Doctoral Programme in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 40th cycle – first call

A mandatory attachment of the application is a description of the research project (max 4 pages) relative to the research areas of the Doctoral Programme in Civil, Environmental and Mechanical Engineering on specific topics as described below.

Curriculum A - Civil and Environmental Engineering

- *Reference persons:* Giuseppe Formetta (UNITN/DICAM), Alessandra Marzadri

A1 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: Urban water risk assessment in a changing climate

Project description: Climate change is already occurring (IPCC, 2023) and urban water infrastructure are increasingly facing substantial risks from natural hazards. It is expected that the extreme events such as floods and droughts may bring to severe urban floods (e.g. Pingale et al., 2014) and growing serious water scarcity situations (e.g. Steeneveld et al., 2016). Furthermore, recent studies demonstrated that together with the social and economic impacts, particular attention should be given also to the impacts on the water-related ecosystems, to account for the loss of biodiversity (European Commission, 2020), ecosystem services (Arrighi and Domeneghetti, 2024) and the land degradation (Weiskopf et al., 2020).

Starting from this background, the PhD student will propose a novel framework to quantify these impacts from single and from multiple hazards, and develop and apply innovative models at different spatial (i.e. neighborhood areas, streets and urban landscape) and temporal (e.g. storm event, seasonal and annual) scales to: i) a more reliable quantification of the frequency of occurrence of compound extreme events such as floods and droughts or heatwaves and droughts, ii) include dynamical society changes in the modeling framework for the impact assessment (i.e. population and economic assets) at high spatial resolution (less than 1km for the city level), and iii) explicitly accounting and quantifying the losses of ecosystem services and biodiversity.

Expected outcomes of the PhD activity can be listed as follows:
1. include compound hazards probability of occurrences into a novel framework for multiple-risk assessment
2. apply and validated the proposed framework on study areas which differs for climate and urbanization levels and for which data of natural hazard impacts (social and economic) are available.
3. propose and test flexible and proactive strategies (i.e. adaptation and mitigation) to contrast the effects of climate change associated with biodiversity loss and ecosystem degradation

The expected results of this PhD scholarship are extremely innovative and in agreement with the aims of the European Green Deal (European Commission, 2019) of tackling climate and environmental-related challenges, thanks to the explicit accounting of compound extreme events, dynamic societal changes, and quantification of losses of ecosystem services/biodiversity.

The **ideal candidate** will have a background in Civil or Environmental Engineering or related fields. Candidates should also possess strong computer, scientific, and analytical expertise, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a positive attitude. Since foreseen activities include model development, the candidate is required to have computational proficiency (or the will to pursue it) preferably in R/python/Matlab and GIS products. It is intended that the developed tools and/or models are produced as free software.

Suggested references (to be not considered as exhaustive for the topic):

Arrighi, C., & Domeneghetti, A. (2024). Brief communication: On the environmental impacts of the 2023 floods in Emilia-Romagna (Italy). Natural Hazards and Earth System Sciences, 24(2), 673-679.

European Commission (2019). The European Green Deal. Communication From the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. COM/2019/640 Final, Brussels. pp. 1–24.

European Commission (2020). EU Biodiversity Strategy for 2030. Bringing Nature Back Into Our Lives, Brussels. pp. 1–23.

IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, 184 pp., doi: 10.59327/IPCC/AR6-9789291691647.

Pingale, S. M., Jat, M. K., & Khare, D. (2014). Integrated urban water management modelling under climate change scenarios. Resources, Conservation and Recycling, 83, 176-189.

Steeneveld, G. J., Klompmaker, J. O., Groen, R. J., & Holtslag, A. A. (2018). An urban climate assessment and management tool for combined heat and air quality judgements at neighbourhood scales. Resources, Conservation and Recycling, 132, 204-217.

Weiskopf, S.R, Rubenstein, M.A., Crozier, L.G., et al., (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. Science of The Total Environment, Volume 733, doi: 10.1016/j.scitotenv.2020.137782

- ***Reference person:*** **Marco Tubino (UNITN/DICAM)**

Participant: Niccolò Ragno (UNITN/DICAM)

A2 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: Planform dynamics of meandering rivers

Meanders are one of the most common morphological pattern through which alluvial rivers manifest themselves. Sinuous shapes are carved along floodplains through the alternation of bank erosion and accretion processes. In the last decades the development and progressive refinement of a mechanistic framework of meandering rivers (Seminara, 2006; Bogoni et al. 2017; Monegaglia et al., 2019) prepared the ground for evolutionary models capable of investigating the long-term planimetric development of meandering rivers.
However, most of the existing morphodynamic models have focused on the spatial scale of individual reaches, where hydro-morphologically homogeneous portions of the channels are considered, thus neglecting the hierarchical conditioning at larger scales. This implies that these models assume that channel migration, which is locally driven by the differential excess of flow speed at the banks, is globally governed by the averaged hydraulic geometry of the reach in question, which is known to strongly affect meanders development. In turn, the reach-averaged hydraulic conditions are modified by non-equilibrium processes at larger scales. Thus, the reference state in state-of-the-art meandering models is based on a constant discharge and spatially invariant hydraulic geometry, while riverbed adaptation to changes in sediment supply, and the related capacity of the flow to carry the sediment supplied, is neglected.

This doctoral proposal addresses such issue to primarily investigate the overlooked, albeit crucial effect of variations of the channel hydraulic geometry in evolutionary models of river meanders. This will be accomplished through an integrated approach, whereby a combination of analytical and numerical modeling are compared systematically with remote sensing observations. Specifically, multispectral satellite data will be extracted and analyzed by combining the cloud computing capability of Google Earth Engine with the process-based software PyRIS (Monegaglia et al., 2018). This nested strategy is expected to provide a tool for analyzing the role of anthropic alterations of flow and sediment regime due to river damming, land use changing, and atmospheric warming.

The ideal candidate will have a background in Environmental Engineering, River Geomorphology or related fields. Candidates should also possess strong computer, scientific, and analytical expertise, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a good attitude for critical thinking. Since foreseen activities include model development, the candidate is required to have computational proficiency (or the will to pursue it) preferably in Python/Matlab and GIS products. It is expected that the results of the research project will be presented at international conferences and published in peer-reviewed high-ranked international journals.

References

Bogoni, M., Putti, M., & Lanzoni, S. (2017). Modeling meander morphodynamics over self-formed heterogeneous floodplains. *Water Resources Research*, 53, 5137–5157.
Monegaglia, F., Tubino, M., & Zolezzi, G. (2019). Interaction between curvature-driven width oscillations and channel curvature in evolving meander bends. *Journal of Fluid Mechanics*, 876, 985–1017.
Monegaglia, F., Zolezzi, G., Güneralp, I., Henshaw, A. J., & Tubino, M. (2018). Automated extraction of meandering river morphodynamics from multitemporal remotely sensed data. *Environmental Modelling & Software*, 105, 171–186.
Seminara, G. (2006). Meanders. *Journal of Fluid Mechanics*, 554, 271–297.

Curriculum B - Mechanics, Materials, Chemistry and Energy

- ***Reference persons:*** **Maria F. Pantano (UNITN/DICAM), Andrea Adami (FBK), Alvise Bagolini (FBK), Leandro Lorenzelli (FBK)**

B1 - scholarship on reserved topics

Funded by: Fondazione Bruno Kessler (FBK)

Title: Electrowetting-on-dielectric (EWOD) devices for digital microfluidic applications

Abstract

Microfluidics is a branch of microsystem technologies with great potential to integrate complex analytical procedures into a small device, thus enabling the detection of biological and chemical analytes in portable and automated systems. Among the different techniques currently available, the recent trend is to move from classical but miniaturized pressure- driven devices to droplet techniques and digital microfluidics, which allow for greater miniaturization and integration of different functionalities without increasing technological complexity. In particular, the Electrowetting On Dielectrics (EWOD) is attracting increasing interest as a droplet-based technique, where the sample and reagents are managed by modulating the wetting properties of a surface by electric fields.

Research project and expected outcomes

The candidate will participate in a research team developing EWOD devices for portable analytical systems with a variety of potential applications, including, for example, the analysis of water quality.

The research project includes various activities, spanning from the design and modeling of novel EWOD MEMS devices to their fabrication and experimental validation. The results of the research activities will be collected in contributions submitted to international scientific journals.

Reference person: **Paolo Scardi (UNITN/DICAM)**

B2 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001"

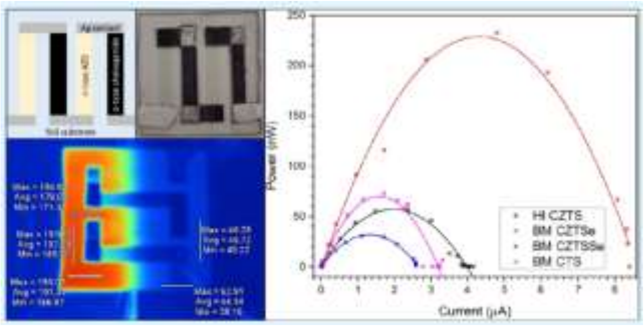
Title: Multifunctional materials for sustainable thin-film thermoelectric devices

Thermoelectric devices are increasingly used in the production of electricity from heat sources, in particular waste heat, for energy recovery and power supply disconnected from the grid. *Multifunctionality* is the key to increasing the performance of thermoelectric materials: in fact, the figure of merit (zT) depends both on the electrical conductivity and inversely on the thermal conductivity, a condition difficult to obtain with most materials. In addition to the growing commitment to research towards increasingly high-performance materials, it is of primary importance to develop sustainable solutions for energy harvesting, both in environmental and economic terms. Indeed, existing thermoelectric materials and devices are invariably based on rare or toxic chemical elements, which pose severe limitations to the development of sustainable, large-scale technologies.

In this thesis project we aim to design and develop multifunctional and sustainable materials for thin film thermoelectric generators (TEG), using technologies ranging from the production of inks for device printing to the more traditional physical vapor deposition (PVD) techniques. Metamaterials design will also be investigated.

The work includes the design of materials and devices, their creation and testing using techniques for characterizing the electrical and thermal transport properties as well as materials microstructure. For this reason, the ideal candidates should have skills or at least a good predisposition for work in an interdisciplinary area between materials science and engineering, in the field of sustainable energy technologies.

All the main characterization techniques required are available in our laboratories, in particular for thermoelectric measurements (thermal and electrical conductivity, Seebeck coefficient, Hall effect for carrier mobility and concentration) and evaluation of the efficiency of the devices (voltage-current-power measurement). Further support comes from the international collaboration network in which the research group has been operating for years. The work is aimed at scientific production, in terms of articles in international journals and participation in conferences, as well as the creation of prototypes of devices, e.g., see below.



Thin film thermoelectric generator (TEG) based on (p-type) kesterite (CZTS or CZTSe) or Cu2SnS3 (CTS) and (n-type) Al-doped zinc oxide (top left). Thermal image of the temperature gradient across a prototype (bottom left). Power curve of several devices (right).
Syafiq et al., ACS Appl. Energy Mater. 5 (5) (2022) 5909–5918.

- *Reference person:* Diego Misseroni (UNITN/DICAM)

B3 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering within the Project HORIZON EUROPE ERC 2022 COG S-FOAM, GA n°101086644 – CUP E63C23000510006

Title: Enhance Architected Materials mechanical properties with Origami design principles

We present a compelling opportunity to engage in cutting-edge research in the field of architected materials and origami-based metamaterials. The objective is to integrate origami/kirigami capabilities into architected cellular structures across various scales, thereby paving the way for metamaterials with significantly enhanced mechanical performance. The focus is on the design of origami-structured lattice metamaterials with the final purpose to attain local and global multistability, functional-graded stiffness-to-weight ratio, energy dissipation, or other mechanical properties. Polyhedron lattice structures will be theoretically investigated whose common strut-and-tie elements will be replaced with multistable, foldable origami patterns. The arrangement of multistable and foldable unit cells gives rise to materials that locally adapt their shape to external action. Depending on the type of the applied action, the metamaterials will gently deform to adapt to object morphology (quasi-static action) or will snap between multistable configurations, each non-adjacent to the other (dynamic action). The non-linear relation between external action and local deformation will be derived by exploiting continuum mechanics theory. The research will encompass the development of theoretical models, numerical algorithms, and experimental prototypes.

The research results will be:
(i) published in high impact international journals in the field of Mechanics of Solids and Structures, Applied Physics, Computational Mechanics, Materials Engineering, Additive Manufacturing, Aerospace Structures and Materials, etc.;
(ii) presented at national and international conferences;
(iii) the realization of proof-of-concept reprogrammable multi-functional metadevices.

This PhD is related to the topic of my ERC CoG SFOAM.

- ***Reference person:*** **Diego Misseroni (UNITN/DICAM)**

Participants: Luca Deseri (UNITN/DICAM), Massimiliano Fraldi (Università degli Studi di Napoli Federico II)

B4 - scholarship on reserved topics

Funded by: University of Trento – Department of Civil, Environmental and Mechanical Engineering within the Project HORIZON EUROPE ERC 2022 COG S-FOAM, GA n°101086644 – CUP E63C23000510006

Title: Homogenization-based modelling of origami-based metamaterials

We offer an enticing opportunity to engage in cutting-edge research in the field of origami-based metamaterials. Our objective is to pioneer an advancement in the development of a continuum equivalent for origami metamaterials, guided by the principles of Floquet-Bloch asymptotic homogenization. Commencing with Floquet-Bloch asymptotic homogenization, the research will yield an advanced conceptualization of lattice-like and block-lattice origami materials to discern the constitutive properties and acoustic behavior of discrete Lagrangian materials. The key innovation in this research lies in the introduction of an enhanced conceptualization scheme, such as Second order Structured Deformations, facilitating the seamless translation of difference equations from discrete systems into macroscopic integral differential equations. These equations not only govern the actual system but also faithfully replicate its mechanical behavior. The research journey extends beyond theoretical boundaries, encompassing the development of sophisticated models, advanced numerical algorithms, and the creation of experimental prototypes aimed at validating the developed theory.

The research results will be:
(i) published in high impact international journals in the field of Mechanics of Solids and Structures, Applied Physics, Computational Mechanics, Materials Engineering, Additive Manufacturing, Aerospace Structures and Materials, etc.;
(ii) presented at national and international conferences;
(iii) the realization of proof-of-concept reprogrammable multi-functional metadevices.

This PhD is related to the topic of my ERC CoG “SFOAM.”

Curriculum C - Modelling and Simulation

- ***Reference persons:*** **Nicola M. Pugno (UNITN/DICAM), Barbara Mazzolai (IIT)**

C1 - scholarship on reserved topics

Funded by: University of Trento – Istituto Italiano di Tecnologia (IIT)

Title: 3D nanoprinting of multifunctional biomimetic structures inspired by natural organisms

Evolution has brought to the development of fascinating biological structures. Nanofabrication technologies provide valuable tools to fabricate artificial biomimetic materials with properties that imitate the natural structures.

This project aims at developing novel multifunctional biomimetic artifacts by merging nanofabricated materials with tailored mechanical properties and microfluidic structures, fabricated by two photon lithography, with functional electrospun fibers and 3D printed multi-materials.

Several biological properties and functionalities will be investigated as models to develop artificial systems embedding sensing and actuation abilities. In particular, plants and soft invertebrates will be the focus of such research, as described in the following.

Due to their low density and impressive mechanical properties, plants provide examples of lightweight yet robust structures (e.g., bamboo, plant seeds). These characteristics are achieved thanks to a hierarchical structure that combines porous architectures with density gradients and hollow parts to increase the flexural stiffness while keeping a lightweight.

Invertebrates with a soft body, as, e.g., octopus, can squeeze and move in any spaces. The octopus can also bend and elongate its eight arms, while the skin adapts to each movement providing at the same time camouflage properties. Camouflage is obtained by chromatophores activated by light, resulting in a skin that combines sensing and actuation properties.

The above biological properties represent some of the research activities will be proposed within this project.

In summary, the expected work spans from biological investigation to design, fabrication, and characterization of the resulting prototypes. The expected outputs are patents and publications on high impact journals on the field.

The intellectual property of the research results that will derive from the activities carried out by the doctoral student is owned by the University and the Financer.

- *Reference person:* Michael Dumbser (UNITN/DICAM)

C2 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: High order structure-preserving numerical schemes for continuum mechanics of mixtures with phase transition

This project deals with the development of new high order accurate structure-preserving finite volume and discontinuous Galerkin finite element schemes for the description of nonlinear continuum mechanics of mixtures (liquid-solid and liquid-gas mixtures) with phase transition. The governing equations are based on the unified thermodynamically compatible model of continuum mechanics of Godunov, Peshkov and Romenski that describes at the same time the dynamics of elasto-plastic solids at large deformations, as well as fluids. We aim at modelling compressible and nearly incompressible two-phase flows with phase transition (liquid-gas and liquid-solid mixtures), also obtaining simplified depth-averaged versions of the governing equations for future environmental and geophysical applications.

The considered first order hyperbolic PDE systems with relaxation will be discretized with new innovative numerical schemes that preserve essential features of the underlying continuous equations exactly also at the discrete level. Particular care will be taken in the low Mach number limit of the equations. Potential applications are industrial liquid-vapour flows, additive manufacturing and environmental and geophysical applications such as debris flows and lava flows.

- *Reference persons:* Alberto Bellin (UNITN/DICAM), Nicola M. Pugno (UNITN/DICAM)

C3 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: Glaciers' stability under global warming

One of the most relevant effects of climate change is global warming, i.e. the increase of mean global temperature. In the mountain regions, and in the Alps in particular, the temperature increased more than global mean, thereby causing significant modifications of the environment. The rise of temperature caused the fast retreat of glaciers, the melting of rock glaciers and permafrost and the change in ice and snow dynamics. These changes impact water resources availability and timing but also the stability of glaciers, snowpacks and permafrost. The evident effect is higher occurrence of instability events which increase the risk of casualties in the Alpine region. Analyzing these dynamics requires an interdisciplinary approach combining expertise in solid mechanics, in particular fracture mechanics, and fluid mechanics, in particular hydrology, given that the presence of water is one of the critical aspects influencing the stability of glacial environments such as glaciers, snowpacks and permafrost. In this context, the changes in the climatic forcing triggers changes in water resources availability and seasonality as well as the stability of ice or snowpacks, such as in the events that occurred in 2022 on the Marmolada glacier, which caused 11 deaths, and the snow avalanche occurred in 2017 in the Rigopiano's hotel, which caused 29 deaths.

We propose to investigate how the changes in the climatic forcing impacts the hydrological and mechanical behavior of the glaciers and snowpacks, thereby exposing them to an increased risk of collapse. The research will couple experimental activities in the field with laboratory experiments finalized to a detailed investigation of the changes of ice and snow mechanical characteristics with the temperature. Fields data, including the data collected in the recent collapse of a plaque of the Marmolada glacier and the Rigopiano snow avalanche, will be interpreted by using numerical simulations and theoretical modelling with the characterization of ice and snow characteristics obtained from laboratory experiments.

The role of melting water in the stability of these masses will be also investigated in relation to its effect on the characteristics of the ice and on the global stability of these masses.

Expected outcomes of the research include the following:

1) a better characterization of mechanical and hydrological (i.e., permeability) characteristics of ice and snowpack masses and their changes with the temperature;
2) a new approach to evaluate the risk of instability of glacier and snowpack masses under the effect of an increasing temperature;
3) an in deep exploration of the water flow in snowpacks and of the flow at the interface between ice and the underlying bedrock in temperate glaciers.

- Reference person: Nicola Tondini (UNITN/DICAM)

C4 - scholarship on reserved topics

Funded by: MUR (Italian Ministry of University and Research) – Dipartimenti di Eccellenza (Departments of Excellence) Project - "Dipartimenti di Eccellenza 2023-2027 (Legge 232/2016)", CUP n. E63C22003880001".

Title: Performance-based analysis of tapered/cellular members for sustainable steel structures

Building solutions today are conceived to be sustainable, being both low-cost from an economic perspective, while also emphasizing: i) resource efficiency (lightweight design, material optimization, no water use); ii) environmental friendliness (zero waste, reduced pollution); iii) adaptability to large spans, and iv) a wide range of transformations, all with a smaller carbon footprint that relies on re-use potential, promoting a more circular economy approach and extending further life cycles.

Traditional industrial frames using hot-rolled members result in uniform material distribution and suboptimal structural designs. More engineered solutions using tapered members with thin-walled sections and/or the inclusion of openings enables improved optimization by reducing self-weight while allowing longer clear spans. The effort, on the other hand, is a slightly more complex fabrication process, but which overall reveals beneficial for all of the mentioned sustainability goals, because everything is factory pre-produced, there is less erection time and effort required, and dismantling is possible, allowing re-use of the elements for future life cycles. Moreover, a lighter structure demands smaller foundations and decreases transportation and building times. As a result of reduced material utilisation and cheaper transportation costs, CO_2 emissions and energy consumption are lowered. On these premises, to meet the ambitious European Green Deal Goal of reducing GHG emissions (GHGe) by at least 55% by 2030 and to establish a resource-efficient and competitive design for steel frames, the research will be focused on the development of new engineering efficient design rules and recommendations for I-shaped web tapered members with/without openings, based on sound numerical and experimental research. In this respect, a comprehensive range of experimental tests on the behaviour of web tapered steel members and cellular beams will be performed. The research will be both numerical and experimental. The expected outcomes are mainly journal and conference papers as well as design guidelines.