**Research interests**

My research interests are in the broad area of multiscale Continuum Mechanics and related areas of Applied Mathematics and Engineering Sciences.

In particular, recent applications towards the achievement of more suitable constitutive equations for modelling the multiscale behaviour of classical and novel materials are active part of my current and future research; here experiments will become essentials to validate the obtained models.

In particular, my last four year experience of supervising and managing several laboratories, such as Materials and Structural Testing, Mechanics and Automatics, Computational Continuum/Solid and Structural Mechanics, Laboratory for physical modeling of structures and photoelasticity, Calibration of Force Devices (Laboratory of the “University Centre of Metrology”) among others, as well as my starting scientific interactions with a few of them are moving my attention more towards bonding my activity with new and classical experimental activities.

My selected work shows my international standing research path, which is predicted to increase because of the upcoming end of my term as dept. head and of my just initiated leave of absence which, undoubtedly, will allow me to give a significant boost to my research profile. The level of the work has a well recognized academic and professional profile through my evident international engagement and through the quality of publications.

Definite research objectives are single out in this document and they are meant to initiate and implement strong lines of research in the Department. This will be adequately initiated though research students and staff, some actually brought from abroad.

The external support could be augmented by following the same mainstream already pursued by my group in Italy through the EU, although a starting grant would definitely be important. Transfer of knowledge from academia to industry may also be provided, as it currently is (see my CV and the references there).

**Research plans**

The research will be focused mainly on the following topics.

***- Compaction of ceramic powders and granular material mechanics***  This is an ongoing research project, actually funded by the EU through the FP7 program. The starting point of the program is based on the fact that ceramic industry is widely developed in Europe and advanced ceramics are known to be crucial for new technologies and hi-tech applications. Nevertheless, it is surprising that the industrial production of ceramic components is still mainly based on empirically engineered processes, often poorly understood and sometimes very difficult to control. The project addresses to an in-depth scientific understanding of the production processing with the aim of a production optimization and the development of new technological and industrial strategies. The proposed network involves universities and leader industries (in the field. Modeling and experimental validation of the forming process of ceramics and modeling, design and experimental analysis of innovative ceramic products are among the main topics of the projects. This is done together with the Group of Solid and Structural Mechanics at the University of Trento, which I currently belong to and which I supervise ad department head.

Theoretical work has been recently published addressing some key issues in regards of granular materials, such as ceramic powders. In this paper a successful application of the new features of the recent field theory of Structured Deformations to granular materials is presented. Indeed, the granular material may be viewed as a continuum composed of much smaller elastic bodies. The multiscale geometry of structured deformations captures the contribution at the macrolevel of the smooth deformation of each small piece in the aggregate (deformation without disarrangements) as well as the contribution at the macrolevel of the non-smooth deformations such as slips and separations between the small bodies in the aggregate (deformation due to disarrangements). Constitutive information may be provided through a suitable free energy. When such free energy response of the aggregate depends only upon the deformation without disarrangements, is isotropic, and possesses standard growth and semi-convexity properties, we establish (i) the existence of a compact phase in which every small elastic body deforms in the same way as the aggregate and, when the volume change of macroscopic deformation is sufficiently large, (ii) the existence of a loose phase in which every small elastic body expands and rotates to achieve a stress-free state with accompanying disarrangements in the aggregate. We show that a broad class of elastic aggregates can admit moving surfaces that transform material in the compact phase into the loose phase and vice versa and that such transformations entail drastic changes in the level of deformation of transforming material points.

For the static problem, “disarrangement phases” have been recently introduced in an ongoing research where, by analysing the same model free energy of the dynamical problem, many more submacroscopically stable phases have been singled out as possible competitors and capable to forming phase boundaries.

This research is heavily carried out with D. R. Owen at the Center for Nonlinear Analysis at Carnegie Mellon University. Prospect collaborations are foreseen with other people of the same Center, especially for further studies on advanced ceramic thin films, such as I. Fonseca, G. Leoni for the variational side of the research, with S. Taasan for computational aspects and, outside the department, with K. Dayal at the CEE-Carnegie Mellon for advanced engineering aspects of this research.

***- Effective properties of random composites: residual stresses and viscoelasticity***. This ongoing project involves a procedure which allows for finding effective constitutive equations for such composites; this is set up to capture their space-time non-local behaviour. Residual stresses are taken into account and the frequency dependence of the RVE-size is discussed. This research is a common project together with Francesco Dal Corso, Mech.& Structural Engineering at the University of Trento, Emanuela Bosco, Math. Dept.-College of Engineering-Brescia and Eindhoven University-Materials Technology. A collaboration with W. J. Drugan at the Dept. of Engineering Physics at the University of Wisconsin-Madison is also foreseen.

Interactions with people in the Department of Mathematical Sciences expert in variational aspects of other formulations used for homogenization are foreseen, such as I. Fonseca, G. Leoni and D. Kinderlehrer.

* + ***Mechanics of Cells and Biomembranes***

Implications of a recent model developed by the candidate, G. Zurlo and M.D. Piccioni for the mechanical behavior of biological membranes are exploited by means of a prototypical problem, which permits to show that the knowledge of the stretching energy density – i.e. the membrane constitutive response with respect to local variations of area

– completely regulates their spatial behavior during ordering-disordering phenomena.

For biomembranes with coexistent fluid phases, the corresponding values of surface

tension, line tension, bending moduli and the thickness profile inside the boundary layer where the order-disorder transition is concentrated are calculated.

Furthermore, thickness changes in cell membranes may be initiated by conformational changes of some domains forming membrane receptors responding as a second messenger to external ligands. Unfortunately, thinning may indicate the possibility of fracture of the membrane, leading to loss of functionality of the cell aggregate. The mentioned response, whose manifestation is cAMP (cycling Adenosine MonophosPhate), may be directly linked to the coupling of conformational and mechanical effects, the former arising in some of the domains cited above. Stationarity of a new Helmholtz free energy, accounting for receptor density and conformation field and strain gradients in membrane thinning or thickening, is investigated. It turns out that the density of active receptors is directly related to the conformation field above and it enters as a source term in the resulting balance equation for the membrane stress. Henceforth, balance laws for the cAMP transporters and for the flux of active receptors, coupled with the former, must be supplied together with a balance between the diffusive powers to yield “sink” due to the outgoing flux provided by the transporters.

Applications to biological materials, including electro-mechanical actuation for nano- biocompatible systems, such as lipid tubuli and planar films, are part of my current future studies.

This work naturally continues the studies on Mechanics of nano-biological systems and it will be done together with K. Dayal (Carnegie Mellon, Civil and Environmental Engineering and Mechanical Engineering), G. Zurlo (LMS Ecole Polytechnique Paris), L. Lunghi and G. Valacchi, Dept. of Biology and Evolution, Div. Of General Physiology, University of Ferrara, Italy, M. Fraldi, Interdisciplinary Center for Research on Biomaterials (CRIB), Università di Napoli Federico II, Napoli-Italy. Other developments about impacts of the current research on bio-inspired materials are foreseen with prospective collaborations with N. Pugno (Polytechnic School of Torino) and Markus J. Buehler (MIT) as well as K. Bertoldi (Harvard), M. Morandotti, G. Leoni, I. Fonseca, D. Kinderlehrer and D. R. Owen (Carnegie Mellon).

***Acoustic and Mechanical Reconfigurable Metamaterials***.

Fundamental studies about modeling and optimization of reconfigurable mechanical metamaterials may be performed. Indeed, on the one hand such materials are believed to have a tremendously high potential for civil and industrial applications and, on the other hand, issues regarding their analysis and design are still not well understood. Reconfigurable acoustic devices may be also among the main targets of this proposal; actually they are particular mechanical metamaterials, given that the latter are capable to sustain propagation of both shear and pressure waves. The striking properties of such materials combined with the capability to adapt their response to real-time changes coming from the surrounding context offer unique challenges in engineering sciences. Strategies suitable to model and optimize purely electromagnetic metamaterials, such as bandgap structures, frequency-selective leading to shielding, low-reflection materials, “perfect lenses”, resonators, etc., may be extended to artificial structures exhibiting analog properties at the acoustic/mechanical level. Mechanical waves may in fact be channeled through innovative devices and structured media, for which the effects of negative refraction remain still widely open. While vibration shielding of limited areas, such as highly precision robot platforms, may be viewed as achievable tasks, protection of urban aggregates from earthquakes and tsunamis are among dreaming applications of novel mechanical reconfigurable metamaterials.

New systems capable to control dispersive elastic wave propagation in submacroscoplically anisotropic substructured media may be analyzed. Simulations delivering the information on the dispersion properties and stop bands for Bloch-Floquet waves will be performed and examples dealing with filtering and focussing devices incorporating structured interfaces as flat lenses will be analyzed. In the same mainstream, single cells and small clusters of two dimensional elastic lattices whose nodal points host gyroscopic spinners will be studied as a prototype reconfigurable structure. Striking responses dominated by shear waves are expected to arise, since they are believed to be linked to vortices generated by the spinners; here band gaps are expected to open up in the desired frequency range.

Given such interesting properties, large-size lattices with embedded spinners will be studied and their effective response will be modelled. Theoretical and numerical studies of this new metamaterial will yield the efficiency range in the presence of reconfigurability.

A new methodology devoted to studying the response of such media will be done through the extension of the recent field theory of “structured deformations”, developed in a purely mechanical context to the multiphysics of metamaterials. The augmented kinematics will account for conformational changes of the single units; related determining sequences may be constructed to describe the details of the local geometry as well as the reconfigurability of the aggregate. “Stress-like” variables and the Helmholtz free energy (of the single unit plus contributions due to the interactions among them in a given area) will be computed to get basic information necessary for the scaling procedure. Volume averages following by a limiting procedure of all of the above quantities will lead to effective kinematical and constitutive information for the structure.

Initial-boundary value problems for predicting the reconfigurability of the aggregate will be finally analysed in their integral form, owing wide possibilities for numerical procedures, including finite element methods. The adaptability of the mechanical response is not explicitly included in the procedure above and, hence, this must be integrated in a suitable way. Optimal control techniques will be applied to enhance the reconfigurability of such structures.

We can foresee collaborations with Carnegie-Mellon,, in particular with I. Fonseca, D. R. Owen and G. Leoni, and CEE K. Dayal, the Univ. of Liverpool (A. Movchan), Harvard (K. Bertoldi, author of papers on structured interfaces) and a new ones with ETH-Zurich through C. Daraio, formerly at Caltech, expert on experiments on small aggregates are envisaged in this phase of the research to face both the modeling and the experimental issues.