eng.* 183(3-4), 309-330
- [10] Terada K, Hori M, Kyoya T, Kikuchi N (2000) **Simulation of the multi-scale convergence in computational homogenization approaches**. *Int. J. Solids and Struct.* 37(16), 2285-3211.
- [11] Terada K, Kikuchi N (2001) **A class of general algorithms for multi-scale analyses of heterogeneous media**. *Comp. Meth. Appl. Mech. Eng.* 190(40-41), 5427-5464.
- [12] Kouznetsova V, Brekelmans WAM, Baaijens FPT (2001) **An approach to micro-macro modelling of heterogeneous materials**. *Computational Mechanics* 27(1), 37-48.
- [13] Kouznetsova V, Geers MGD, Brekelmans WAM (2002) **Multi-scale constitutive modelling of heterogeneous materials with a gradient-enhanced computational homogenization scheme**. *Int. J. Num. Meth. Eng.* 54(8), 1235-1260.
- [14] Yvonnet J, He Q (2010) **A non-concurrent multiscale method for computing the response of hyperelastic heterogeneous structures**. *Eur. J. Comput. Mech.* 19, 105–116.
- [15] Lehmann E, Loehnert S, Wriggers P (2012). **Computational homogenisation of polycrystalline elastoplastic microstructures at finite deformation**. *Technische Mechanik* 32(2-5), 369-379.
- [16] Kouznetsova VG, Geers MGD (2008) **A multi-scale model of martensitic transformation plasticity**. *Mechanics of Materials* 40(8), 641-657.
- [17] de Bortoli D, Adziman F, de Souza Neto EA, Pires FMA (2018) **Constitutive modelling of mechanically induced martensitic transformations: Prediction of transformation surfaces**. *Engineering Computations* 35(2), 772-799.
- [18] Sánchez PJ, Blanco PJ, Huespe AE, Feijóo RA (2013) **Failure-oriented multi-scale variational formulation: Micro-structures with nucleation and evolution of softening bands**. *Comp. Meth. Appl. Mech. Eng.* 26(3), 281-301.
- [19] Blanco PJ, Sánchez PJ, de Souza Neto EA, Feijóo RA (2014) **Variational foundations of RVE-based multiscale models**. LNCC Research & Development Internal Report.
- [20] Blanco PJ, Sánchez PJ, de Souza Neto EA, Feijóo RA (2016) **Variational foundations and generalized unified theory of RVE-based multiscale models**. *Arch. Comp. Meth. Eng.* 23, 191–253. (published online Dec 2014)
- [21] de Souza Neto EA, Blanco PJ, Sánchez PJ, Feijóo RA (2015) **An RVE-based multiscale theory of solids with micro-scale inertia and body force effects**. *Mechanics of Materials* 80, 136–144.
- [22] Toro S, Sánchez PJ, Blanco PJ, de Souza Neto EA, Huespe AE, Feijóo RA (2016) **Multiscale formulation for material failure accounting for cohesive cracks at the macro and micro scales**. *Int. J. Plasticity* 76,75-110.
- [23] Blanco PJ, Sánchez PJ, Rocha FF, Toro S, Feijóo RA (2023) **A consistent multiscale mechanical formulation for media with randomly distributed voids**. *Int. J. Solids and Structures* 283.
- [24] Feijóo RA, Blanco PJ, de Souza Neto EA, Sánchez PJ (2023) **Novel multiscale models in a multicontinuum approach to divide and conquer strategies**. *Computational and Applied Mathematics* 42(4)
- [25] Carneiro AMC, Pires FMA, de Souza Neto EA (2024) **Multiscale contact homogenisation: A novel perspective through the method of multiscale virtual power**. *Comp. Meth. Appl. Mech. Eng.* 432.
- [26] Carneiro AMC, Carvalho RP, de Souza Neto EA, Pires FMA (2025) **Multiscale contact homogenisation through the method of multiscale virtual power: Computational implementation and numerical aspects**. *Comp. Meth. Appl. Mech. Eng.* 445.
- [27] Wriggers P, Reinelt J (2009) **Multi-scale approach for frictional contact of elastomers on rough rigid surfaces**, *Comp. Meth. Appl. Mech. Eng.* 198 (21), 1996–2008.
- [28] Sadowski P, Stupkiewicz S (2010) **Combined effect of friction and macroscopic deformation on asperity flattening**, *Tribology International* 43(9), 1735–1741.
- [29] De Lorenzis L, Wriggers P (2013) **Computational homogenization of rubber friction on rough rigid surfaces**, *Comput. Mater. Sci.* 77, 264–280
- [30] Stupkiewicz S, Lewandowski MJ, Lengiewicz J (2014) **Micromechanical analysis of friction anisotropy in rough elastic contacts**, *Int. J. Solids Struct.* 51(23), 3931–3943.
- [31] Rocha FF, Blanco PJ, Sánchez, PJ, de Souza Neto EA, Feijóo RA (2021) **Damage-driven strain localisation in networks of fibres: A computational homogenisation approach**. *Computers and Structures* 255.
- [32] Quang HK (2019) **A computational multiscale approach to the micro-discrete to macro-continuum transition**. PhD Thesis. Swansea University.
- [33] Blanco PJ, Clausse A, Feijóo RA (2017) **Homogenization of the Navier-Stokes equations by means of the Multi-scale Virtual Power Principle**. *Comp. Meth. Appl. Mech. Eng.* 315 760-779, 2017.
- [34] Labusch M, Schröder J, Lupascu DC (2019) **A two-scale homogenization analysis of porous magneto-electric two-phase composites**. *Arch. Appl. Mech.* 89, 1123-1140.
- [35] Blanco PJ, Pinheiro FA, Novotny AA (2024) **A novel multiscale model for micro-structured electromagnetic media**. *Proc. R. Soc. A* 480(2303).
- [36] Novotny AA, Pinheiro FA, Blanco PJ (2026) **Topological derivative multiscale approach for the design of broadband epsilon-near-zero metamaterials**. *J. Comput. Physics* 548.



## 11<sup>th</sup> International Congress of the Croatian Society of Mechanics (11<sup>th</sup> ICCSM)

From September 30 to October 3, 2025, the 11th International Congress of the Croatian Society of Mechanics (11th ICCSM) took place in Vodice, Croatia. It was the latest in the series of international congresses organized by the Croatian Society of Mechanics (CSM). The CSM is an association with the aim of promoting education, research and application in the field of solid and fluid mechanics.

The ICCSM events are triennial and were first held thirty years ago. The aim of the Congress is to provide a forum for the exchange of new ideas and achievements in the mechanical sciences. The scope of the congress is quite broad and covers all areas of theoretical, computational, and experimental mechanics.

For the first time, the 11th ICCSM had the status of an ECCOMAS Special Interest Conference and was held under the auspices of the Central European Association for Computational Mechanics (CEACM).

The Congress gathered 113 participants from 12 countries (*Figure 1*). Three distinguished plenary lecturers took part: *Laura De Lorenzis* (ETH Zürich), *Wing Kam Liu* (Northwestern University & Co-Founder of HIDENN-AI, LLC), and *Jörg Schröder* (Universität Duisburg-Essen) (*Figure 2*). Following his plenary lecture, *Professor Jörg Schröder* was awarded the Honorary Membership Plaque of the Croatian Society of Mechanics.

In addition to the plenary lectures, a total of 83 contributed lectures were presented. The International Scientific Committee comprised 57 highly respected scientists from 21 countries. The Congress Chairmen were *Marko Čanađija* and *Leo Škec*.

Three special sessions were organized:  
SS01 - Emerging Trends in Mechanical Metamaterials,  
*Giuseppe Failla* and *Andrea Russillo*, University of Reggio Calabria, Italy

**Figure 1:**  
*Participants at the 11th ICCSM after the Opening Ceremony*



SS02 - Mechanics of Non-Conventional Materials and Structures,

*Raffaele Barretta*, University of Naples Federico II, Italy /

*Noël Challamel*, Université Bretagne Sud, France /

*Nicholas Fantuzzi*, University of Bologna, Italy /

*Marzia Sara Vaccaro*, University of Naples Federico II, Italy

SS03 - State-of-the-Art on the Dynamic Behaviour of Materials and its Applications,

*Borja Erice*, Mondragon Unibertsitatea & IKERBASQUE, Spain /

*Louise Le Barbenchon*, Arts et Métiers, I2M, France /

*Nina Čeh*, University of Rijeka, Croatia /

*Maria Lišner*, University of Oxford, United Kingdom



**Figure 2:**

Plenary lecturers:

*Prof. Laura De Lorenzis, Prof. Wing Kam Liu and Prof. Jörg Schröder*

The congress excursion on the afternoon of October 2 was organized to Šibenik. Šibenik is not only the administrative and economic center of the region but is also situated in a beautiful natural and historical setting. The bay in which the town lies marks the mouth of the Krka River, a well-known karst river. Šibenik has a charming old town center and two UNESCO World Heritage monuments: the Cathedral of St. James and the Fortress of St. Nicholas, one of the city's four fortresses. During the excursion, participants visited the Barone Fortress, which offers a magnificent view of Šibenik and its archipelago. In addition, they had the opportunity to visit the Cathedral of St. James and stroll through the oldest part of the city.

The Congress concluded with a lecture by *Gabrijela Grozdanić*, Ph.D., the winner of the Croatian Society of Mechanics Award for Young Scientists for 2025 (*Figure 3*).

A post-congress boat trip to Krka National Park took participants through the archipelago, past the UNESCO World Heritage site Fortress of St. Nicholas, into the St. Ante Channel, and then into Šibenik Bay. The boat continued into the mouth of the Krka River and cruised along Lake Prokljan to Skradinski Buk, the largest waterfall in Krka National Park. There, participants disembarked, enjoyed some free time, and visited the park's main attractions.

The lectures are published in the Book of Abstracts and in the Proceedings of the 11th ICCSM. More info can be found at <https://csm.hr/iccsm2025>. ●



**Figure 3:**

*Prof. Marko Čanađija*, the president of the CSM and  
*Gabrijela Grozdanić*, Ph.D., the winner of the Croatian Society of Mechanics  
Award for Young Scientists for 2025

## DTE2027 & CFC2027

The International Association for Computational Mechanics (IACM) is pleased to announce that the 4<sup>th</sup> IACM Digital Twins in Engineering Conference (DTE2027) and the 24<sup>th</sup> IACM Computational Fluids Conference (CFC2027) will be held consecutively in March 2027 in Yokohama, Japan. These two flagship IACM conferences will be organized as fully in-person events, providing an excellent opportunity for intensive scientific exchange and networking. Following the experience of WCCM 2022, which could not be fully realized as an in-person event, DTE2027 and CFC2027 will offer the IACM community a valuable and timely occasion to reconnect through face-to-face discussions, presentations, and collaborations.

DTE2027 will focus on advances in digital twin technologies and the fusion of data-driven and physics-based engineering, while CFC2027 will cover cutting-edge developments in computational fluid dynamics and related multiphysics applications. Together, these conferences will offer a comprehensive platform spanning theory,



computation, data science, and real-world engineering applications. To further promote participation in both events, a discounted registration scheme is planned for participants attending both DTE2027 and CFC2027 consecutively. Details of this joint registration discount will be announced in due course. We warmly invite researchers, engineers, and practitioners from academia and industry worldwide to join us in Yokohama in March 2027 and contribute to advancing computational mechanics, digital engineering, and computational fluids through vibrant in-person engagement. ●

by  
Yoshitaka Wada (Kindai University)  
& Mitsuteru Asai (Kyushu University)

## Summer Camp for Students

“The Summer Camp for Students” is a successful series hosted by JSCES since 2013. The 2025 event was held at a traditional Japanese-style lodge in Tsukuba City, Ibaraki Prefecture (Figure 1).

Figure 1:  
Participants of the JSCES summer camp for students 2025





**Figure 2:**  
*Discussions at the poster session*

The two-day, one-night program featured a series of talks on research topics and career development delivered by researchers and practitioners from academia, industry, and government, representing a wide range of backgrounds in computational engineering.

In addition, a student-led lecture session and poster presentations (*Figure 2*) were included. Participants shared diverse career paths and experiences after completing graduate school and after earning a Ph.D. Overall, the camp offered opportunities to build connections among students and researchers and served as an active forum for discussion. ●

by  
*Naoto Mitsume (University of Tsukuba)*

## **JSCES Summer School 2025 on Nonlinear Finite Element Method for Elastoplastic Analysis**

A three-day course “JSCES Summer School 2025 on Nonlinear Finite Element Method for Elastoplastic Analysis” was held from September 16 to 18, 2025, at Chuo University, Korakuen Campus in Tokyo. The course was first held in August 2013. Since then, it has been held annually, except in 2020 when it was postponed due to the COVID-19 pandemic. The 2025 session marks the 12th iteration.

Topics covered included the fundamental theory and numerical algorithms for nonlinear finite element analysis using inelastic constitutive models such as elastoplasticity, as well as practical techniques for computer implementation. The instructors were Prof. Kenjiro Terada (Tohoku University), Prof. Mao Kurumatani (Ibaraki University), Prof. Isao Saiki (Kyushu Institute of Technology), Prof. Kazumi Matsui (Yokohama National University), Prof. Tateki Ishii (National College of Technology, Kisarazu), and Prof. Yuki Yamakawa (Tohoku University). They delivered enthusiastic lectures to attendees, including students and practitioners involved in computational engineering (*Figure 3*). After the lectures, there was a Q&A session featuring discussions and questions, followed by a networking event where attendees and instructors engaged in technical discussions and exchanged information (*Figure 4*). ●

by  
*Yuki Yamakawa (Tohoku University)*

**Figure 3:**  
*Lecture in JSCES Summer School 2025*



**Figure 4:**  
*Networking event*



### Report from

## The Japan Association for Computational Mechanics

The Japan Association for Computational Mechanics (JACM) is a union of researchers and engineers working in the field of computational mechanics mainly in Japan. The JACM is a loosely coupled umbrella organization covering 29 computational mechanics related societies in Japan through communication with e-mail and web page (<https://ja-cm.org/index-e.html>). The number of individual members is over 350. JACM members actively participate in the IACM activities.

On September 6th, 2025, the 2025 JACM annual meeting and award ceremony were held in Green Computing Systems Research and Development Center of Waseda University in Tokyo. The meeting was also broadcasted by Zoom to remote participants.

In this year, JACM inducted three new honorary members. Before the award ceremony, new honorary members were introduced. They have distinguished records of researches and services to computational mechanics related professional societies. The new honorary members are *Professor Takayuki Aoki* (Professor Emeritus, Institute of Science Tokyo), *Professor Chisachi Kato* (Professor Emeritus, The University of Tokyo) and *Professor Yoji Shibutani* (Professor Emeritus, Osaka University). Each of the new honorary members gave a short speech, after their introductions.

Following the introduction of the new honorary members, the award ceremony took place. There are three categories of JACM Awards. They are the JACM Computational Mechanics Award which is the highest award, JACM Fellows Award and the JACM Young Investigator Award. *Professor Kazunori Fujisawa*

(Kyoto University), *Professor Koji Fukagata* (Keio University) and *Professor Takanori Uchida* (Kyushu University) were awarded 2025 the JACM Computational Mechanics Award (Figure 1).



**Figure 1:**

Recipients of the 2025 JACM Computational Mechanics Award,

(a) Kazunori Fujisawa  
(Kyoto University)

(b) Prof. Koji Fukagata  
(Keio University)

(c) Prof. Takanori Uchida



**Figure 2:**

Recipients of the 2024 JACM Fellows Award,

(a) Prof. Dai Okumura  
(Nagoya University)

(b) Prof. Kazuki Shibanuma  
(The University of Tokyo)

(c) Prof. Daisuke Tawara  
(Ryukoku University)

(d) Prof. Makoto Uchida  
(Osaka Metropolitan University)

The recipients of the JACM Fellows Award were *Professor Dai Okumura* (Nagoya University), *Professor Kazuki Shibanuma* (The University of Tokyo), *Professor Daisuke Tawara* (Ryukoku University) and *Professor Makoto Uchida* (Osaka Metropolitan University) (Figure 2). The winners of JACM Young Investigator Award were *Professor Naoto Mitsume* (Tsukuba University) and *Professor Yi Cu* (Nagoya University) (Figure 3).

The second part of the annual meeting was the eighth JACM awardee seminar. The purpose of this seminar series is to have researchers who received the JACM awards recently give lectures on their latest research activities. Two lectures were given in the seminar.

The first one entitled “Evolution and outlook of high-accuracy particle

methods for free-surface flows” was presented by *Professor Takuya Matsunaga* (The University of Tokyo), who is the JACM Young Investigator Award winner of year 2024.

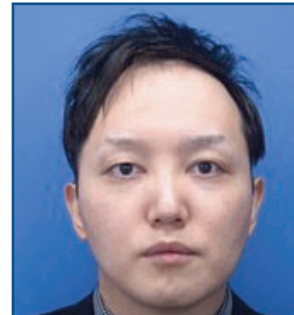
The second one was “Toward the Social Implementation of

Powder and Multiphase Flow Simulation” given by *Professor Mikio Sakai* (The University of Tokyo), received the JACM Computational Mechanics Award of year 2023. At the end of the 2025 JACM meeting, we took a group photo (Figure 4).

On Tuesday, December 2, 2025, JACM took a part of the Fifteenth Computational Mechanics Symposium together with eight other computational mechanics related academic societies in Japan. This annual event, held every December, organized by the Science Council of Japan (SCJ; <https://www.scj.go.jp/en/scj/index.html>). It has been held in December since 2011. The symposium was held in a combined in-person and on-line format. Approximately 50 attendees gathered in the SCJ conference hall, while more than 200 participants joined remotely.

In the Fifteenth Symposium, eight young researchers representing the participating computational mechanics related academic societies in Japan presented their latest research accomplishments. *Professor Takuya Terahara* (Waseda University) (Figure 5), the recipient of the 2023 JACM Young Investigator Award, represented JACM and delivered a presentation “Mitral Valve Flow Analysis with Actual Leaflet Contact Representation for Heart Valve Repair”. In this presentation, he discussed about his research on fluid-structure interaction using Isogeometric Analysis for biomedical applications.

Following the presentations by the young researchers, a special session on Future Directions for Disaster Prevention and Mitigation was held. It is noted that Japan has had many natural disasters such as those due to huge earthquakes, typhoons and increasingly frequent extreme weathers. Participants of the symposium recognized that Disaster Prevention and Mitigation is an important area of computational mechanics/science research. ●



**Figure 3:**  
Recipients of JACM Young Investigators Award  
(a) Professor Naoto Mitsume (Tsukuba University) (b) Professor Yi Cu (Nagoya University)



**Figure 4:**  
Group Photo of the 2025 JACM annual meeting



**Figure 5:**  
Professor Takuya Terahara of Waseda University

## USNCCM18

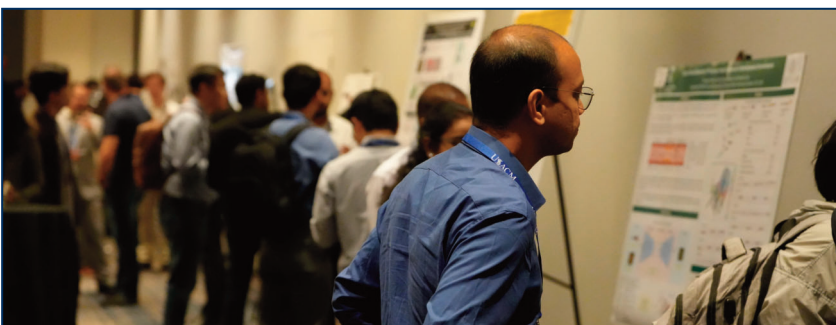
The 18th U.S. National Congress on Computational Mechanics (USNCCM18) was held in the vibrant city of Chicago from July 20—24, 2025. The 2025 Congress marked a symbolic return to roots for the parent organization: The US Association for Computational Mechanics (USACM). The first USNCCM was also held in Chicago, in 1991. The growth of the field is vividly reflected in the Congress's evolution — from approximately 400 attendees at the inaugural meeting to more than 1,250 participants in 2025. This expansion underscores USNCCM's stature as one of the two leading forums for the broader field of computational science in the US and internationally. As in recent years, the Congress brought together world-leading computational researchers in academia, national laboratories, research institutes and industry, representing a truly global community from around the world.

USNCCM18 had three well-attended pre-congress short courses on Phase Field Fracture, GPUs for Constitutive Modelling, and Foundation Models in Computational Mechanics. The main Congress had networking events, a mentoring session, a career panel, an industry focused panel, a funding panel and a student poster competition. The Congress featured among its plenary and semi-plenary speakers a diverse group of research leaders representing academia, government, and industry: Roger Ghanem, Dennis Kochmann, Marta D'Elia, Ann Almgren, John Dolbow, Lucy Zhang, Vipin Kumar, Ashley Spear, Adrian Buganza-Tepole and James Guest. The technical program consisted of nearly 1053 talks organized across 87 minisymposia in 227 sessions. They spanned an ambitiously wide range of topics, including scientific machine learning and artificial intelligence; verification, validation, and uncertainty quantification; optimization; scientific visualization; computational solid and fluid mechanics; materials; advanced manufacturing; and geosystems and earth sciences. Highlights included a Special Topic minisymposium on Fundamental Concepts in Scientific Machine Learning and a Late-breaking Topic minisymposium on Computational Science of Hazards. 403 students attended, most of them presenting talks and/or some of the 53 posters.

The Congress was supported by a number of organizations and institutions: The National Science Foundation, The Grainger College of Engineering at University of Illinois Urbana-Champaign, the McCormick School of Engineering at Northwestern University, the Whiting School of Engineering at Johns Hopkins University, the Oden Institute at University of Texas at Austin, the School of Advanced Computing and the Viterbi School of Engineering at University of Southern California, the Michigan Institute for Computational Discovery and Engineering at University of Michigan, Los Alamos National Laboratory, Sandia National Laboratories, Idaho National Laboratory, Ansys, XSight, Wiley, Elsevier, the International Association for Computational Mechanics and the Society for Industrial and Applied Mathematics.

This Congress marked the retirement of Ruth Hengst, the former Executive Director of USACM. For roughly two decades, Ruth has been the quiet hand behind the Association, its Congresses and numerous Thematic Conferences. Her foresight and deep knowledge of processes steered the 2021 Congress in the aftermath of the COVID pandemic, and in very concrete ways set the 2025 Congress, on a path to success.

**Figure 1:**  
*USNCCM18 Poster Session*



In concluding this brief report, we note that USNCCM18 once again proved to be an epitome of the ways in which computation has become the dominant language of science. The extraordinary rise of scientific AI—and its continued ability to exceed expectations—was a recurring theme. At the same time, the rigor of computational science remains precisely the discipline needed to ensure trustworthiness of AI.

## Workshop on Emerging Trends in Nanomechanics: Experimental, Computational, and Machine Learning Approaches

The workshop on Emerging Trends in Nanomechanics: Experimental, Computational, and Machine Learning Approaches was held on September 15–17, 2025, at the Beckman Institute of the University of Illinois Urbana-Champaign. The workshop was organized under the auspices of the U.S. Association for Computational Mechanics (USACM) within the Technical Thrust Area on Nanotechnology and Lower Scale Phenomena.

The goal of the workshop was to bring together researchers spanning experimental mechanics, computational modeling, and data-driven approaches to identify emerging scientific directions and open challenges in nanomechanics. The emphasis of the workshop was on understanding how advances in machine learning, multiscale modeling, and materials characterization are reshaping nanoscale modeling. The technical program was organized around five thematic areas: (i) Machine learning and uncertainty quantification in computational materials science, (ii) Mechanics and physics of low-dimensional materials, (iii) Defects and interfaces, (iv) Coarse graining across scales, and (v) Multiscale design of materials and inverse problems. The workshop featured 20 invited oral presentations, five panel discussions, and a student-focused poster and lightning-talk session.

A recurring theme throughout the workshop was the growing convergence of physics-based modeling and data-driven methods. Speakers highlighted recent progress in generative models, machine-learned interatomic potentials, and surrogate modeling frameworks, while also emphasizing the importance of physical constraints, interpretability, and uncertainty quantification. Several talks demonstrated how hybrid approaches that combine first-principles calculations, statistical mechanics, and machine learning can accelerate materials discovery while maintaining physical fidelity.

Low-dimensional and nanostructured materials formed another major focus of the workshop. Presentations showcased advances in experimental techniques such as electron ptychography, in-situ transmission electron microscopy, and dark-field X-ray microscopy, enabling three-dimensional and time-resolved characterization of deformation mechanisms, phase transformations, and defect dynamics at nanometer length scales. These experimental advances were closely connected to theoretical and computational efforts aimed at understanding the mechanics, electronic structure, and thermodynamics of nanoscale systems.

Defects and interfaces emerged as a unifying topic across multiple sessions. Talks and panel discussions addressed grain boundary structure and phase transitions, dislocation–interface interactions, and the role of line defects in controlling mechanical response and stability. Participants emphasized the need for models that explicitly account for interface structure, evolution, and history, rather than treating interfaces as idealized boundaries.

The workshop was attended by 43 participants, including faculty, staff scientists, graduate students, and postdoctoral researchers. In addition to the invited talks and panel discussions, the workshop included 23 poster presentations and lightning

**Figure 2: (left)**  
Session one panelists

**Figure 3:(below)**  
Poster competition winners



talks, providing early-career researchers with opportunities to present their work, receive feedback, and engage with leaders in the field. The workshop format fostered lively discussions, cross-disciplinary interactions, and new collaborations. The workshop was organized by Nikhil Admal (University of Illinois Urbana-Champaign), Susanta Ghosh (Michigan Technological University), Harley Johnson (University of Illinois Urbana-Champaign), and Krishna Garikipati (University of Southern California), with guidance from Amartya Banerjee (USACM Chair, University of California, Los Angeles), and logistical support from Valarie Selio and Bethany Roicki (USACM). The U.S. Army Research Office supported the workshop through award W911NF2510171 (Solid Mechanics Program and Synthesis & Processing Program). Additional information, including abstracts and recorded talks, is available at <https://nanomaterials2025.usacm.org/>.

## Artificial Intelligence & Digital Twins for Earth Systems (AIDT4ES) Workshop

The USACM's newest Technical Thrust Area (TTA) on Energy & Earth Systems (E&ES) organized its first thematic workshop on Artificial Intelligence & Digital Twins for Earth Systems (AIDT4ES), which was held September 22-24, 2025 in Austin, TX. Additional information about the workshop is available on the workshop website at [aidt4es.usacm.org](http://aidt4es.usacm.org).

Artificial Intelligence/Machine Learning (AI/ML) technologies have grown exponentially over the past decade, and there is increasing interest to integrate these technologies into energy and Earth systems modeling. Digital twins (DTs) are computational models that are dynamically updated using data from their physical twins to persistently represent the behavior of unique physical systems or processes, and serve as a basis for model predictive decision making. The AIDT4ES workshop brought together approximately 100 researchers from 6 countries working to integrate AI/ML methods within Earth systems modeling towards creating predictive DTs. It featured 4 invited plenary lectures, 7 technical sessions consisting of a total of 35 contributed talks, and 2 poster sessions.

The talks and posters presented at AIDT4ES spanned a wide range of topics including data-driven parameterizations for subgrid-scale physics, efficient data-driven surrogates, coupling methodologies for rigorously combining conventional and data-driven models, data-driven physics discovery, data assimilation, optimal control/decision making under uncertainty, and optimal experimental design. Importantly, the presentations mapped to subject areas of primary interest to the E&ES TTA, namely climate and Earth system modeling, geomechanics, geodynamics and seismology, energy, Carbon sequestration, capture and storage, and oil/gas recovery. The invited plenary lecturers were Prof. Alice Gabriel (UC San Diego), Prof. Artem Korobenko (U Calgary), Dr. Bill Lipscomb (Lawrence Berkeley National Lab) and Prof. Felix Hermann (Georgia Tech). Their talks mapped to several areas directly relevant to the workshop's themes, namely earthquake physics, wind turbine wake modeling, weather/climate emulators, and underground CO<sub>2</sub> storage.

The AIDT4ES workshop was chaired by the E&ES TTA Chair, Dr. Irina Tezaur (Sandia National Labs). In addition to Dr. Tezaur, the organizing committee also included Prof. Omar Ghattas (UT Austin), Prof. Hannah Lu (UT Austin), Prof. Patrick Heimbach (UT Austin), Prof. Clint Dawson (UT Austin), Prof. Steve Sun (Columbia U) and Prof. Yuri Bazilevs (Brown U). The organizers gratefully

acknowledge the Oden Institute for Computational Engineering & Sciences at UT Austin for providing the venue for AIDT4ES as well as extensive administrative support, coordinated primarily by Nasiha Muna (UT Austin). They additionally wish to thank ExxonMobil for their generous monetary support, which helped keep registration fees low for participants. ●

**Figure 4:**  
*AIDT4ES Delegates*



## **GIMC SIMAI YOUNG 2026** **Pisa, June 3-5, 2026**

GIMC and SIMAI are pleased to announce the third edition of their joint workshop for young scientists ( $\leq 35$ ), to be held in Pisa on June 3–5, 2026. The workshop offers a forum to share recent research, explore emerging trends, and encourage interaction.

The program features plenary talks by leading scientists, a session for GIMC–SIMAI Young Award recipients, participant-organized parallel sessions, and a poster session. Contributions from all areas of applied mathematics and computational mechanics are welcome as oral or poster presentations.

All details can be found on the website:  
<https://events.dm.unipi.it/event/331/> ●

## **3rd German-Italian Workshop on** **"Common Research Interests** **in Computational Mechanics"** **Udine, February 19-20, 2026**

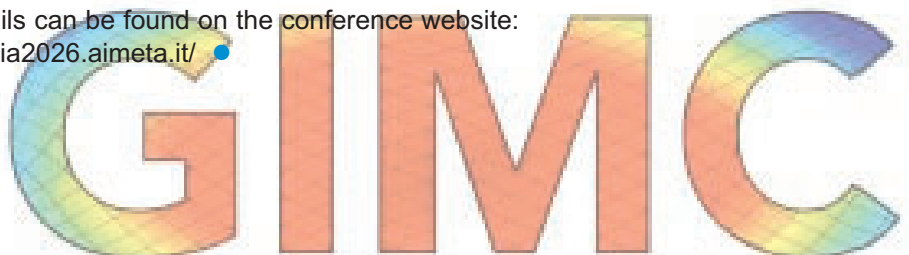
**B**uilding on the success of the first two editions held in Udine (2018) and Aachen (2023), the upcoming Joint GACM–GIMC Workshop on “Common Research Interests in Computational Mechanics”, which will be held in Udine on February 19-20, 2026, aims to further consolidate and expand collaborations between the German Association of Computational Mechanics (GACM) and the Italian Group of Computational Mechanics (GIMC).

Additional info is available at the website:  
<https://cism.it/en/activities/courses/E2601/> ●

## **XXVII AIMETA Conference** **Brescia, September 7-10, 2026**

**T**he XXVII AIMETA Conference of the Italian Association of Theoretical and Applied Mechanics, which includes the GIMC among its affiliated groups, will take place in Brescia from September 7 to 10, 2026. The conference program will cover a broad spectrum of topics in theoretical and applied mechanics. In addition, several minisymposia will be devoted to computational mechanics, involving the Italian computational mechanics community and coordinated by GIMC, also in collaboration with other AIMETA groups.

Further details can be found on the conference website:  
<https://brescia2026.aimeta.it/> ●



## MECOM 2025

### XLI Argentinian Congress on Computational Mechanics

Buenos Aires, Argentina

November 11-14, 2025



**Figure 1:**  
*Prof. Pablo Kler (AMCA's president) speech at Opening Ceremony; from left to right: Prof. Antonio Caggiano, Ing. Sebastián Civallero (UBA), Prof. Paula Folino, Ing. Alejandro M. Martínez (Dean, FI-UBA), Prof. Marcela Goldschmit and Prof. Guillermo Etse*

The XLI Argentine Congress on Computational Mechanics (MECOM 2025) took place from November 11th through November 14th, 2025, in the city of Buenos Aires, Argentina. This new edition of the annual AMCA Congresses was organized by researchers from the Faculty of Engineering dependent on Buenos Aires University (UBA), together with the Argentine Association for Computational Mechanics (AMCA).

The Organizing Committee included **Prof. Paula Folino** (President), **Prof. Marcela Goldschmit**, and **Prof. Antonio Caggiano**. The Scientific Committee was chaired by **Prof. Pablo Mininni**, **Prof. Guillermo Etse** and **Prof. Mario Storti**.

The Congress hosted eight Invited Lecturers, **Prof. Paul Steinmann** (Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany), **Prof. Rainald Löhner** (George Mason University, USA), **Prof. Liberato Ferrara** (Politecnico di Milano, Milano, Italy), **Prof. Umberto Berardi** (Politecnico di Bari, Bari, Italy), **Prof. Fernando Fraternali** (Università degli Studi di Salerno, Salerno, Italy), **Prof. Eduardo Dvorkin** (Facultad de Ingeniería, Universidad de Buenos Aires, Argentina), **Prof. Alberto Cardona** (Universidad Nacional del Litoral, Santa Fe, Argentina), and **Prof. Jorge Dolado** (Donostia International Physics Center, Donostia-San Sebastian, Spain).

Abstracts and full-length papers were submitted to a peer review process prior to publication. Accepted full-length papers have been published in the proceedings series "Mecánica Computacional", which are openly available at the following website:

<https://amcaonline.org.ar/ojs3/index.php/mc>, while abstracts have been published in the proceedings series "Resúmenes de Mecánica Computacional" that can be found at <https://amcaonline.org.ar/ojs3/index.php/rmc>.

The Conference consisted of 22 Technical Sessions with more than 240 papers presented.

A special session was devoted to undergraduate students, with awards for best posters, that were granted to:

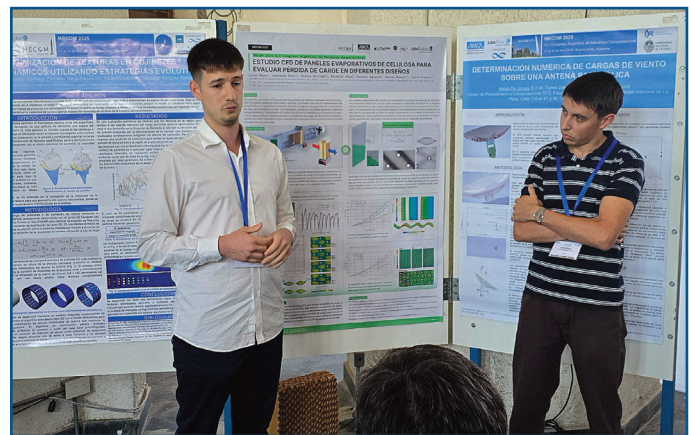
1. **Alexis De Urraza**, from the Computational Fluid Dynamics Group, Facultad de Ingeniería, Universidad Nacional de La Plata, La Plata, Argentina.
2. **Juan Lucas Meyer** and **Leonardo G. Bieri** from the Regional Faculty Paraná, Universidad Tecnológica Nacional, Paraná, Argentina.



**Figure 2:**  
*All conference participants at the FI-UBA Las Heras main stairs*



**Figure 3:**  
*Prof. Alberto Cardona during his plenary lecture*



**Figure 4:**  
*Participants of the Congress poster session*



**Figure 5:**  
*Prof. Mario Storti and Adrián Lew during the special session to honor Prof. Gustavo Buscaglia*



**Figure 6:**  
*Part of the Organizing Committee during an afternoon coffee break at the MECOM 2025*

3. **María M. Farré Plá**, from the Laboratory of Numerical Methods in Engineering (LMNI), Facultad de Ingeniería, Universidad de Buenos Aires, Buenos Aires, Argentina.

The Congress also included other activities like the special session to honor Prof. Gustavo Buscaglia, who was also remembered by his friends, family and the AMCA community lead by the words of his sisters, Prof. Adrian Lew, Prof. Ramón Codina, among others.

## CALL FOR PAPERS

The Argentine Association for Computational Mechanics (AMCA) announces the XLII Argentine Congress on Computational Mechanics (MECOM 2026) to be held in Mendoza, Argentina, organized by the Regional Faculty of National Technology University (FRM-UTN). The Conference will be chaired by **Dr. Ing. Gustavo Gioacchini**, and **Prof. Ing. Francisco Caderón** in the Organizing Committee and **Prof. Ing. Gustavo Palazzo** and **Dr. Ing. Pablo Martín** in the Scientific Committee.

More information will be published in <https://amcaonline.org.ar/mecom2026/>. ●



## Message from the Executive Board

The year 2025 has been a highly productive one for ABMEC, with strong scientific activity, international engagement, and continued efforts to support our computational mechanics community.

As we move into 2026, we look forward to new opportunities to expand our visibility, strengthen partnerships, and further contribute to the global IACM community. ●

## CILAMCE 2025

The Ibero-Latin American Congress on Computational Methods in Engineering (CILAMCE), a long-standing scientific event promoted by ABMEC, has been held regularly since 1977. Focusing on the advancement of fundamentals and applications of computational methods, it brings together researchers, professors, students, and professionals from various fields of computational mechanics, playing a key role for the development of Brazil and its partner countries.

The 46th edition took place in Vitória, Brazil, from November 24 to 27, 2025. It was organized in collaboration with the Federal University of Espírito Santo (UFES) and chaired by *Professors Prof. Elcio Cassimiro Alves* and *João Victor Fragoso Dias*. The event welcomed 553 participants, featured seven keynote lectures, 487 papers presented in 34 mini-symposia, and the Agustín Ferrante Award – a traditional undergraduate student competition recognizing exceptional research talents.

This edition of CILAMCE also held the Special Session “Breaking Barriers: Promoting Gender Equity in Engineering Education and Research”, highlighting the role of women in Engineering and fostering equality in Engineering research environments. The Special Session was conducted by *Professors Silvana de Nardin* (Federal University of São Carlos), *Roberta Lima Gomes* and *Lúcia Catabriga* (Federal University of Espírito Santo). The significant presence of women in the field was further reflected by two female keynote speakers, including *Professor Elena Atroshchenko* (University of New South Wales) and *Irina Tezaur* (Sandia National Laboratories).

The keynote lineup also featured the following eminent names: *Prof. Cláudio Ruggieri* (University of São Paulo); *Prof. Hadi Hajibeygi* (TU Delft); *Prof. John Dolbow* (Duke University) and *Prof. Victor Yepes* (Universitat Politècnica de València).



**Figure 1:**  
*Elena Atroshchenko*  
University of New South  
Wales



**Figure 2:**  
*Hadi Hajibeygi*  
TU Delft



**Figure 3:**  
*Dr. Irina Tezaur*  
Sandia National Laboratories



**Figure 4:**  
*João Victor Fragoso Dias -*  
Co-Chair & *John Dolbow*

## Support for local events

In 2025 ABMEC proudly started an initiative to support local events, by means of financial support and institutional endorsement. This initiative contributed to the realization of the following events: Brazilian Workshop on Scientific Machine Learning for Predictive Modeling, held at the National Laboratory for Scientific Computing (LNNC) on 22 September 2025; Workshop on Innovation in Structural Engineering: Machine Learning and Artificial Intelligence, held at the Federal University of Minas Gerais (UFMG), from 12-14 November 2025. Each one of these events attracted 100 participants. ●

## CILAMCE 2026

ABMEC is pleased to announce that CILAMCE 2026 will be held in Bogotá, capital of Colombia, from November 26 to 29, 2026.

The event is being organized by professors *José A. Guerrero* (chair) and *Mario Jiménez* (co-chair) from Universidad del Rosario. This will be another great opportunity to participate in an internationally relevant event, engage with leading figures and many qualified peers in the field and visit the beautiful city of Bogotá.

Additional information about CILAMCE 2026 is available at [www.cilamce.com.br](http://www.cilamce.com.br). ●



## ENGOPT 2026

ABMEC is also pleased to endorse EngOpt 2026, an important forum on Engineering Optimization. EngOpt 2026 will be held in Lisbon, from September 16 to 18, 2026.

More information can be found at [engopt2026.tecnico.ulisboa.pt](http://engopt2026.tecnico.ulisboa.pt). ●



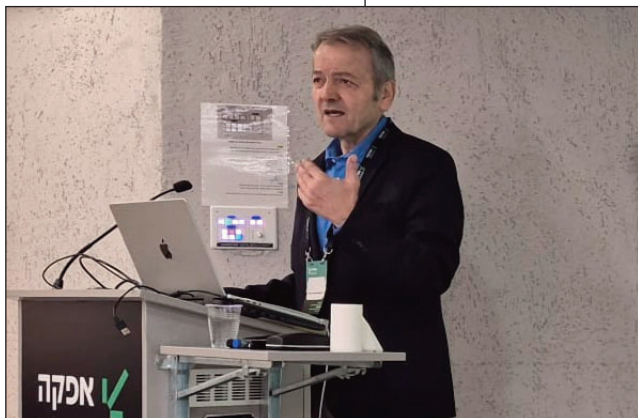
## ABMEC Awards

**A**BMEC recognizes excellence in computational mechanics through three annual awards. The ABMEC Award is the association's highest honor, granted to individuals for lasting contributions throughout their careers. The ABMEC Award for Young Scientists honors researchers aged 40 or younger who have made significant impacts in the field. Established in 2022, the ABMEC Award for the Year's Best Doctoral Thesis highlights outstanding doctoral research in computational mechanics. The recipients of the 2025 Awards are:

- ABMEC Award: *Prof. Luiz Fernando Martha* – Pontifical Catholic University of Rio de Janeiro;
- ABMEC Award for Young Scientist: *Prof. David Leonardo Amorim* – Federal University of Sergipe;
- ABMEC Award for the Year's Best Doctoral Thesis: *Mauricio Vitali Mendes* – University of Brasilia;

\* Honorable mention: *Murilo Henrique Campana Bento* – University of São Paulo. ●

## ISCM-53



**Figure 1:**  
 Prof. Adnan Ibrahimbegovic  
 delivering his lecture at  
 ISCM-53

During 2025, the Israel Association for Computational Methods in Mechanics (IACMM) organized two symposia. The first symposium (**ISCM-53**) was organized by **Dr. Sara Naftali** (School of Medical Engineering in Afeka – Tel Aviv Academic College of Engineering) and **Dr. Uri Albocher** (School of Mechanical Engineering in Afeka – Tel Aviv Academic College of Engineering).

The opening lecture was delivered by the invited speaker **Prof. Adnan Ibrahimbegovic** from the Universite de Technologie Compiègne – Alliance Sorbonne Universite, France and was entitled “*Synergy between Multiphysics/Multiscale Modeling and Artificial Intelligence.*” Figure 1 illustrates Prof. Ibrahimbegovic

presenting his lecture at ISCM-53.

The central motivation of the talk was to explore the complementarity between classical multiphysics and multiscale modeling approaches and emerging model-building strategies based on artificial intelligence. Prof. Ibrahimbegovic emphasized that the knowledge accumulated through decades of research in computational mechanics enables an a priori selection of efficient reduced-order models, grounded in well-justified assumptions and appropriate kinematic constraints.

In parallel, **Prof. Ibrahimbegovic** highlighted the significant recent advances in artificial intelligence and statistical data-analysis techniques applied to solid and structural mechanics. The lecture raised several thought-provoking questions, including how these two paradigms can be developed synergistically, and how they can benefit from each other's advances.

The ISCM-53 included 11 other lectures, presented by researchers from academia. These lectures spanned over a broad spectrum of computational mechanics topics such as structural optimization, electro-mechanical coupled problems, parameter identification, identification of elastic inclusions, damage modeling, immersed boundary method, etc.

During the ISCM-53, a competition for the best presentation was held and the winner was **Mr. Amit Sayag**, a graduate student from the Faculty of Aerospace Engineering, Technion – Israel Institute of Technology. The title of Mr. Sayag's talk was “*Identification of an Elastic Inclusion Using a Time-Dependent Adjoint Method.*” Figure 2 shows Mr. Sayag during his talk.

**Figure 2:**  
 Mr. Amit Sayag, the winner of  
 the ISCM-53 competition  
 for the best presentation,  
 during his talk



## ISCM-54

The second symposium (**ISCM-54**) was held on December 25th 2025 at Technion – Israel Institute of Technology, Haifa, and the local organizers were **Dr. Hezi Grisarò** and **Dr. Nicolò Pollini**, from the Civil and Environmental Engineering, Technion – Israel Institute of Technology.

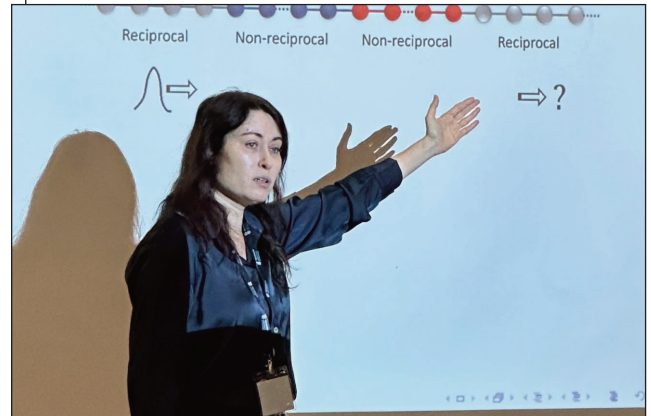
The ISCM-54 included 2 keynote lectures and additional 14 talks presented by researchers from academia and industry. Specifically, the first keynote lecture was given by **Dr. Lea Beilkin-Sirota** from the School of Mechanical Engineering, Tel Aviv University, and the talk entitled “Feedback-based metamaterials for enhanced waveguiding” (see Figure 3).

The second keynote lecture was delivered by **Prof. Miles B. Rubin**, from the Faculty of Mechanical Engineering, Technion – Israel Institute of Technology, and the talk entitled “A purely mechanical version of a thermomechanical Eulerian formulation of a size dependent elastic-inelastic Cosserat continuum” (see Figure 4).

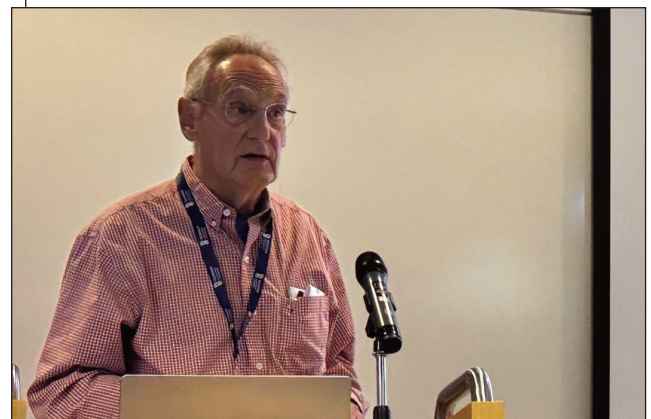
The other 14 lectures spanned over a broad spectrum of computational mechanics topics such as structural topology optimization, soft materials, deep learning, fracture modeling of materials, etc.

During ISCM-54, a best presentation competition was held, and the winner was **Mr. Maxime Levy**, a PhD student in the School of Mechanical Engineering at Tel Aviv University. His presentation was entitled “A phase-field model for heterogeneous materials with application to bone fracture.” Figure 5 shows Mr. Levy during his talk.

In addition, **Ms. Rachel Yovel**, a PhD student at Ben-Gurion University of the Negev, received the best presentation award for the combined ISCM-52 and ISCM-53. Figure 6 shows Ms. Yovel receiving her award certificate. ●



**Figure 3:**  
Dr. Lea Beilkin-Sirota delivering her keynote lecture at ISCM-54



**Figure 4:**  
Prof. Miles B. Rubin delivering his keynote lecture at ISCM-54



**Figure 5:**  
Mr. Maxime Levy, the winner of the ISCM-54 competition for the best presentation, during his talk



**Figure 6:**  
Ms. Rachel Yovel, the winner of the best presentation award of the combined ISCM-52 and ISCM-53, receiving her award certificate

## Report from The Association of Computational Mechanics Taiwan (ACMT)

In 2025, the Association of Computational Mechanics Taiwan (ACMT) continued to promote interdisciplinary academic exchange, underscoring Taiwan’s research strength and international connections in computational mechanics. The following summarizes the year’s major events:

From **July 1 to 4, 2025**, many ACMT members attended the international conference COMPSAFE 2025 in Kobe, Japan. After the conference, participating members gathered for a dinner to share research findings and conference experiences, further strengthening professional exchange and friendship within the community.



**Figure 1 & 2:**  
*Attendees enjoying a dinner at COMPSAFE 2025*

ACMT also collaborated with the Department of Civil Engineering at National Taiwan University and the Sanlien Foundation to organize a science camp for high school students. A total of 26 students participated in this three-day event, engaging in hands-on scientific activities and creative art projects inspired by protein structures—an experience that fostered creativity, teamwork, and curiosity in science.



**Figure 3 & 4:**  
*Views from the Summer Camp*

The Third ACMT Annual Conference and the Sixteenth Taiwan Boundary Element Method Conference were held at National Yang Ming Chiao Tung University from **September 26 to 27, 2025**. Continuing the enthusiastic response from previous years, the conference featured a series of keynote and invited talks by prominent domestic scholars, offering a diverse and rich program that highlighted Taiwan’s research achievements and innovative progress in computational mechanics.



**Figure 5 & 6:**  
*Prof. Yeong-Bin Yang*



*Prof. Yao-Wen Chang*



**Figure 7, 8, 9 & 10:**  
*Prof. Jia-Lin Tsai*



*Prof. Ching-Sen Wu*



*Prof. Yi-Ju Chou*



*Prof. Li-Wei Liu*

This year marked the first presentation of the ACMT Awards, recognizing outstanding contributions by members in research, teaching, and service.

**Computational Mechanics Distinguished Contribution Award:**

*Prof. Yeong-Bin Yang* (Department of Civil Engineering, National Taiwan University)

**Computational Mechanics Award:**

*Prof. Ming-Jyh Chern* (Department of Mechanical Engineering, National Taiwan University of Science and Technology), *Prof. Tung-Wu Lu* (Department of Biomedical Engineering, National Taiwan University)

**Computational Mechanics Young Scholar Award:**

*Assoc. Prof. Tsung-Hui Huang* (Department of Mechanical Engineering, National Taiwan University), *Prof. Judy P. Yang* (Department of Civil Engineering, National Yang Ming Chiao Tung University), Distinguished *Prof. Nien-Ti Tsou* (Department of Materials Science and Engineering, National Yang Ming Chiao Tung University).



**Figure 11, 12 & 13:**  
*Prof. Yeong-Bin Yang*



*Prof. Ming-Jyh Chern*



*Prof. Tung-Wu Lu*

**Service Award:**

*Assoc. Prof. Pai-Chen Guan* (Department of Systems Engineering and Naval Architecture, National Taiwan Ocean University), *Assoc. Prof. Chi-Hua Yu* (Department of Engineering Science, National Cheng Kung University)

These awardees have made long-term and significant contributions to academic research, professional service, and talent cultivation, laying a solid foundation for the advancement of computational mechanics in Taiwan.

As ACMT continues to grow, it remains committed to fostering academic exchange, nurturing young talent, and strengthening global collaborations to advance the future of computational mechanics. ●

The Canadian Association for Computational Science and Engineering (CACSE/ACCSG) continues to strengthen Canada’s national community in computational science, computational engineering, and computational mechanics. Since its founding, CACSE has worked to connect researchers, trainees, and practitioners across disciplines and institutions, while also increasing Canada’s visibility within the international computational mechanics community.

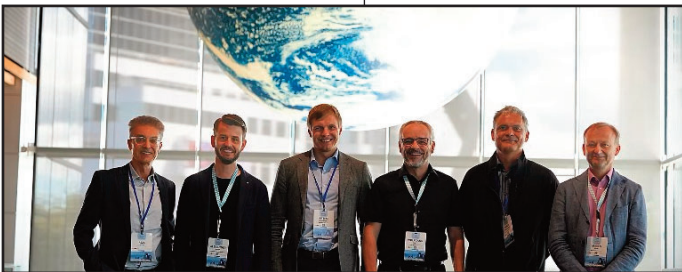
We also wish to recognize the vision and efforts of the Association’s **founding Directors: Dr. Serge Prudhomme, Dr. Reza Vaziri, Dr. Artem Korobenko, and Dr. Marc Laforest.** Their leadership helped establish CACSE as a national platform for scientific exchange and collaboration in computational science and engineering.

CACSE was created to foster a stronger, more connected Canadian community in computational modeling, simulation, numerical methods, data-driven scientific computing, and engineering applications. In a country with a broad geographic footprint and many outstanding but distributed research groups, CACSE plays an important role in creating opportunities for interaction across universities, disciplines, and career stages. The Association’s activities have also helped strengthen links between Canadian researchers and the broader international community, including through engagement with IACM and major global congresses.

**Looking Back: A Landmark Year with WCCM 2024 in Vancouver**

**Figure 1:**  
*Looking back at WCCM-PANACM 2024 and looking forward to WCCM-ECCOMAS 2026*

A major recent milestone for CACSE was the successful hosting of the **16th World Congress on Computational Mechanics (WCCM 2024)** together with the **4th Pan American Congress on Computational Mechanics (PANACM 2024)** in **Vancouver, British Columbia, on July 21–26, 2024.** The congress was co-organized by IACM and CACSE, and it marked the first time these major events were held in Canada.



Hosting WCCM 2024 in Vancouver was an important moment for the Canadian computational mechanics community. It showcased Canada’s research strength, organizational capacity, and growing international presence. It also created a valuable opportunity for Canadian students, postdoctoral scholars, early-career researchers, and established investigators to engage with colleagues from around the world without leaving the country. As we now look ahead to **WCCM–ECCOMAS 2026 in Munich, Germany, on July 19–24, 2026,** Vancouver remains a timely point of

reflection as it demonstrated that Canada can host large-scale international congresses at the highest level and contribute meaningfully to the global computational mechanics community.

**Recent CACSE Annual Conferences**

**Figure 2:**  
*3rd CACSE conference, Banff, AB, January 3-6, 2025*

In addition to its international engagement, CACSE has continued to build a strong national rhythm through its annual meetings. These events have become an important forum for sharing new developments, fostering collaboration, and supporting trainees.



The **3rd Conference of CACSE** took place in **Banff, Alberta, on January 3–6, 2025,** with a focus on **Recent Trends and Developments in Computational Science and Engineering.** The meeting continued the Association’s tradition of bringing together researchers from across Canada in a setting that encourages both scientific exchange and community building.

More recently, the **4th Conference of CACSE** was held again in **Banff, Alberta, on January 9–11, 2026**, with the same broad focus on recent trends and developments in computational science and engineering. These Banff meetings have helped CACSE consolidate a national identity and have provided an increasingly visible home for Canadian scholarship in computational mechanics, scientific computing, and computational engineering.



**Figure 3:**  
4th CACSE conference, Banff, AB, January 9-11, 2026

### Looking Ahead: C3SE 2026 and WCCM–ECCOMAS 2026

CACSE is now preparing for the **1st Canadian Congress on Computational Science and Engineering (C3SE 2026)**, which the Association describes as an invitation to researchers, professionals, and students to participate in a new national congress format. This marks an exciting next step in the growth of the Canadian community and signals CACSE's broader ambition to expand beyond a recurring conference series into a larger congress-style event with wider participation and visibility. At the same time, CACSE members are looking forward to WCCM–ECCOMAS 2026 in Munich, one of the flagship international events in the field. This upcoming congress offers another important opportunity for Canadian researchers to contribute to and shape global conversations in computational mechanics and computational methods in science and engineering.



### A Growing Community with a National and International Role

As CACSE moves forward, its mission remains both timely and important. Computational science and engineering are central to addressing today's largest challenges, including sustainable energy, advanced manufacturing, aerospace, health, infrastructure, climate, materials, and multiscale modeling. Canada has exceptional expertise in these areas, and CACSE provides a national home where that expertise can be connected, showcased, and amplified. At the same time, CACSE's vision extends beyond Canada. An important priority for the Association is to foster stronger **multi-national collaboration** by building links with peer organizations, research groups, and international partners. In the coming years, CACSE hopes to help organize joint **multi-national workshops** and related scientific events that bring together researchers, trainees, and practitioners across borders. Such initiatives would further expand opportunities for collaboration, strengthen knowledge exchange, and reinforce Canada's role in the global computational science and engineering community.

We warmly invite colleagues, students, and collaborators to engage with CACSE's upcoming activities and to join us in continuing to build a vibrant, inclusive, and internationally connected computational science and engineering community

#### President:

**Dr. Artem Korobenko**, University of Calgary

#### Vice-President:

**Dr. Robert Gracie**, University of Waterloo

#### Treasurer:

**Dr. Ahmad Shakibaeinia**, Polytechnique Montréal

#### Members-at-Large:

**Dr. Fabian Denner**, Polytechnique Montréal

**Dr. Leyla Amiri**, Université de Sherbrooke

**Dr. Rajeev Jaiman**, University of British Columbia



# WCCM-ECCOMAS 2026

17th World Congress on  
Computational Mechanics

10th European Congress on Computational  
Methods in Applied Sciences and Engineering



[wccm-eccomas2026.org](http://wccm-eccomas2026.org)



IACM



Munich, Germany 19 -24 July 2026



## Congress Chairs

**WOLFGANG A. WALL**, TECHNICAL UNIVERSITY OF MUNICH, GERMANY

**ALEXANDER POPP**, UNIVERSITY OF THE BUNDESWEHR MUNICH, GERMANY

**MAREK BEHR**, RWTH AACHEN UNIVERSITY, GERMANY

## Honorary Chair

**EKKEHARD RAMM**, UNIVERSITY OF STUTTGART, GERMANY

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**gacm** German Association for  
Computational Mechanics

# WCCM–ECCOMAS 2026

## A Landmark Event for Computational Mechanics

Wolfgang A. Wall  
Alexander Popp  
and  
Marek Behr

### Munich 2026 – Where Science Meets a Vibrant City

From **19–24 July 2026**, the global computational mechanics community will gather in Munich, Germany, for the **17th World Congress on Computational Mechanics (WCCM) and the 10th ECCOMAS Congress** – one of the most prestigious joint events in our field.

Hosted at the International Congress Center Munich (ICM), the congress will bring together researchers and practitioners from academia, industry, and government worldwide.

A small anecdote for football enthusiasts: the congress opens on the evening of the FIFA World Cup final, so expect an atmosphere in Munich that combines scientific excitement with global sporting spirit.

Munich itself offers an exceptional setting: a city where centuries-old traditions meet cutting-edge innovation. From historic landmarks and vibrant cultural life to world-class research institutions and industry, Munich provides an inspiring backdrop for a truly global scientific gathering.

### A Record-Breaking Congress in Challenging Times

The preparations for WCCM–ECCOMAS 2026 are well advanced – and the response from the community has been overwhelming. We are witnessing **record numbers of submitted abstracts and registrations**, making this congress **the largest in the history of computational mechanics**.

This strong participation is particularly remarkable given the current global challenges, including geopolitical uncertainties and rising travel costs. It sends a powerful message: **science continues to connect people across borders**, and our community remains vibrant, resilient, and forward-looking. The sheer scale and diversity of contributions underline the growing importance of computational mechanics as a cornerstone of modern science and engineering.

### A World-Class Scientific Program

Participants can look forward to a truly outstanding scientific program, including:

- **2 distinguished opening lectures** by eminent speakers from outside our community, offering perspectives on the relationship between science and society as well as on the philosophy of science
- **24 high-caliber plenary lectures** delivered by internationally leading experts

*“ science continues to connect people across borders,  
and our community remains vibrant, resilient, and forward-looking.”*

- **More than 300 minisymposia**, covering the full spectrum of computational mechanics and emerging interdisciplinary fields
- A rich selection of contributed sessions and special technology sessions

These core elements reflect the breadth and depth of our discipline – from fundamental methods to industrial applications. The congress will open with a formal ceremony featuring **prestigious awards from IACM and ECCOMAS**, celebrating excellence across our community. A carefully curated social program, including a **welcome reception** and a memorable **conference dinner + party**, will ensure ample opportunities for networking and exchange. Together, these elements will guarantee a stimulating and rewarding conference experience at the highest scientific level.

*“ .... create the most attractive congress experience ever for young researchers ..... foster interaction, networking, and career development .... strengthening the sense of community ... engage and contribute .... ”*

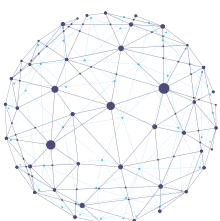
### Beyond Tradition: New Formats for a New Generation

While WCCM–ECCOMAS 2026 builds on a long tradition of excellence, what truly distinguishes this edition are new formats and initiatives that go beyond anything previously seen at our congresses. We are particularly proud to introduce several innovative elements – here we highlight just a few.

#### (1) Next Generation in Computational Engineering (NGCE)

A central highlight is the **Next Generation in Computational Engineering (NGCE)** initiative. Our goal is ambitious: to create **the most attractive congress experience ever for young researchers**. The NGCE activities are designed to foster interaction, networking, and career development, while strengthening the sense of community among early-career scientists. At the same time, participants of all career stages are warmly invited to engage and contribute.

The program is organized by the **ECCOMAS Young Investigator Committee (EYIC)** in collaboration with a dedicated **NGCE Committee**. Highlights include: **Science Slam, Career Lunch, City Quest, Pub Crawl, Arts & Science Contest**, and many more. We encourage all participants to keep an open mind – and an open schedule – to take part in these unique activities.



I A C M



## (2) Career Fair in Computational Engineering (CFCE)

For the first time, the congress will host a **Career Fair in Computational Engineering (CFCE)** as a dedicated two-day event. This initiative aims to **bridge the gap between academia and industry**, providing a platform where companies, research institutions, and young talents can connect directly. Participants will have the opportunity to explore career paths, discuss research applications, and establish valuable professional contacts – an important step toward strengthening the innovation ecosystem of our field.

## (3) Sustainability and Responsibility

Sustainability is a key concern for WCCM–ECCOMAS 2026. As a concrete measure, **all registered participants will receive a public transport ticket for the entire Munich city area for the full week**, encouraging environmentally friendly mobility and reducing the carbon footprint of the event.

## (4) Family Support and Inclusivity

We are committed to making the congress accessible to all members of our community. To support participants with families, we will offer **childcare solutions through local service providers**, as well as **dedicated spaces at the conference venue**.

This initiative aims to enable researchers with young children to fully participate in the congress experience.

*“ ... aims to bridge the gap between academia and industry, providing a platform where companies, research institutions, and young talents can connect directly. ”*

## Join Us in Munich

WCCM–ECCOMAS 2026 promises to be more than just a conference – it will be **a celebration of our field, our community, and our shared future**.

We warmly invite you to join us, bring your ideas, your curiosity, and your enthusiasm, and be part of this landmark event.

We look forward to welcoming you in Munich!

*Wolfgang A. Wall  
Alexander Popp  
and  
Marek Behr*



# IACM Events

**19 - 20 Feb 2026 3<sup>rd</sup> Joint Workshop between GIMC (Italy) and GACM (Germany)**

*Venue:* Udine, Italy

*Contact:* <https://spancold2026.cimne.com/>

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**19 - 22 May 2026 C3SE 2026 - 1<sup>st</sup> Canadian Congress on Computational Science and Engineering**

*Venue:* Montreal, Canada

*Contact:* <https://www.cacse-accsq.ca/upcoming-events>

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**24 - 27 May 2026 CSME-CFDSC-CSR 2026 - Canadian Society for Mechanical Engineering (CSME), the Computational Fluid Dynamics Society of Canada (CFDSC), and the Canadian Society of Rheology (CSR)**

*Venue:* Vancouver, Canada

*Contact:* <https://www.csmecongress.org/>

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**3 - 5 June 2026 31<sup>st</sup> Computational Engineering Lecture by the Japan Society for Com. Eng. & Computer Science**

*Venue:* Nagoya City, Japan

*Contact:* <https://www.jsces.org/koenkai/31/>

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**1 - 3 July 2026 CMN 2026 - Congress on Numerical Methods in Engineering**

*Venue:* Gijón, Spain

*Contact:* <https://cmn2026.semni.org/>

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**19 - 24 July 2026 WCCM - ECCOMAS 2026 17<sup>th</sup> World Congresses on Computational Mechanics**

*Venue:* Munich, Germany

*Contact:* <https://wccm-eccomas2026.org>

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**7 - 10 Sept 2026 AIMETA 2026**

*Venue:* Brescia, Italy

*Contact:* <https://brescia2026.aimeta.it/>

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**12 - 15 March 2027 CFC 2027 - 24th IACM Computational Fluids Conference**

*Venue:* Yokohama, Japan

*Contact:* <https://cfc2027.iacm.info/>

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**12 - 18 March 2027 DTE 2027 - 4th IACM Digital Twins in Engineering Conference**

*Venue:* Yokohama, Japan

*Contact:* <https://dte2027.iacm.info/>

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**25 - 28 May 2027 M2P 2027 - Emerging Technologies in Computational Science for Industry, Sustainability & Innovation**

*Venue:* Terrasini (Palermo), Italy

*Contact:* <https://m2p2027.cimne.com/>

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**14 - 16 June 2027 ADMOS 2027 - XIII International Conference on Adaptive Modeling & Simulation**

*Venue:* Barcelona, Spain

*Contact:* <https://admos2027.cimne.com/>

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**14 - 17 June 2027 MARINE 2027 - XII International Conference on Computational Methods in Marine Engineering**

*Venue:* Ravenna, Italy

*Contact:* <https://marine2027.cimne.com/>

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**27 - 30 June 2027 COUPLED 2027 - XII International Conference on Coupled Problems in Science & Engineering**

*Venue:* Palma de Mallorca, Spain

*Contact:* <https://coupled2027.cimne.com/>

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**6 - 10 Sept 2027 COMPLAS 2027 – XIX International Conference on Computational Plasticity**

*Venue:* Barcelona, Spain

*Contact:* <https://complas2027.cimne.com/>