TIME TABLE

TIME	Monday	Tuesday	Wednesday	Thursday	Friday
	June 23	June 24	June 25	June 26	June 27
09.00 - 09.45	Registration	Schmauder	Sadowski	**Hu**	Sadowski
09.45 - 10.30	Ghosh	**Hu**	Sadowski	**Hu**	Sadowski
11.00 - 11.45	**Hu**	Trovalusci	Ghosh	Sadowski	Trovalusci
11.45 - 12.30	Hu	Trovalusci	Ghosh	Trovalusci	Trovalusci
14.00 - 14.45	Schmauder	Ghosh	Fantuzzi	Fantuzzi	
14.45 - 15.30	Schmauder	Ghosh	Fantuzzi	Fantuzzi	
16.00 - 16.45	Schmauder	Fantuzzi	Workshop	Workshop	
16.45 - 17.30	Schmauder	Workshop	Workshop	Workshop	
18.00	Welcome aperitif				

ADMISSION AND ACCOMMODATION

The course is offered in a hybrid format, allowing participants the flexibility to attend either in person or remotely via the Microsoft Teams platform. Admission to on-site attendance is granted on a first-come, first-served basis to comply with the capacity of the lecture room.

Registration fees:

- **Early Bird On-Site Participation: € 650.00 + VAT***
  Deadline: April 23, 2025
- **Late On-Site Participation: € 800.00 + VAT***
  Deadline: June 10, 2025
- **Live Streaming Online Participation: € 250.00 + VAT***
  Deadline: June 10, 2025

On-site participation includes a complimentary bag, five fixed menu buffet lunches, hot beverages, downloadable lecture notes.
Online participation includes downloadable lecture notes.

Application forms should be submitted online through the website: http://www.cism.it. A confirmation message will be sent to participants whose applications are accepted.
Upon request, and subject to availability, a limited number of on-site participants can be accommodated at the CISM Guest House for € 35 per person per night. To request accommodation, please contact foresteria@cism.it.

** where applicable; bank charges are not included - Italian VAT is 22%.*

CANCELLATION POLICY

Applicants may cancel their registration and receive a full refund by notifying the CISM Secretariat in writing (via email) no later than:
- April 23, 2025, for early bird on-site participation;
- May 23, 2025, for late on-site participation;
- June 10, 2025, for online participation.

No refunds after the deadlines. Cancellation requests received before these deadlines and incorrect payments will be subject to a € 50.00 handling fee.

CISM GRANTS

A limited number of participants from universities and research centers who do not receive support from their institutions can request a waiver of the registration fee and/or free lodging. Requests should be sent to the CISM Secretariat by **April 23, 2025**, along with the applicant's curriculum vitae and a letter of recommendation from the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

For further information please contact:
CISM (Seat of the course)
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tel. +39 0432 248511 (6 lines)
e-mail: cism@cism.it | www.cism.it

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

ACADEMIC YEAR 2025
The Juan Lasheras Session

RECENT ADVANCEMENTS IN MULTISCALE AND MULTIPHYSICS MODELLING OF COMPLEX MATERIALS

Advanced School
coordinated by

Tomasz Sadowski
Lublin University of Technology
Lublin, Poland

Patrizia Trovalusci
Sapienza University of Rome
Rome, Italy

Udine *June 23 - 27* 2025

RECENT ADVANCEMENTS IN MULTISCALE AND MULTIPHYSICS MODELLING OF COMPLEX MATERIALS

Recent advancements in multi-physics and multiscale modelling of complex materials, which are materials endowed with micro-structure, detectable at different scale levels (nano, micro, meso, macro), and characterised by a complex material behaviour (plasticity, damage, fracture) are required by novel applications.

Advanced composites (ACs), consist of various components (metal, polymer, ceramic, etc.) with complicated internal architectures, including porosity, and reinforcement with fibres or particles of different properties, shapes, and sizes. Optimal distribution of the (1) reinforcing phase within the matrices or (2) different phases in multiphase materials is the major task in designing complex composites to get the required material response to the various kinds of loads. The AC's macroscopic properties are subjected to multi-degradation phenomena which are governed by multiphysics processes that occur at one to several scales below the level of observation, suggesting the application of multiscale approaches. A thorough understanding of how these processes influence the reduction of stiffness and strength is of key importance for the analysis of existing, and the design of improved, complex materials. It is widely recognized that important macroscopic material properties, such as stiffness and strength, are governed by processes occurring at one to several scales below the macro-observation. A thorough understanding of how these processes influence gross behaviour is key to the analysis and the design of existing and/or performance-improved composite materials (multiscale analysis).

The recent advancement in applied computer science and artificial intelligence in the multiphysics modelling of materials aims at modelling of multi-damage and failure processes, validated through experimental assessment of local mechanical properties and microstructures. For example, data-driven parametrically-upscaled constitutive models with machine learning and uncertainty quantification are a novel idea which proposes a parametric representation of lower-scale microstructural descriptors expressed as functions of representative aggregate microstructure parameters including data information about microstructural morphology and crystallography. The application of a machine learning tool is utilized for the generation of constitutive descriptors. Moreover, recently proposed non-local data-driven models for green ACs with particular emphasis on the derivation of the formulation of non-classical models for materials continua and the description of the necessary algorithms and procedures adopted to develop the proposed multiscale model.

Furthermore, innovative multiscale modelling strategies applied to the study of ACs under static and fatigue loading to crack initiation on atomistic and microstructural length scales as well as macroscopic final failure using scale-appropriate methods will be also of interest for the course, to compare these approaches with experimental results for many practical cases. The course also covers recent developments in the modelling of complex materials as non-local continua obtained through the adoption of multiscale approaches.

PRELIMINARY SUGGESTED READINGS

Sadowski T., Trovalusci P. (Eds), (2014): Multiscale Modelling of Complex Materials, CISM Courses and Lectures No. 403, International Centre for Mechanical Sciences, Wien NewYork. Springer, Vol. 556.

Ghosh S., Machine learning-enabled parametrically upscaled constitutive models for bridging length scales in Ti and Ni alloys, in Innovative Lightweight and High-Strength Alloys, Mohammed A. Zikry: (editor), Elsevier, May 2024.

Weber G., Pinz M. and Ghosh S., Machine learning-enabled self-consistent parametrically-upscaled crystal plasticity model for Ni-based superalloys, Computer Methods in Applied Mechanics and Engineering, Vol. 402, Art. 115384, December 2022.

Trovalusci P., Pau A., Derivation of microstructured continua from lattice systems via principle of virtual works. The case of masonry-like materials as micropolar, second gradient and classical continua. Acta Mechanica, 225 (1), 157-177, 2014.

Tuna, M., Trovalusci, P. (2020), Scale-dependent continuum approaches for discontinuous assemblies: "explicit" and "implicit" non-local models, Mechanics Research Communications, 103, 103461.

Xu, Y., Kuang, Z., Yang, J., Huang, Q., Huang, W., Hu, H., 2024. Quantum computing enhanced distance-minimizing data-driven computational mechanics, Computer Methods in Applied Mechanics and Engineering 419, 116675.

Yang, J., Huang, W., Huang, Q., Hu, H., 2022. An investigation on the coupling of data-driven computing and model-driven computing. Computer Methods in Applied Mechanics and Engineering 393, 114798.

Postek E., Sadowski T. Impact model of the Al 2 O 3 /ZrO 2 composite by peridynamics. Compos. Struct. 2021, 271, 114071.

Schmauder, S., Schäfer, I., Eds. (2016), Multiscale Materials Modeling: Approaches to Full Multiscaling, Berlin, Boston: De Gruyter.

LECTURES

All lectures will be given in English. Lecture notes can be downloaded from the CISM web site. Instructions will be sent to accepted participants.

INVITED LECTURERS

Somnath Ghosh - Johns Hopkins University Baltimore, Maryland, USA
5 lectures on: Data-Driven Parametrically-Upscaled Constitutive Models (PUCM) with Machine Learning and Uncertainty Quantification for Multiscale Modeling of Fatigue and Damage in Metals and Composites.
The Parametrically-Upscaled Constitutive Models incorporate a parametric representation of lower-scale microstructural descriptors in higher-scale constitutive coefficients.

Nicholas Fantuzzi - University of Bologna, Italy
5 lectures on: Non-local data-driven Modelling for Advanced Green Materials.
Application of non-local modelling strategies in non-classical continua by considering industrial applications for advanced green and sustainable materials in civil, mechanical and biomedical engineering will be discussed.

Heng Hu - Ningxia University/Wuhan University, China
5 lectures on: Data-driven Computational Mechanics for Composite Materials and Structures.
The lectures cover constitutive data generation techniques, quantum computing enhanced data-driven algorithms and data-model-coupling techniques.

Tomasz Sadowski - Lublin University of Technology, Poland
5 lectures on: Modelling and Experimental Assessment of Multi-Damage Processes and Fracture of Ceramic and Metal-based Composites.
The lectures cover a description of (1) experimental assessment of local mechanical properties by micro-indentation, (2) modelling with a triple-scale approach starting from the atomistic description.

Siegfried Schmauder - University of Stuttgart, Germany
5 lectures on: Multiscale and Multiphysics Modeling of Materials Behaviour.
Content: (1) Introduction to multiscale and multiphysics modelling, (2) Introduction to an atomistic approach by applying atomistic Monte Carlo simulations, (3) Micromechanical Modelling of Complex microstructures, and (4) Meso, Macro and Damage Mechanics.

Patrizia Trovalusci - Sapienza University of Rome, Italy
5 lectures on: Multiscale approaches for the modelling of complex materials as discrete-to size dependent non-local continua.
Derivation of macroscopic constitutive laws for non-classical continua (micromorphic, etc.), i.e. non-local models with internal length and dispersive properties, by defining direct links with lattice systems.