# LIGHTEN

**Ultralight membrane structures towards a sustainable environment**

H2020-MSCA-ITN ♦ ITN - Innovative Training Network ♦ EID - European Industrial Doctorates

Second Training School

# Computational mechanics and data-driven design of materials and structures

2 – 3 – 4 May 2022

DICAM, University of Trento (Italy) and online via Zoom

| Time (CEST) | Monday 5/2/22 | Tuesday 5/3/22 | Wednesday 5/4/22 |
|---|---|---|---|
| 9.00 – 10.30 | Introduction to yield surface theory (F. Dal Corso - UNITN) | User material subroutines and yield surfaces implementation (M. Penasa - CAEmate) | Introduction to supervised learning with Gaussian Processes and Artificial Neural Networks (M. Bessa - TU Delft) |
| 10.30 – 11.00 | Coffee break | | |
| 11.00 – 12.30 | Introduction to yield surface theory (F. Dal Corso - UNITN) | User material subroutines and yield surfaces implementation (M. Penasa - CAEmate) | Introduction to Bayesian optimization (M. Bessa - TU Delft) |
| 12.30 – 14.00 | Lunch break | | |
| 14.00 – 15.30 | Introduction to Object Oriented Programming (M. Penasa - CAEmate) | Linear and nonlinear viscoelasticity implementation (F. Bosi - UCL) | Introduction to Unsupervised Learning with k-means clustering for the SCA (M. Bessa - TU Delft) |
| 15.30 – 16.00 | Coffee break | | |
| 16.00 – 17.30 | Introduction to Object Oriented Programming (M. Penasa - CAEmate) | Linear and nonlinear viscoelasticity implementation (F. Bosi - UCL) | Introduction to the data-driven framework (M. Bessa - TU Delft) |
| | Working dinner | | |

Registrations requests should be sent by April 27 to: lighten.project@ucl.ac.uk

Organised by:

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## Monday 5/2/22 | 9.00 – 10.30 and 11.00 – 12.30 CEST

**Introduction to yield surface theory**
by *Francesco Dal Corso* – University of Trento

An overview will be given on the main theoretical aspects of yield surfaces, with particular reference to:

- Haigh-Westergaard representation
- Criteria for ductile materials
- Criteria for fragile materials

Remarks will be also given on yield surfaces for anisotropic and viscoelastic polymeric membranes.

Reference:


- D. Bigoni (2012). *Nonlinear Solid Mechanics: Bifurcation Theory and Material Instability*. Cambridge University Press.
- Bosi, F., Pellegrino, S. (2017). Molecular based temperature and strain rate dependent yield criterion for anisotropic elastomeric thin films. *Polymer* 125, 144-153


After earning a PhD in Materials and Structural Engineering at the University of Trento, Italy, Francesco Dal Corso won a postdoctoral fellowship at the Department of Applied Mathematics and Theoretical Physics, University of Cambridge. He is currently an Associate Professor of Solid and Structural Mechanics at the University of Trento. His research activity is devoted to the Mechanical behaviour of Solid and Structures. He has co-authored over 40 journal papers and has co-guest edited a Special Issue of the Journal of the Mechanics and Physics of Solids in 2020.

## Monday 5/2/22 | 14.00 – 15.30 and 16.00 – 17.30 CEST

**Introduction to Object Oriented Programming**
by *Massimo Penasa* – CAEmate srl

An overview of Object Oriented Programming and its application to engineering problems will be given.

- Introduction to programming for engineering applications
- Data structures in Python
- Exercises and examples implementation (tests)

The ESRs are required to bring a laptop computer with Jupyter installed on it, be prepared on Python syntax (tutorial1, tutorial2, tutorial3)

Dr Massimo Penasa is co-founder and director of CAEmate SRL, an innovative software company focused on the development of the cloud-based platform WeStatiX for structural design, engineering workflow automation and structural health monitoring. He has wide experience as structural designer and project manager in international infrastructure projects. He is also a lecturer for international engineering chambers and for the courses of Computational Mechanics at the University of Trento. Dr Penasa has been responsible for tutoring a number of University students during his doctorate programme, together with teaching activities and scientific advisory.


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## Tuesday 5/3/22 | 9.00 – 10.30 and 11.00 – 12.30 CEST

**User material subroutines and yield surfaces implementation**

by *Massimo Penasa* – CAEmate srl

A practical overview of the implementation of User Material Subroutines and their use in FE solvers will be given.

- Nonlinearities in FEA and integration of user materials
- UMAT examples, introduction to FORTRAN interface for Abaqus, UMAT linking
- Exercises and simulation examples with Abaqus (tests)

The ESRs are required to bring a laptop computer with Abaqus installed on it and enabled for compiling UMATs (Fortran Compiler is required)

Dr Massimo Penasa is co-founder and director of CAEmate SRL, an innovative software company focused on the development of the cloud-based platform WeStatiX for structural design, engineering workflow automation and structural health monitoring. He has wide experience as structural designer and project manager in international infrastructure projects. He is also a lecturer for international engineering chambers and for the courses of Computational Mechanics at the University of Trento. Dr Penasa has been responsible for tutoring a number of University students during his doctorate programme, together with teaching activities and scientific advisory.

## Tuesday 5/3/22 | 14.00 – 15.30 and 16.00 – 17.30 CEST

**Linear and nonlinear viscoelasticity implementation**

by *Federico Bosi* – UCL

The lectures will cover the main computational aspects of engineering viscoelasticity, with a focus on the implementation of linear and nonlinear constitutive modelling of viscoelastic materials.

Covered topics include:

- Numerical implementation of linear viscoelasticity
- Recursive Integration Algorithm for linear and nonlinear viscoelasticity
- Examples of numerical implementation for linear and nonlinear viscoelasticity
- Application to a nonlinear thermo-viscoelastic constitutive modelling for NASA Superpressure Balloons

Federico Bosi is an Associate Professor in the Department of Mechanical Engineering at UCL. Prior to joining in 2017, he was a postdoctoral scholar (2015-2017) in the Space Structure Laboratory at the California Institute of Technology, USA. He earned his PhD degree (2014) in Engineering of Civil and Mechanical Structural Systems from the University of Trento, where he was a Marie Curie Early Stage Researcher in the Solid and Structural Mechanics Group. His research activity is devoted to studying the mechanics of solids and structures, with a particular interest in the nonlinear, time-dependent, and thermo-mechanical response of highly deformable materials and flexible mechanical systems.

References:


- Taylor, R., Pister, K., Goudreau, G., 1970. Thermomechanical analysis of viscoelastic solids. *Int. J. Numer. Meth. Eng.* 2, 45-59.
- Lai, J., Bakker, A., 1996. 3-d schapery representation for nonlinear viscoelasticity and finite element implementation. *Comput. Mech.* 18, 182-191.
- Bosi, F., Pellegrino, S. (2018). Nonlinear thermomechanical response and constitutive modeling of viscoelastic polyethylene membranes. *Mech. Mat.,* 117, 9-21.



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## Wednesday 5/4/22 | 9.00 – 10.30 CEST

**Introduction to supervised learning with Gaussian Processes and Artificial Neural Networks**
by *Miguel Bessa* – TU Delft

This lecture will provide a short introduction to supervised learning following by condensing the following lectures:
https://github.com/bessagroup/3dasm_course

Covered topics include:

- 1D and 2D regression with Gaussian Processes
- 1D and 2D regression with Artificial Neural Networks
- Assessment via common error metrics

Reference: Murphy, Kevin P. Probabilistic machine learning: an introduction. MIT press, 2022. Available online here:
https://probml.github.io/pml-book/book1.html

Miguel Bessa is an Associate Professor in the Materials Science and Engineering Department at Delft University of Technology. He is also the director of an inter-faculty Artificial Intelligence lab called MACHINA, dedicated to machine intelligence advances for materials design. In addition, he was the recipient of a Veni personal grant (2019). Prior to coming to the Netherlands, he was a postdoc scholar in Aerospace at the California Institute of Technology (2017), and received his PhD (2016) in MechEng at Northwestern University as a Fulbright scholar. He has 25 publications and envisions a new era in relation to the design of materials and structures through AI.

## Wednesday 5/4/22 | 11.00 – 12.30 CEST

**Introduction to Bayesian optimization**
by *Miguel Bessa* – TU Delft

This lecture will provide a short introduction to Bayesian optimization following the GpyOpt library.

Covered topics include:

- Algorithmic introduction
- Tutorial with practical implementation
- Assessment on different benchmark functions

Reference: Murphy, Kevin P. Probabilistic machine learning: an introduction. MIT press, 2022. Available online here:
https://probml.github.io/pml-book/book1.html

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## Wednesday 5/4/22 | 14.00 – 15.30 CEST

**Introduction to Unsupervised Learning with k-means clustering for the SCA**
by *Miguel Bessa* – TU Delft

This lecture will provide a short introduction to unsupervised learning with k-means clustering by applying the algorithm to create Representative Volume Elements of materials as needed for the Self-consistent Clustering Analysis (SCA) method. A brief introduction to the SCA is also provided.

Covered topics include:

- K-means clustering algorithm
- Assessment via common error metrics
- SCA introduction

Reference: Murphy, Kevin P. Probabilistic machine learning: an introduction. MIT press, 2022. Available online here: https://probml.github.io/pml-book/book1.html

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## Wednesday 5/4/22 | 16.00 – 17.30 CEST

**Introduction to the data-driven framework**
by *Miguel Bessa* – TU Delft

This lecture will provide an overview of the full data-driven process.

Covered topics include:

- Design of Experiments
- Automated simulations
- Machine learning
- Optimization

Reference: Bessa, Miguel A., et al. "A framework for data-driven analysis of materials under uncertainty: Countering the curse of dimensionality." Computer Methods in Applied Mechanics and Engineering 320 (2017): 633-667.

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