Marco Moscatelli, PhD
Curriculum Vitae et Studiorum

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Contents

1 . Research Experience

- 09/2024 – on going. **Assistant Professor (maître des conférences)**. MISES group - Insitut Jean le Rond d'Alembert at Sorbonne University (France).

- 01/2022 – 08/2024. **Post-Doctoral Researcher**. DICA - Politecnico di Milano (Italy).
  - Developed and implemented analytical methods and finite element codes with new constitutive models, for the simulation of the thermo-mechanical behavior of textile reinforcements made up of synthetic fibers, typically used in tyres. Project in collaboration with Pirelli Tyre Spa.
  - Guided an experimental campaign for the identification of the thermo-mechanical behavior of yarns and cords used in tyres.
  - Investigated and modelled the behavior of architectured structural elements to explore new phenomena such as wave attenuation, wave localization and topological band gaps.

- 10/2018 – 04/2022. **Doctoral Researcher**. École polytechnique (France) and Politecnico di Milano (Italy).
  - Developed homogenization techniques to efficiently model the dynamic behavior of composite materials by means of finite element analyses and analytical methods.
  - Designed and studied a system for harvesting the mechanical energy carried by environmental vibrations, exploiting metamaterials.
  - Designed an experimental setup and conducted experimental tests for the validation of the theoretical results.

2 . Education

- 10/2018 – 04/2022. **Ph.D. in Structural Mechanics**. Cotutelle between École polytechnique (France) and Politecnico di Milano (Italy).
  Thesis : Metamaterials for energy harvesting at small scale.
  - Conducted the doctoral research in each of the two hosting research units.
  - Thesis defended in France.

- 10/2015 – 07/2018. **M.Sc. in Civil (Structural) Engineering**. Politecnico di Milano (Italy).
  Thesis : Locally resonant materials: wave propagation analyses and application to impact absorbers.
  Period abroad : 01/2016 – 07/2016, Royal Institute of Technology, KTH (Stockholm, Sweden), exchange program.

- 09/2012 – 09/2015. **B.Sc. in Civil and Environmental Engineering**. Politecnico di Milano (Italy).
  Thesis : Simplified analysis of the structural behavior of the Palazzetto dello Sport of Rome.

3 . Awards

- 04/2023. **IP Paris Department Best PhD Thesis Award.**
  Department of Mechanics and Energetics. Prize : 3000 €.

4 . Languages

- **Italian**. Mother tongue.
- **English**. Proficient.
- **French**. Proficient.

5 . Technical Skills

- **Programming**. Matlab, Fortran, Python, Freefem++, Wolfram Mathematica.
- **Simulation**. Abaqus FEA, Comsol Multiphysics, Sap2000, Gmsh.
- **Productivity**. Git, LaTeX, Office package, Autocad.

6 . Conferences & Workshops

- July 10-12, 2024. **GIMC SIMAI YOUNG 2024**. Naples (Italy).
- May 7-9, 2024. Invited speaker to **Euromech Colloquium 649**. Metamaterials and Architected Materials for Novel Energy Harvesting Solutions, London (UK).
- Jun 28, 2023. **Seminar CS4 - DICA**. Building the energy transition through the technologies of environmental and civil engineering, Milan (Italy).
- Oct 5, 2022. **Workshop at Pirelli**. Workshop of the researchers - Jointlabs, Milan (Italy).
- Sep 4-8, 2022. **XXV Aimeta Congress 2022**. Palermo (Italy).
- Jun 6-9, 2022. **ECCOMAS Congress 2022**. Oslo (Norway).
- Aug 22-27, 2021. **Ictam Congress 2020+1**. Milan (Italy).
- Sep 15-19, 2019. **XXIV Aimeta Congress 2019**. Rome (Italy).

7 . Extra-Curricular Courses

- Jul 1-5, 2019. Thematic school "Metagenierie 2019 : Principles and engineering applications of acoustic metamaterials" (Olèron, France).
- Aug 20-30, 2019. Thematic school "Wave propagation in complex and microstructured media" (Cargèse, France).

8 . Mentoring Activities

- Gen 2024 – on going. Luigia Saraceni (Politecnico di Milano), Constitutive modelling and simulation of textile reinforcements (Master), with C. Comi.
- Feb 2021 – Jul 2021. Enzo Tosoni (Politecnico di Milano), Modelling and simulation of impacts absorbing metamaterials, with C. Comi, A. Corigliano, R. Ardito.

9 . Publications

Theses

1. Marco Moscatelli. Metamaterials for energy harvesting at small scale. PhD thesis, Institut Polytechnique de Paris, Politecnico di Milano, 2022. `https://theses.hal.science/tel-03714470`
2. Marco Moscatelli. Locally resonant materials : wave propagation analyses and application to impact absorbers. Ms. Thesis., Politecnico di Milano, 2018. `http://hdl.handle.net/10589/141566`

Articles published or accepted in indexed journals

1. M. Moscatelli, C. Comi, J.-J. Marigo, Wave transmission in quasi-periodic lattices, Philosophical Transactions of the Royal Society A, 2024. `https://doi.org/10.1098/rsta.2023.0351`.
2. M. Moscatelli, C. Comi, J.-J. Marigo, Taut cables with hanging masses: a metamaterial-like dynamic behavior, European Journal of Mechanics / A Solids, 2024. `https://doi.org/10.1016/j.euromechsol.2024.105330`
3. M. Moscatelli, L. Pires da Costa, P. Caracino, S. Agresti, G. Novati, C. Comi, Elasto-viscoplastic model for rayon yarns, Meccanica, 2024. `https://doi.org/10.1007/s11012-024-01785-3`
4. M. Moscatelli, C. Comi, and J.-J. Marigo. On the dynamic behaviour of discrete metamaterials: From attenuation to energy localization. Wave Motion, 104:102733, 2021. `https://doi.org/10.1016/j.wavemoti.2021.102733`
5. M. Moscatelli, C. Comi, and J.-J. Marigo. Energy Localization through Locally Resonant Materials. Materials, 13(13):3016, 2020. `https://doi.org/10.3390/ma13133016`
6. C. Comi, M. Moscatelli, J.-J. Marigo. Two scale homogenization in ternary locally resonant metamaterials. Materials Physics and Mechanics, 44:8–18, 2019. `https://mpm.spbstu.ru/article/2020.75.2/`
7. M. Moscatelli, R. Ardito, L. Driemeier, and C. Comi. Band-gap structure in two- and three-dimensional cellular locally resonant materials. Journal of Sound and Vibration, 454:73–84, 2019. `https://doi.org/10.1016/j.jsv.2019.04.027`

Inbook

1. C. Comi, D. Faraci, M. Moscatelli, J.-J. Marigo. The Role of Homogenization in Metamaterials Analysis. In: Bittencourt, M., Labaki, J. (eds) Proceedings of the 8th International Symposium on Solid Mechanics. MECSOL 2022. Lecture Notes in Mechanical Engineering. Springer, Cham. `https://doi.org/10.1007/978-3-031-59804-3_15`

Conference proceedings

1. M. Moscatelli, C. Comi, J.-J. Marigo, Attenuation and localization of waves in taut cables with suspended masses, in: eccomas2022. `https://www.scipedia.com/public/Moscatelli_et_al_2022a`

2. M. Moscatelli, C. Comi, J.-J. Marigo, One-dimensional metastructures composed of cables with scatter masses: waves, vibrations and band gaps, in: AIMETA2022. `https://doi.org/10.21741/9781644902431-85`

3. C. Comi, D. Faraci, M. Moscatelli, J.-J. Marigo, Homogenization and metamaterials: an effective alliance, in: MECSOL2022. `https://re.public.polimi.it/handle/11311/1229811`

4. M. Moscatelli, C. Comi, J.-J. Marigo, Locally Resonant Materials for Energy Harvesting at Small Scale, in: AIMETA2019. `https://doi.org/10.1007/978-3-030-41057-5_50`

10 . Teaching Activities

Teaching experience

- From 2024 to present. **Sorbonne Université and Polytech Sorbonne** (total hours : 130) :
  - LU2ME001 - Mécanique des solides rigides (taught in French).
    Type : TD/contrôle final.
    Level : Licence.
    Hours : 26.
    Number of students : 31
  - LU3ME103 - Vibrations, équilibre et stabilité (taught in French).
    Type : TD/contrôle final.
    Level : Licence.
    Hours : 26.
    Number of students : 31
  - MU4MEM14 - Mécanique des Milieux Continus (taught in French).
    Type : TD/contrôle final.
    Level : Master.
    Hours : 14.
    Number of students : 22
  - EPU-G8-AEF - Éléments finis (taught in French).
    Type : TP/TD/contrôle final.

Level : Master.
Hours : 64.
Number of students : 26

- From 2019 to 2024. **Politecnico di Milano** (total hours : 250.5) :
  - 2023 – 2024. **Theory of plasticity** (taught in English).
    Type : TP/TD/contrôle final.
    Level : M.Sc. Civil Engineering for Risk Mitigation.
    Hours : 29.
    Number of students : 66
  - 2023 – 2024. **Scientific and technical communication** (taught in English).
    Type : TP/tutorat/contrôle continu.
    Level : M.Sc. Civil Engineering.
    Hours : 8.
    Number of students : 77
  - 2023 – 2024. **Computational mechanics and inelastic structural analysis** (taught in English).
    Type : TP/TD/contrôle final.
    Level : M.Sc. Civil Engineering.
    Hours : 23.5.
    Number of students : 106
  - 2023 – 2024. **Scientific and technical communication** (taught in Italian).
    Type : TP/tutorat/contrôle continu.
    Level : M.Sc. Civil Engineering.
    Hours : 21.
    Number of students : 54
  - 2022 – 2023. **Theory of plasticity** (taught in English).
    Type : TP/TD/contrôle final.
    Level : M.Sc. Civil Engineering for Risk Mitigation.
    Hours : 31.
    Number of students : 66
  - 2022 – 2023. **Scientific and technical communication** (taught in English).
    Type : TP/contrôle continu.
    Level : M.Sc. Civil Engineering.
    Hours : 8.5.
    Number of students : 69
  - 2021 – 2022. **Structural mechanics** (taught in Italian).
    Type : TD/contrôle final.
    Level : B.Sc. Architectural design.
    Hours : 35.5.
    Number of students : 167

- 2021 – 2022. **Scientific and technical communication** (taught in English).
  Type : TP/contrôle continu.
  Level : M.Sc. Civil Engineering.
  Hours : 28.
  Number of students : 58
- 2020 – 2021. **Structural mechanics** (taught in Italian).
  Type : TD/contrôle final.
  Level : B.Sc. Architectural design.
  Hours : 29.
  Number of students : 161
- 2020 – 2021. **Scientific and technical communication** (taught in English).
  Type : TP/contrôle continu.
  Level : M.Sc. Civil Engineering.
  Hours : 21.
  Number of students : 71
- 2019 – 2020. **Structural mechanics** (taught in Italian).
  Type : TD/contrôle final.
  Level : B.Sc. Environmental and land planning engineering.
  Hours : 16.
  Number of students : 188

Courses in details

- **Computational mechanics and inelastic structural analysis**.
  Presentation of the course : This course presents the linear elastic problem for solids and structures, with its variational formulations. The core of the course is about the finite element method and its implementation. The elasto-plastic problem is then presented and used to describe the behaviour of materials and structures. The theory of limit analysis for elasto-plastic continua and structures is finally treated.
  The student at the end of the course is expected to know how to implement the finite element method for linear elastic problems, and the formulation of the elasto-plastic constitutive models for solids and structures. He is also expected to be able to apply the theory of limit analysis for the determination of the collapse load of bi-dimensional elasto-plastic frame structures, and to know the theory of limit states for elasto-plastic bodies and structures subjected to variable and/or repeated loads.
  My contribution to the course : I guide the students in the development and implementation of finite element codes with the software Matlab and Gmsh. I also have the role of presenting and solving exercises on the topics related to the course. The students have to form groups and develop a finite element code on their own to solve some specific problems that I deliver to them at the beginning of the course. I assess the students' knowledge at the end of the course by means of written and oral exams, and evaluating their projects on the finite element method.

- **Theory of plasticity**.
  Presentation of the course : This course aims at presenting in detail the linear elastic problem,

its variational formulations, and the elasto-plastic behaviour for solid continua and structural elements. The theory of limit analysis is then formulated for variable and repeated loads.
The student at the end of the course is expected to know the theory of limit states for elasto-plastic bodies and structures subjected to variable and/or repeated loads, and to be able to apply it for the determination of the collapse load of bi-dimensional elasto-plastic frame structures. He is also asked to know the formulation of an elasto-plastic constitutive model.
My contribution to the course : I present and solve exercises related to the topics faced during the course. I also show how to use the software SAP2000 to carry out a numerical analysis for the determination of the collapse load and displacements of an elasto-plastic frame structure. I assess the students' knowledge at the end of the course by means of written and oral exams.

- **Structural mechanics (Scienza delle costruzioni)**.
  Presentation of the course : This course has the objective to provide the student with the theoretical tools for analysing 2D frame structures, for the computation of local stresses and global forces in a generic section, for the determination of displacements undergone by a structure, for assessing the material resistance, and for the analysis of the equilibrium stability.
  Beyond the theoretical understanding, the student is expected to quantify the properties listed above.
  My contribution to the course : I present and solve exercises related to the topics of the course, aiming at providing the student with a clear understanding of how to carry out the computations of the quantities of interest for analysing a structure or a solid. I assess the students' knowledge at the end of the course by means of written and oral exams.

- **Scientific and technical communication**.
  Presentation of the course : This course aims at helping the student to organize a technical report (addressing in particular the master thesis manuscript) and to provide the essentials for an effective written and oral communication of technical and scientific contents.
  At the end of the course, the student is expected to be able to use the principal scientific databases, building a bibliography for a master thesis, present and visualize technical results in an effective way, deliver technical and scientific presentations, and write a curriculum.
  My contribution to the course : I show the students how to use the main tools offered by the software Matlab to visualize and modify figures, and to deal with imported data. I also teach them how to use the software LaTeX to prepare a thesis.

11 . Research

I focus my efforts in the understanding and modelling of phenomena related to both *theoretical and applied mechanics*. My research interests mainly include *slender structures*, *periodic homogenization*, *constitutive modelling*, and *computational mechanics*.

In particular, on one hand I aspire to answer fundamental problems related to the mechanical behaviour of architectured and heterogeneous materials that may offer novel or unexpected global responses, such as wave attenuation and wave guiding capabilities or localization phenomena. On the other hand, I also look for solutions to more practical problems questioned by industrial collaborators.

Doctoral thesis

I carried out my PhD thesis at the École Polytechnique (in France), in cotutelle with the Politecnico di Milano (in Italy). Together with Jean-Jacques Marigo and Claudia Comi, my first original results were obtained in the field of *metamaterials* and were related to the development and study of localization phenomena for energy harvesting applications.

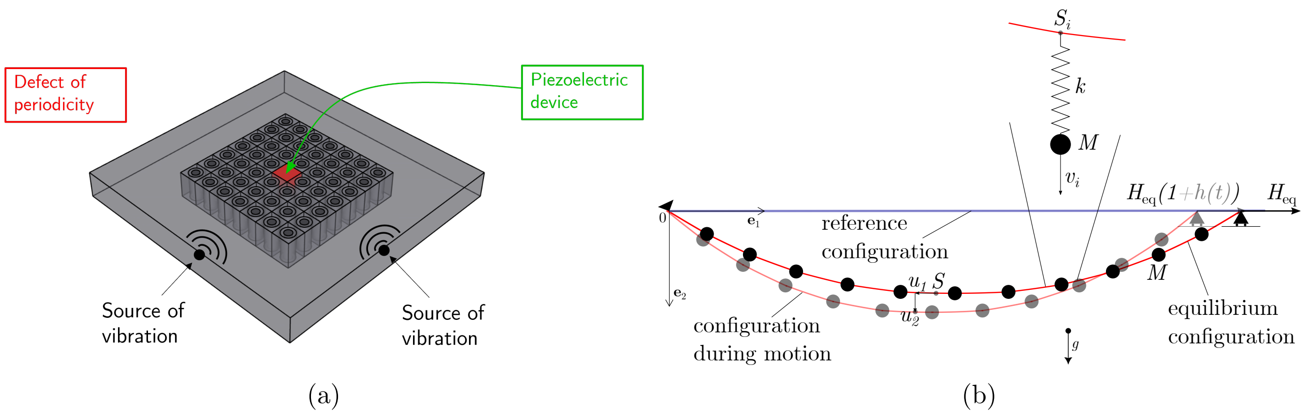


Figure 1: (a) Sketch of a periodic heterogeneous metamaterial with a compact defect. (b) A 1D system composed of a cable pre-tensioned by a force H_{eq}, with periodically distributed point-wise masses M hanging through elastic springs of stiffness k.

My work dealt with problems of wave diffraction in periodic domains with or without the presence of a compact perturbation. Specifically, I was interested in the propagation of classical (mechanical and acoustical) waves in *Locally Resonant Metamaterials* LRMs (see figure 1a), and in the vibrations of *suspended slender structures* (e.g. cables) with a set of point-wise attached, possibly resonating, objects (see figure 1b).

The interest came from the need of optimizing the performances of compact *energy harvesters*. Ambient vibrations are indeed one of the most accessible sources of mechanical energy, that can be exploited for energy harvesting applications. However, vibrations are generally distributed on a broad region, resulting in a great challenge for harvesting devices. Energy can be more easily collected and converted when it is concentrated, and it is less usable when it is spread out. Wave localization can thus play a key role in this framework.

The aforementioned problems involve several scales (such as the global dimension of the domain, the wave length, and the period), therefore many questions regarding their modelling arise.

To efficiently predict the behaviour of LRMs, I developed and applied *periodic homogenization techniques* that were able to predict their peculiar capabilities in terms of wave control and wave focusing. The microstructural local resonances at the level of the unit cells composing the heterogeneous material interact with the propagating wave, activating phenomena of wave attenuation at a sub-wavelength scale. Macroscopically, this behaviour was predicted by deriving the effective elastic stiffness and mass, with the latter being negative at certain intervals of frequencies corresponding to band gaps, i.e. to gaps of frequencies in the essential spectrum of the problem.

Exploiting this peculiar behaviour, I analysed the effect that a compact defect of periodicity can have on the macroscopic response of a LRM. Specifically, I showed that these local perturbations of the periodic domain generate localized eigenmodes that are exponentially decaying away from the defect. These modes can thus be activated by an external vibrations, enabling for the collection of the energy they carry.

With regards to the vibrational behaviour of suspended slender structures, the hanging objects play the role of scattering elements, strongly affecting their dynamics. The problem was approached by making the assumption that the horizontal force H_{eq} in figure 1b is high enough to look at the system as a taut cable, and thus decoupling its transversal motion from the axial one. This enabled for deriving a discrete equation governing the dynamics of the system, whose solutions were propagating or attenuated waves depending on an effective frequency-varying mass.

With this technique, I was able to prove that cables with periodic hanging objects possess band gaps and thus behave as metastructures. These results constitute a novel interpretation of the problem and were also experimentally confirmed (see figure 2 for a picture of the experimental set-up).

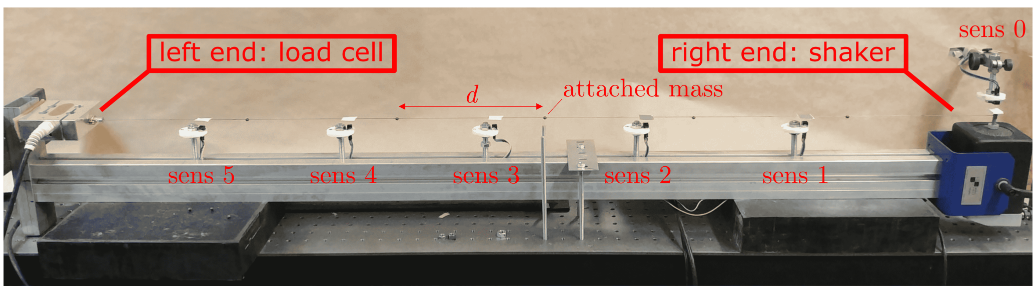


Figure 2: Experimental set-up used to measure the vibrations of a suspended cable with hanging masses.

The theoretical findings described are quite general, in the sense that the equations governing the dynamics of the cable analysed can be used to describe other metastructures, as it is the case for the classical 1D mass-in-mass lattice and the 2D system shown in figure 6, presented in the next subsection. Typically, periodic domains are treated by applying a Bloch-Floquet transform, that is based on periodicity and that considers the domain as unbounded. The strength of the approach followed in my thesis work is the fact that it is not based on Bloch-Floquet's analyses, and can thus be extended to describe structures that may be bounded or unbounded, periodic or quasi-periodic, and that may contain compact defects.

Post-doctoral research

After my PhD, I became a post-doctoral researcher at Politecnico di Milano. The main project I am currently following is about the development of constitutive models for the *simulation of the mechanical behaviour* of the polymeric-based yarns and cords used as reinforcements inside rubber composites, such as in tyres (cf. figure 3).

This work is financed by Pirelli Tyre Spa, and thus guided by their internal needs. Along with myself, the team is composed of two professors (Claudia Comi and Giorgio Novati), two industrial collaborators from the R&D Materials department of Pirelli (Paola Caracino and Simone Agresti),

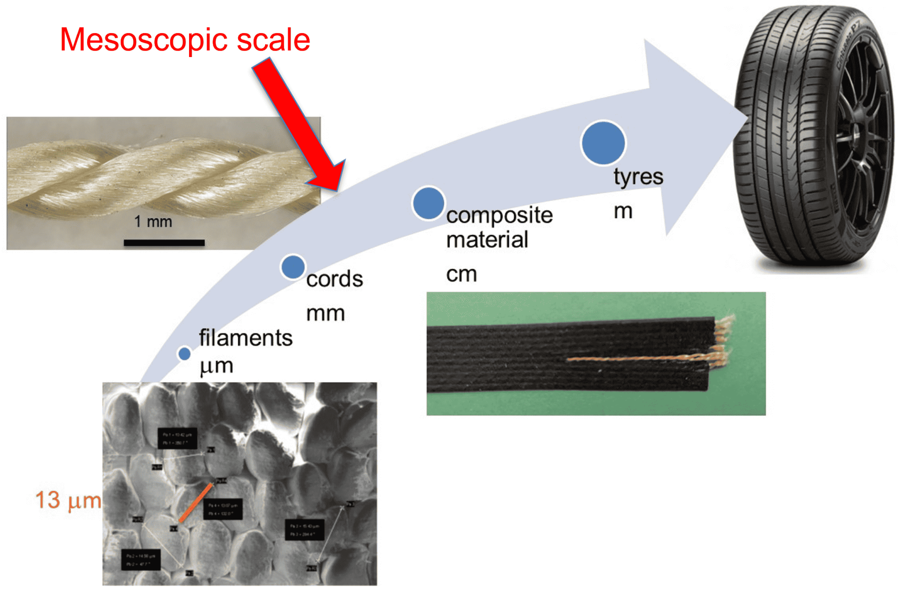
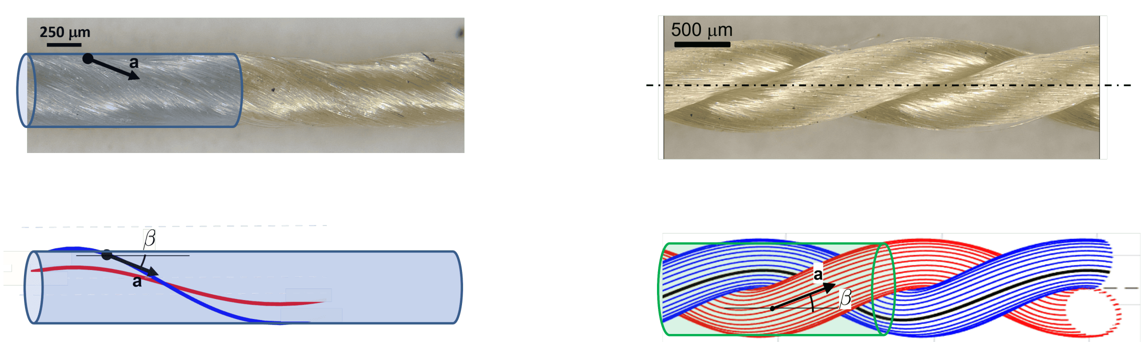


Figure 3: Schematic representation of the scales involved in the project with Pirelli.

two PhD students (Lucas Pires da Costa and Emmanuel Denis Manoni), and two Master students (Luigia Saraceni and Carlo Rossi). In particular, I contribute by exploring and implementing in finite element codes new constitutive models that can be used by Pirelli for predicting the behaviour of the aforementioned reinforcements.



(a) (b)

Figure 4: Microscopic image of (a) a yarn and (b) a cord composed of 2 plies. The unit vector $\boldsymbol{a}$ represents the tangent to a generic fibre, that is inclined of a position-dependent angle β with respect to the longitudinal axis of the yarn/cord. Vector $\boldsymbol{a}$ thus denotes the material direction of the transversely isotropic model.

Polymeric yarns and cords are made up of hundreds of textile filaments (or fibres) twisted together. Typically, yarns (of the same or different filament materials) are twisted together to form cords, also

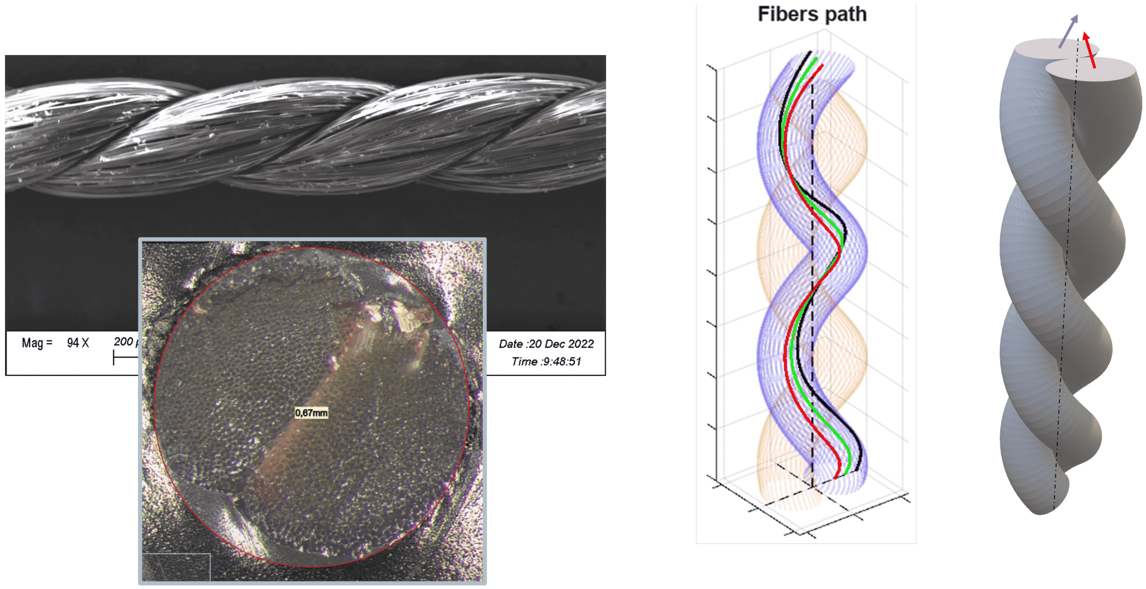


Figure 5: Tomographic images of a two-plies cord (left), geometric modelling of the fibers (center), and continuum representation (right). At each point of the continuum representation, the material direction is obtained from the unit vector locally tangent to the fibre and defined by the geometric model.

known as multi-ply yarns. Microscopic images of a yarn and a cord made up of rayon are shown in figure 4. These 1D structural elements possess high flexural flexibility while having high stiffness and strength in the longitudinal direction. Different scales are involved (see figure 3). The project positions itself at a mesoscopic scale and aims at developing a global three-dimensional model that, starting from the material behaviour at the level of the fibres, and including material inelastic effects together with geometric effects, can effectively predict the behaviour of yarns and cords in different stress conditions. Material inelastic effects are thus integrated with a geometrical modelling of the reinforcement microstructure. The result is a novel *phenomenological material model*, formulated in the framework of the thermodynamics of irreversible processes, for twisted yarns and cords made up of polymeric fibres. More specifically, we treat the textile reinforcements as a continuum, characterized by a *viscoelastic* and *viscoplastic transversely-isotropic* behaviour, with locally defined material directions that depend on the filaments and yarns twist level (see figures 4 and 5). Moreover, to account for the different behaviour of the fibres when loaded in tension and in compression, a bi-modular material behaviour is also considered.

In parallel with the main project, I continue to collaborate with Jean-Jacques Marigo and Claudia Comi on problems related to the realm of metamaterials. Specifically, we are currently interested in modelling and understanding the phenomenon of wave propagation in *quasi-periodic* systems. For this, we consider the 2D lattice shown in figure 6 of continuous and infinite wave guides (horizontal bars) coupled by slender beams that are quasi-periodically distributed. Specifically, we treat the problem of longitudinal waves propagating along the bars.

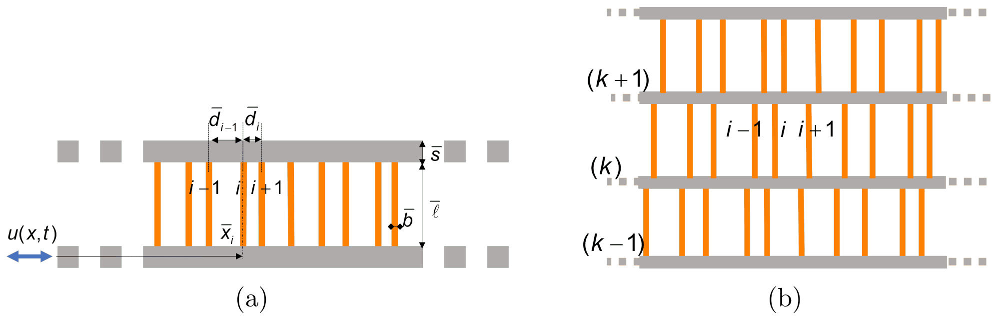


Figure 6: Schematic of quasiperiodic lattices: (a) one dimensional problem of two-bars connected by beams i with quasi-periodic distribution; (b) two dimensional case with parallel bars (k) connected by beams i with quasi-periodic distribution.

By varying the quasi-periodic distribution of the beams, so-called *topological band gaps* may appear and populate the spectrum of the problem. These stop bands are of particular interest for activating topological modes and topological wave guides. In this context, the word "topological" is used to denote the robustness of the phenomena with respect to the presence of defects in the system under consideration. Exploiting some of the results valid for the dynamics of cables with hanging objects, we were again able to reduce the problem to a discrete equation, whose solutions depend on the behaviour of an effective frequency-varying mass.

Perspective research

My research program for the following years will be focused mainly on the topics which were initiated in recent years. Below, starting from what I foresee as the closest open possibilities, these topics are summarized with some details on concrete research questions and applications.

Dynamics of slender structures. Several ideas and preliminary results related to the behaviour of slender structures are waiting to be extended.

As engineering cables are usually lengthy and flexible, their equilibrium configuration is generally far from the reference (or initial) one, and their steady-state vibrations can involve large displacements and are often dominated by geometric non-linearities. This can lead to the activation of a plethora of phenomena, such as hardening or softening at a primary resonance response, secondary and internal resonances, and parametrically excited responses, to name but a few.

Beyond the practical interest, the mechanics of cables systems thus offers an optimal playground for fundamental research on different phenomena in dynamics. Although these structures are among the simplest ones, their dynamic behaviour is indeed very rich. Endowing them with point-wise scattering elements can activate novel behaviours, as it was the case for the the small vibrations of a taut cable. Following this path, preliminary results were recently obtained considering small vibrations around a non-rectilinear equilibrium configuration, i.e. with an initial sag, of a suspended cable with point-wise distributed masses (e.g. as in figure 1b). The initial sag causes a coupling between the longitudinal and transversal motion of the cable and plays the role of a parameter for the problem. Additionally, the coupled behaviour can be strongly influenced by the presence of the scattering elements. Depending on the initial sag, the band structure of the spectrum obtained for a taut cable is modified, with the presence of mode veering phenomena and localized modes. My interest is that of pursue these studies to obtain general properties valid for this type of structures and, more generally, to give a better understanding of the aforementioned phenomena, approaching the problem at increasing complexity and decreasing assumptions.

I also plan to extend the results obtained for 2D elastic lattice structures of the type shown in figure 6. Our approach to the problem of wave propagation in quasi-periodic elastic lattice systems seems to offer a promising path to follow for determining the conditions under which a topological band gap may appear, by looking at what happens when a periodic system asymptotically becomes quasi-periodic. This is of great importance for an optimal design and use of these architectured systems (or *metastructures*) in engineering applications.

Mechanics of fibres reinforced materials. Building constitutive models and finite element codes able to predict the behaviour of fibres reinforced materials is of fundamental importance in different fields of solid mechanics.

In this framework, I envisage to improve and extend the viscoelastic and viscoplastic bi-modular anisotropic material model developed during my latest post-doctoral research in two directions. On one hand, the model is currently developed with the small strain assumption. Accordingly, I want to extend it to account for large strains. On the other hand, I plan to account for the evolution of the fibres. In the case of fibres reinforcements, accounting for large strains is often not enough to give a good prediction of the material behaviour. This is due to the fact that fibres can reorient themselves independently from the deformation of the equivalent continuum. This concept is very similar to the so-called "remodelling" behaviour typically observed in living tissues (such as muscles and bones), for which the internal structure of the biological material can evolve to better respond to external stimuli. In practical terms, I'll have to consider the evolution of the inclination of the unit vector defining the material directions locally.

Liquid filled composite materials. Concerning the "long-distance" objectives, I am currently starting to deal with composite materials made up of a soft matrix (typically an elastomer) filled with liquid inclusions.

The practical interest in this emerging class of materials stems from their potential to enable an abundance of new technologies and unexpected behaviours (in this sense, they can be classified as *metamaterials*). For instance, depending on the size of the liquid particles, the global behaviour of the composite may result to be stiffer than the material used for the matrix, although liquid particles are less stiff than the solid matrix.

From a fundamental perspective, this class of materials provides a new avenue of research because of the limited understanding that we have at present of the mechanics of deformable interfaces between fluids and solids. These materials are indeed endowed with a novel ingredient that is the presence of *elasto-capillarity effects*, caused by the surface tension that is developed at the matrix-inclusions interfaces.

Theoretical studies on elastomers filled with liquid particles fully accounting for elasto-capillarity appear to have been reported in the literature only recently. At the moment, the study is "limited" to an isotropic incompressible elastomer filled with a random isotropic distribution of monodispersed spherical inclusions. Nevertheless, it has been shown that an initial shape other than spherical for the liquid particles is responsible for the creation of pre-stresses in the elastomeric matrix. These residual stresses are necessary to balance the initial interfacial forces generated by the elasto-capillary phenomenon. The presence of existing pre-stresses may generate *material*, *structural* or *superficial instabilities*.

In this regard, I envisage the following main generalizations. To account for more general configurations and fabrication processes, a major question is represented by the implications that such residual stresses may have on the macroscopic response of the composite. A key objective is thus the modelling of such behaviour. This entails a proper description of the kinematic and kinetic response of the composite, depending on whether displacement or traction jumps are allowed at the interfaces. This is of great importance both in statics and dynamics. To account for mechanically responsive interfaces, I will have to consider them with their own energetic contribution. This comprises both the work of the initial surface stress (that can be constant or vary with the deformation of the solid) and/or the surface elastic energy. I plan to account for these generalizations by exploiting a bottom-up approach, using analytical and numerical homogenization techniques. The final objective would be that of developing a general framework for describing the mechanical response of this novel class of materials.