Doctoral Programme in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 40th cycle – second 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 person:* Giorgio Rosatti (UNITN/DICAM)

Participants: Daniel Zugliani (UNITN/DICAM), Massimiliano Pittore (Eurac), Alice Crespi (Eurac)

A1 - scholarship on reserved topics

Funded by: University of Trento – Eurac Research.

Title: Coupling data-driven modelling of debris flow release susceptibility on large scale with physically–based modelling runout areas and intensities on catchment scale

Debris flows are rainfall-induced phenomena, triggered by high intensity, short duration rainfall, following an antecedent long duration precipitation, bringing soil to saturation [Armanini et al., 2006 Martinengo et al, 2023 Turkington et al, 2016]. The combination of such events gives debris flow little predictability, and the unexpected sudden triggering, makes the phenomenon insidious, with heavy consequences for settlements, people and infrastructures located on the alluvial fans. Potential changes in the intensity and/or frequency of heavy precipitation events due to climate change are likely to cause changes in debris flows occurrence and should be considered within risk management procedures [Turkington et al, 2016], but this task can prove challenging in mountainous areas with complex orography subjected to intense anthropic processes.

Currently, debris flow risk management follows four steps: i) the statistical analysis of past precipitation extreme events; ii) the study of the hydrological response of the catchment; iii) the hydraulic modelling of the debris flow; and iv) the definition of the debris flow hazard map. Different hydrological and hydraulic software has been developed in the last decades, to cover the increasing demand of high resolution and fast models with a limited number of parameters to set, thus increasing the range of possible choices for conducting the analysis and the mapping.

In general, two approaches are possible: data-driven, statistical modelling of debris flow release susceptibility on large scale [Steger et al, 2022] and physically based modelling of debris flow runout areas and intensities on catchment scale [Rosatti et al, 2018]. Both methodologies have advantages and drawbacks: on the one side, large-scale modelling requires few basic input data sets, and thus it can be applied over large areas, but the considerable level of abstraction and neglecting the complexity of the phenomena of interest may result in significant uncertainties. On the other side, physically based models allow for producing high-quality simulations, which are the base for the hazard mapping and the risk management, but they are specific for the local catchment scale and cannot be extended over large areas.

In this research we want to analyze the strengths, weaknesses and potential improvements of the modelling frameworks for debris flows and develop an integrated approach to provide consistent debris flow hazard information at multiple spatial and temporal scales, also allowing the inclusion of climate-change scenarios. The aim is to implement statistical methods starting from physically measured/modelled data, integrate the large-scale analyses with the physical model outputs and identify the key parameters to detect or predict other potential debris flow prone areas. Furthermore, the uncertainties underlying the modelling approaches will be investigated to support practice-oriented sustainable procedures in the field of risk management.

- *Reference person:* Lorenzo Giovannini (UNITN/DICAM)

Participant: Dino Zardi (UNITN/DICAM)

A2 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering

Title: Assessment of atmospheric dispersion processes in a mountain valley to support the implementation of vehicle emission reduction policies

The understanding and quantification of pollutant dispersion over complex terrain are much more difficult than over flat areas, as dispersion processes are affected by atmospheric interactions with the orography at different spatial scales. In this regard, several aspects, concerning both our understanding and ability to observe and model processes related to pollutant dispersion over complex terrain, still remain to be investigated.

Building on these considerations, the present project aims to test different modeling tools to reproduce pollutant dispersion processes over complex terrain, with the final objective of assessing the impact of the implementation of different policies aiming at reducing pollutant emissions from vehicular traffic. In particular, the Adige Valley will be taken as a case study, evaluating pollutant dispersion from vehicular traffic on the Brenner highway. In fact, mountain valleys and basins represent a critical hotspot for air quality, since major sources of pollutants in mountainous regions are generally located in these contexts, where the main urban areas and traffic routes develop, and most of the population lives.

The research activity will be carried out both using state-of-the-art meteorological and dispersion models and analyzing data from experimental measurements. The Weather Research and Forecasting (WRF) model will be used for the meteorological simulations, while atmospheric pollutant dispersion models with different levels of complexity will be tested, ranging from regulatory models, widely used by environmental protection agencies, to more advanced tools, including Lagrangian particle models.

Modeling results will be compared with experimental data collected in the study area, including measurements from innovative low-cost sensors, which allow a more detailed spatial representation of pollutant concentrations. This will allow the evaluation of the ability of the meteorological-atmospheric dispersion modeling chain to reproduce the observed pollutant concentrations in the study area, including critical situations, such as traffic congestion during periods characterized by low atmospheric dispersion conditions.

Then, the project will focus on evaluating the effects on pollutant concentrations in the study area of different policies related to vehicular traffic management, including dynamic motorway traffic management with reduced speed limits. Moreover, the effects of vehicle fleet turnover will be investigated.

The results of the present project will be presented at international conferences, such as the EGU annual meeting, the International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes (HARMO) and the AMS Symposium on Boundary Layers and Turbulence. Moreover, results are expected to be published in peer-reviewed high-ranked international journals.

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: MEMS microfluidic devices for analytical systems

Abstract

Microfluidics is a branch of microsystem technologies aiming at integrating complex analytical procedures into miniaturized, automated devices. In this kind of systems, precise handling of tiny liquid samples is of paramount importance to enable the detection of specific biological and chemical species.

The overall goal of this research project is to develop novel microfluidic devices based on the technology of microelectromechanical systems (MEMS) to achieve miniaturization and integration of different functionalities, including sample management and analysis. To this aim, Electrowetting On Dielectrics (EWOD) techniques will be explored. In EWOD devices the sample and reagents are managed in the form of drops, which are moved, split and mixed by modulating the wetting properties of surfaces by electric fields.

Research project and expected outcomes

The candidate will participate in a MEMS research team developing microfluidic devices, with access to full MEMS design and microfabrication facilities. The research project will focus on the design and modeling of novel microfluidic devices, the microfabrication of the MEMS devices in a fully equipped, class 100 cleanroom, and the experimental validation of the obtained prototypes. The results of the research activities will be collected in contributions submitted to international scientific journals, and presented in high profile conferences.

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

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

B2 - 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."
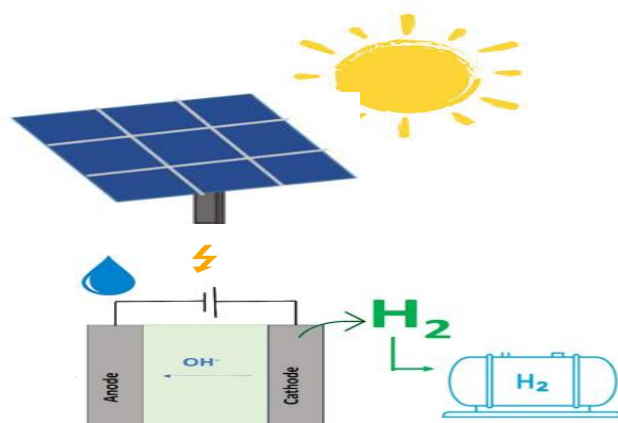
Curriculum C - Modelling and Simulation

- *Reference person:* Narges Ataollahi (UNITN/DICAM)

C1 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering

Title: Integrated PV-AEM Electrolyzer System for Efficient Green Hydrogen Production

Hydrogen is an energy carrier capable of bridging gaps in energy transition and aligning with the European Green Deal's 2050 climate neutrality objectives. The utilization of anion exchange membrane water electrolyzer (AEMWE) has emerged as a promising and environmentally friendly method for hydrogen production. These electrolyzers operate at lower temperatures and pressures compared to traditional proton exchange membrane (PEM) counterparts, offering improved energy efficiency and reduced costs. However, the existing electrolyzers, including both PEM and AEM types, encounter reliability and durability challenges when operated with the fluctuating power supply common in renewable energy generation like photovoltaic (PV) system. This is evident from accelerated material degradation and performance decline. Beyond ensuring efficient operation amidst dynamic loading, achieving the full potential of electrolyzer systems powered by PV electricity demands a deeper comprehension of performance and durability. Understanding degradation mechanisms and devising strategies to mitigate them are crucial steps towards extending the operational lifespan of electrolyzer systems in dynamic operating modes driven by renewable energy sources. This thesis aims to integrate PV technology with an AEM electrolyzer creating an efficient system for green hydrogen production. The endeavor involves developing a comprehensive dynamic model of the AEM electrolyzer, utilizing advanced computational methods and interdisciplinary insights to elucidate underlying principles governing electrical and thermal transport properties as well as electrochemical processes. The primary objective is to optimize the efficiency and performance of electrolyzer within this integrated PV-electrolyzer system. In addition, this thesis will explore novel membrane materials and design strategies for electrolyzer systems, with a focus on enhancing their durability, selectivity, and conductivity. The outcome of this thesis will be disseminated through publication in scientific international journals, as well as through conference presentations, workshops and seminars contributing to advancements in the field of energy harvesting and conversion.

Green hydrogen production by PV powered electrolyzer

- *Reference persons:* Daniele Zonta (UNITN/DICAM), Marco Broccardo (UNITN/DICAM)

C2 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering.

Title: Vibrational bridge monitoring based on single pass SAR satellite images

Large infrastructures need continuous maintenance because of materials degradation due to atmospheric agents and their persistent use. This problem makes it imperative to carry out persistent monitoring of infrastructure health conditions in order to guarantee maximum safety at all times. The main issue of early warning infrastructure fault detection is that expensive in-situ distributed monitoring sensor networks have to be installed.

In this regard, the potential of spaceborne Synthetic Aperture Radar for the monitoring of critical infrastructures is demonstrated in geographically extended areas, even in the presence of clouds, and in really tough weather. DInSAR satellite interferometry [1] allows to monitor slow phenomena of the territory (subsidence, landslides) at a reduced cost. However, the high uncertainty of the measurements and the low sampling frequency do not allow to replace the traditional monitoring of bridges with this technology. Specifically, due to sampling rate limitation, vibrational monitoring has been simply not considered to date.

Only very recently, preliminary studies [2] demonstrated that vibrational information of infrastructures, such as bridges, can be obtained from single pass SAR images via the analysis of the micro-motions modes of the structure. In this project this capability will be validated with ground truth in-situ measurements, aimed at confirming the capability to detect effectively vibrational modes of bridges, as well as supporting the derivation of a calibration model. In addition, the applicability of the processing framework, or sub-optimal version of it, for on-board deployment on constellations aimed at providing condition monitoring/early warning commercial products will be assessed.

EXPECTED OUTCOMES

- Scientific papers published in high impact factor international journals.

- A prototype of a decision support and early warning system for bridge management, which integrates SAR vibrational methods.

- Possible patent(s) on research outputs.

[1] Selvakumaran S., Plank S., Geiß C., Rossi C., Middleton C., Remote monitoring to predict bridge scour failure using Interferometric Synthetic Aperture Radar (InSAR) stacking techniques, International Journal of Applied Earth Observation and Geoinformation, 2018, 73, Pages 463-470.

[2] Biondi F., Addabbo P., Liberata Ullo S., Clemente C. Orlando D., Perspectives on the Structural Health Monitoring of Bridges by Synthetic Aperture Radar, Remote Sens. 2020, 12(23), 3852.

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

C3 - scholarship on reserved topics

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: Andrea Massa (UNITN/DICAM)

Participants: Giacomo Oliveri (UNITN/DICAM), Paolo Rocca (UNITN/DICAM), Marco Salucci (UNITN/DICAM).

C4 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering.

Title: Innovative Unconventional Array Antenna Architectures for Non-Terrestrial Networks

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In the ever-evolving landscape of wireless communications, with the increasing need for global connectivity, the exploration of non-terrestrial networks (NTNs) based on the use of low Earth orbit (LEO) satellites has emerged as a promising frontier. In this framework, the development of new antenna technology is paramount for unlocking the full potential of NTNs in future wireless communications. By enhancing coverage, increasing data rates, mitigating interference, improving resilience, optimizing energy efficiency, and ensuring scalability, advanced antennas will play a pivotal role in shaping the next generation of global connectivity. In order to connect ground stations to LEO satellites, electronic scanning array antennas are the ideal solution for achieving connectivity on-the-move due to their low-profile and agile beam pointing capabilities. However, these antennas are expensive and complex as compared to antennas characterized by a mechanical or hybrid scanning. The number of radiating elements increase significantly, and their dimension decrease when a large field of view and a large frequency bandwidth are required. A priority is nowadays the identification and optimization of antenna architectures (including radiating elements and beamforming network layout) suitable for large field of view and a large frequency bandwidth.

The objective of the PhD research activity will therefore be the study and development of innovative methodologies for the design and analysis (also based on HW emulators already available at the ELEDIA@UniTN laboratory) of unconventional array antennas (UAAs) for NTN enabling new cost-effective solutions.

To this end, the activity PhD Student will join a transdisciplinary team of Researchers and Professors working on a wide variety of domains from fundamental EM and antenna theory to advanced numerical antenna modelling, as well as advanced system-by-design methodologies for their analysis and optimization-driven design. The research activity will be conducted under the supervision of the PI/Advisor and the members of the ELEDIA@UniTN at DICAM of the University of Trento.

The expected outcomes of this activity can be listed as follows:

1. Review and analysis of the literature on UAAs architecture and design methods and of the specifications and requirements for NTNs;

2. Study and development of novel techniques for the design of new UAAs costeffective array architectures for NTNs;

3. Modeling and optimization of dedicated single radiator to be integrated in the novel array solutions;

4. Design and analysis of multiple Pareto-optimal trade-off UAA solutions for NTNs for both uplink (ground to space) and downlink (space to ground) segments.

Suggested selected references:

[1] P. Rocca, et al., "Unconventional phased array architectures and design methodologies - A review," Proc. IEEE – Special Issue on 'Phased Array Technologies,' Invited Paper, vol. 104, no. 3, pp. 544-560, Mar. 2016.

[2] P. Rocca, et al., "An irregular two-sizes square tiling method for the design of isophoric phased arrays," IEEE Trans. Antennas Propag., vol. 68, no. 6, pp. 4437-4449, Jun. 2020.

[3] A. Massa, et al., "On the design of complex EM devices and systems through the system-by-design paradigm - A framework for dealing with the computational complexity," IEEE Trans. Antennas Propag., vol. 70, no. 2, pp. 1328-1343, Feb. 2022.

[4] P. Rocca, et al., "Pareto-optimal domino-tiling of orthogonal polygon phased arrays," IEEE Trans. Antennas Propag., vol. 70. no. 5, pp. 3329-3342, May 2022.

[5] G. Oliveri, et al., "Capacity-driven low-interference fast beam synthesis for next generation base stations," IEEE Trans. Antennas Propag., vol. 70, no. 6, pp. 4472-4484, Jun. 2022.

[6] N. Anselmi, et al., "Optimal capacity-driven design of aperiodic clustered phased arrays for multi-user MIMO communication systems," IEEE Trans. Antennas Propag., vol. 70, no. 7, pp. 5491-5505, Jul. 2022.

[7] N. Anselmi, et al., "A self-replicating single-shape tiling technique for the design of highly modular planar phased arrays - The case of L-shaped rep-tiles," IEEE Trans. Antennas Propag., vol. 71, no. 4, pp. 3335-3348, Apr. 2023.

[8] A. Benoni, et al., "Design of clustered phased arrays by means of an innovative power pattern matching-driven method - The linear array case," IEEE Trans. Antennas Propag., 2024 (in press).

Curriculum D - Architecture and Planning, Landscape

Reference person: **Sara Favargiotti (UNITN/DICAM)**

Participant: Marco Ciolli (UNITN/DICAM)

D1 - scholarship on reserved topics

Funded by: University of Trento - Department of Civil, Environmental and Mechanical Engineering within the projects MIUR PRIN 2017 – project number: 201735N7HP – CUP E64I19002500001, EIT FOOD 2022 Helpfood 4.0 and EIT FOOD 2024 SEEDS4FUTURE – CUP E63C24000170006.

Title: Regenerative foodscapes for people and nature: integration of landscape transformation with food dynamics and water management for the transition of cities and territories

Research focuses

In recent decades, the uncontrolled growth of urban cities and the soils sealing, have brought to light the need to change direction with new development paradigms for cities and territories in order to allow them to continue living without harming or losing existing ecosystems (Dramstad et al., 1996, Munafò, 2020; European Union, 2012). Furthermore, in the last few years also, one of the Coronavirus effects was the reactivation of reflections about the relation among natural and urban environments. The countryside, the hamlets, the inner areas, the small villages, became among the most valuable places to live, work, relax, and enjoy the everyday life. While urban areas are growing, expanding often-generating problems of congestion and pollution, other areas over Europe are suffering of an increasingly trend of depopulation and marginalization. More than 60% of European population live outside urban contexts (EU 2013, data refer to "intermediate regions" and "rural areas"). These phenomena are further aggravated because of their concomitance with the effects associated with climate change: formation of heat islands, increase in frequency and magnitude of drought and flooding periods. Therefore, a careful planning of water management, habitat conservation and ecological reconnection of natural environments is essential in order to change direction.

The doctoral position investigates the meaning and role of foodscapes in urban transformations through the lens of landscape design, transformation, and management with specific attention to water management and biodiversity enhancement. It deals with challenges connected to community structure, migrations, and demographic dynamics, as well as territorial transformations due to urban development and climate change impacts. Through a "research-by-design" approach, the candidate is expected to investigate the concept of regenerative foodscapes with a critical and theoretical perspective and to propose operational actions and tools to address more consistently foodscapes as part of the nature-based solutions (NBS) network with the collaboration of public administrations.

Specific topics

The doctoral candidate will specifically be devoted to investigating the values in the relation among the territorial resources of food and water systems as collective resources to protect and take care of territories, to create a territorial strategy, and to promote the enhancement of territorial natural capital. The research will aim to propose policies, actions, and practices as an innovative solution for the adaptive management of collective natural resources in urban areas. The research will specifically address the topic on the Trentino region as a testing ground, compared and confronted with national and

international case studies. The interdisciplinary and multiscalar methodology is based on a design research approach, including GIS mapping, literature reviews, interviews, surveys, participatory design, learning-by-doing, involving local communities, associations, administrators, and public authorities.

Expected outcomes of the PhD activity can be listed as follows:

1. literature review on landscape, food and water management dynamics in urban areas to develop a consistent theoretical framework;

2. mapping of urban/rural ecological systems and connections related to food dynamics on the case study area(s) in Trentino: data collection, maps and diagram elaborations, policy tools collection and analysis, communities' needs;

3. collection of national and international of best practices;

4. developing strategies and tools that are replicable and scalable;

5. communication and dissemination activities: attending national and international events and meetings and elaboration of reports and scientific publications (research papers, essays, etc.).

"Regenerative foodscapes for people and nature" wants to propose a PhD activity to train an interdisciplinary figure capable of intercepting the needs of professionals with the proactive thrusts of academic research according to a "Learning by doing" approach. At the end of the PhD program, the researcher will be able to manage innovative, interdisciplinary strategies for urban planning, integrating the aspects of landscape planning and design, biodiversity conservation, ecological connectivity with aspects related to the quantity and the quality of the water resource.