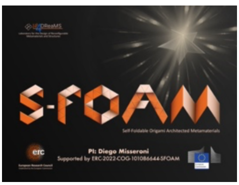
University of Trento- Italy
Department of Civil, Environmental
and Mechanical Engineering

WORKSHOP ON ORIGAMI METAMATERIALS AND ARCHITECTED MATERIALS FOR INNOVATIVE ENGINEERING SOLUTIONS

Trento, January 16, 2024 - DICAM

WORKSHOP PROGRAM
and
BOOK OF ABSTRACTS

Room 2R, 14.30



ERC-CoG *"SFOAM - Self-Foldable Origami-Architected Metamaterials"*
(ERC-2022-COG-101086644-SFOAM, **PI: Diego Misseroni**)
ERC-AdG *"BEYOND - Beyond hyperelasticity: a virgin land of extreme materials"*
(ERC-ADG-2021-101052956-BEYOND, **PI: Davide Bigoni**)

Workshop Venue

The venue is the Department of Civil and Environmental Engineering, located at Via Mesiano 77, Trento:

- The scientific sessions will take place in the 2R room on the second floor.
- The working dinner will be held at Villa Madruzzo restaurant, situated at Via Ponte Alto 28, 38121 Cognola, Trento.

Speakers

- Anna Pandolfi | *Politecnico di Milano, Italy*
- Alessandro Reali | *Università degli Studi di Pavia, Italy*
- Simone Morganti | *Università degli Studi di Pavia, Italy*
- Alessio Gizzi | University of Rome "Campus Bio-Medico", Italy
- Daniele Bianchi | University of Rome "Campus Bio-Medico", Italy
- Roque Pitangueira| *Federal University of Minas Gerais, Brasil*
- João Pedro C. V. Norenberg|Unesp - Câmpus de Ilha Solteira, Brasil
- Diego Misseroni | *University of Trento, Italy*
- Davide Bigoni | *University of Trento, Italy*

Local Organizing Committee

- Davide Bigoni
- Luca Deseri
- Diego Misseroni

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Tuesday January 16, 2024	
14:20 – 14:30	**Opening Prof. Deseri, Prof. Bigoni, Prof. Misseroni**
14:30 - 15:50	**SESSION 1 (Chair: Prof. Deseri)**
14:30 – 15:10	Anna Pandolfi **Modelling fracture and failure with eigenerosion**
15:10 – 15:50	Alessandro Reali **Some advances and applications in isogeometric analysis of coupled and complex problems**
15:50 – 16:10	*Coffee break*
16:10 - 17:50	**SESSION 2 (Chair: Prof. Bigoni)**
16:10 – 16:30	Simone Morganti **Mixed isogeometric collocation methods with application to cardiac electromechanics**
16:30 – 16:50	Alessio Gizzi **Constitutive formulation of fiber-distributed homogenized constrained mixtures**
16:50 – 17:10	Daniele Bianchi **Topological optimization in additive manufacturing: integration of numerical homogenization and finite element analysis**
17:10 – 17:30	Roque Pitangueira **FEM-SPIM coupling for modeling quasi-brittle material**
17:30 – 17:50	João Pedro C. V. Norenberg **Sensitivity and uncertainty analysis of bistable vibration energy harvesters**
17:50 – 18:00	*10 minutes break*
18:00 - 19:00	**SESSION 3 (Chair: Prof. Pugno)**
18:00 – 18:20	Diego Misseroni **ERC CoG Self-foldable origami-architected metamaterials: kick-off meeting**
18:20 – 18:40	Davide Bigoni **ERC AdG Beyond hyperelasticity: one year after the beginning, perspectives and challenges**
18:40 – 19:00	**Closing**
20:00 – 22:00	*Working dinner*

Modelling fracture with eigenerosion

A. Pandolfi[1]

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The numerical simulation of complex physical phenomena requires efficient and robust algorithms which can be implemented in multiple processor computers. Examples of hard problems are propagation of fractures. In such cases, major complications derive from the necessity to keep track of evolving boundaries. In the finite element framework, the evolution of the boundaries requires the use of ad hoc techniques to modify adaptively the spatial discretization of the bodies, i.e., mesh adaptation.

In view of subsiding numerical difficulties related to the spatial discretization of volumes, alternative algorithms, in some cases based on brilliant concepts, have been proposed. Meshfree methods represent a particular class of numerical algorithms that do not rely on the definition of a grid, but, in contrast, use the geometry of the simulated object for calculations. They may facilitate the simulation of increasingly demanding problems treating nonlinear material behavior, complex geometry, discontinuities, singularities, and so on. As alternative to the finite element method, meshfree methods are attractive regarding the process of discretizing volumes in meshes, which in most cases is avoided.

We present the static version of a meshless method for the simulation of explicit crack propagation in brittle materials. The method relies on the discretization of the system into a finite number of elements or particles, representative of the surrounding material. In the spirit of element erosion procedures, the propagation of cracks is modeled by removing material elements or particles upon the attainment of a fracture criterion. The failure criterion adopted here is based on energetic arguments and relies on the neighborhood construction for capturing locally the degeneration of the material.

References:

[1] A. Pandolfi, B. Li, and M. Ortiz. Modeling fracture with material-point erosion. *International Journal of Fracture*, 184, (2013), 3–16.

[2] A. Pandolfi, B. Li, and M. Ortiz. Modeling fracture with material-point erosion. *International Journal of Fracture*, 184, (2013), 3–16.

[3] A. Pandolfi, K. Weinberg, and M. Ortiz. A comparative accuracy and convergence study of eigenerosion and phase-field models of fracture. *Computer Methods in Applied Mechanics and Engineering*, 386, (2021), 1–15.

Some advances and applications in isogeometric analysis of coupled and complex problems

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Isogeometric Analysis (IGA) is a successful simulation framework originally proposed by T.J.R. Hughes et al., in 2005, with the aim of bridging Computational Mechanics and Computer Aided Design. In addition to this, thanks to the high-regularity properties of its basis functions, IGA has shown a better accuracy per degree-of-freedom and an enhanced robustness with respect to standard finite elements in many applications - ranging from solids and structures to fluids, as well as to different kinds of coupled problems - opening also the door for the approximation in primal form of higher-order partial differential equations.

After a concise introduction of the basic isogeometric concepts, this lecture aims at presenting an overview of some recent advances in IGA with a special focus on coupled problems where the characteristics of IGA seem to be of great advantage. In particular, applications that will be discussed include the simulation of fluid-structure interaction in different contexts like, e.g., biomechanical problems, studies on the effect of mechanically-induced stresses on prostate cancer growth, thermo-mechanical simulations of additive manufacturing processes, electro-mechanical simulations for biological tissues, and the use of phase-field modeling for fracture and topology optimization problems or for predicting the polarization evolution in elastic ferroelectric materials.

Mixed isogeometric collocation methods with application to cardiac electromechanics

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We first investigate primal and mixed u-p isogeometric collocation methods for application to nearly-incompressible isotropic elasticity. As benchmarks for what might be considered acceptable accuracy, we employ constant-pressure Abaqus finite elements that are widely used in engineering applications. As a basis of comparisons, we present results for compressible elasticity. The performance of the proposed methods will be evaluated on benchmark problems. Small deformations will be initially considered, but also an extension to large deformations will be introduced.

We also present the isogeometric collocation formulation – which is more cost-effective than the standard Galerkin approach – for solving complex and computationally expensive coupled electromechanical problems. The collocation scheme for electrophysiology enables a fast and simple discretization of the monodomain equation and it is directly applicable to clinically relevant scenarios, such as a tissue composed by different types of cells. Moreover, the approach can be coupled with the mechanics to perform electromechanical simulations and, since the characteristic length of the two problems are well distinct, two different meshes are employed to achieve a greater computational performance. We also introduce an immersed scheme based on the hybrid collocation approach and the finite cell method to handle complex geometries in the collocation framework.

Constitutive formulation of fiber-distributed homogenized constrained mixtures

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The orientation distribution of the reinforcing fibers in active tissues requires micromechanics governing principles. The present contribution generalizes the homogenized constrained mixture theory, proposing a theoretical framework that enables simple analytical solutions that help to understand the evolution of the fiber arrangements under uniaxial loading. The analysis suggests a natural tendency of the fiber distribution to form a peak in the direction of loading and a spread increasing with the ratio of the fiber half-life time and the time constant governing loading-related fiber production. A considerable history-dependence of the fiber distribution evolution is further observed, explaining why considerably different orientation distributions are experimentally measured.

Topological optimization in additive manufacturing: integration of numerical homogenization and finite element analysis

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In recent years, there has been significant progress in the development of innovative materials designed to replicate the lightweight and robust characteristics observed in biological structures such as bones, honeycombs, sponges, and wood. These materials are characterized by a porous microstructure that alternates between solid and void. Concurrently, advancements in manufacturing techniques, particularly 3D printing, have revolutionized the production of cellular materials across various sectors, notably in healthcare.

However, the efficiency of 3D printing manufacturing is influenced by factors such as the type of material (e.g., rigid or flexible), infill pattern, and printing parameters, potentially leading to prolonged production times. This seminar will present a simple case study where a computational tool has been developed, integrating numerical homogenization and topological optimization implemented in ANSYS Mechanical. The aim is to explore the impact of different infill patterns on the mechanical performance of 3D-printed flexible orthotics.

Specifically, computational homogenization has been employed to simulate the mechanical properties of various infill patterns. Different infills have been scrutinized in terms of mechanical properties and printing performance (e.g., speed and accuracy). The determined constitutive properties have been applied to the computational geometry, and diverse loading scenarios have been analyzed under working conditions.

Using the outcomes of these structural simulations, several topology optimization analyses have been conducted with the goal of minimizing the compliance of the frontal region of the insole while reducing its mass below a specified threshold. This study aims to identify a mass distribution that minimizes material usage and printing time, while maintaining an acceptable structural response. Furthermore, the computational approach not only streamlines the printing process by optimizing material distribution in the final object but also serves as a valuable computational tool for enhancing the effectiveness of 3D printing manufacturing in production optimization.

FEM-SPIM coupling for modeling quasi-brittle materials

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The lecture presents an adaptive coupling between Smoothed Point Interpolation Methods (SPIMs) and the Finite Element Method (FEM) for modeling quasi-brittle material. The nonlinear behaviour can be represented by scalar damage, smeared crack or phase-field models. In the adaptive approach, the domain is initially discretised with a relatively coarse FEM mesh and, during the solution process, FEM patches are replaced by meshless discretisations according to certain selection criteria. Refinement is also considered. The coupling is illustrated by some relevant simulations.

Sensitivity and uncertainty analysis of bistable vibration energy harvesters

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This presentation is about the conversion of vibrational energy into electricity, focusing on the challenges of nonlinear energy harvesters. While linear devices exhibit dynamic simplicity, they face limitations in output power at frequencies distant from the natural frequency. Nonlinear energy harvesters offer a solution by expanding the frequency bandwidth but have dynamic complexity and high sensitivity to perturbations. This research investigates the impact of variability in physical parameters on nonlinear bistable energy harvesters, aiming to enhance the understanding of their performance under diverse conditions and find alternatives to boost electrical generation.