

# Doctoral Programme in Civil, Environmental and Mechanical Engineering

## Research subjects proposed for the 39<sup>th</sup> 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, **preferably** on one of the research themes suggested below. Candidates applying for a scholarship on a reserved topic (with an ID and in red) must write a project proposal related to the specific topic of the scholarship.

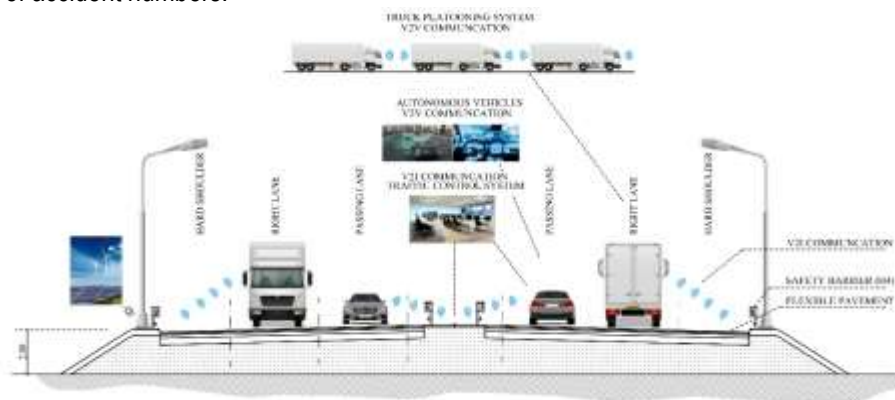
## Curriculum A - Civil and Environmental Engineering

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

### Title: Life Cycle Assessment of Smart Roads

#### Introduction

Smart roads (*cf. Figure*) are the new perspective of mobility. Smart roads can be defined as digitalized infrastructures compatible with the new assisted types of automated or semi-automated driving. In smart roads, vehicles exchange information with each other (Vehicle-to-vehicle technology "V2V") and with road infrastructures (Vehicle-To-Infrastructure technology "V2I"). Therefore, the transport system is generally safer than the traditional one (manually driven vehicles). Furthermore, on smart roads users are provided with real-time services by means of onboard vehicle devices and smartphones. In smart roads IOT (Internet of Things) systems allow structures (pavement, bridges, viaducts, tunnels) to be supervised in real-time by modifying the mode of ordinary and extraordinary maintenance, more precisely, by taking a proactive rather than reactive approach which is mostly the case nowadays. The benefits involving the infrastructure are considerable: lane capacity increase due to the reduction in the driver's perception and reaction times (human factor), reduction in the frequency of flow-breakdown phenomena (flow instability) and safety improvement resulting from the potential reduction of accident numbers.



#### Description

This project mainly focuses on the estimation of the environmental burden and energy consumption related to the construction, operation and maintenance of smart roads, compared to traditional ones.

Several case studies regarding smart roads in cut and embankment sections will be considered taking into consideration realistic traffic conditions. To evaluate the environmental sustainability of smart roads compared to traditional roads, a typical Life Cycle Assessment (LCA) will be applied.

In this research, the following software will be used: "SimaPro", "PaLATE", "Aimsun" and "COPERT".

The results of this project will be expressed by means of environmental impact indicators, including:

- energy and water consumption;
- global warming potential (GWP);
- human toxicity potential (HTP);
- air pollutants release;
- production of hazardous waste.

#### Outcomes

The main results of the proposed project will be published in scientific journals, book chapters and conference proceedings.

**Title: Reliability-Based Design Optimization of metastructures and metamaterials**

The primary objective of this project is to harness the potential of metastructures and metamaterials through the application of Reliability-Based Design Optimization (RBDO). The application of RBDO to metastructures and metamaterials represents a groundbreaking approach that has the potential to have a significant impact on the design and performance of complex structural systems. Metastructures, composed of interconnected finite periodic and quasi-periodic substructures, offer remarkable design possibilities and multifunctional capabilities. Similarly, metamaterials possess extraordinary properties at smaller scales that are not found in nature, such as negative refractive index, acoustic cloaking, and electromagnetic wave manipulation. By integrating reliability-based optimization techniques, engineers can systematically account for uncertainties in material properties, loading conditions, and other design parameters, thereby ensuring enhanced structural integrity, performance, and robustness while minimizing the risk of failure.

RBDO, in the context of metastructures, involves the formulation of optimization problems that maximize structural reliability taking into account uncertainties, often measured by probabilistic metrics such as the reliability index or the probability of failure. Through an iterative process, the design is refined based on these reliability measures, leading to metastructures that exhibit high performance, resilience, and safety in various operating conditions. This optimization approach enables engineers to consider multiple factors affecting structural reliability, including manufacturing tolerances, material property variations, and environmental loads.

Metamaterials instead, are engineered materials with unique properties not found in natural materials. They are designed to exhibit unconventional mechanical, thermal, acoustic, or electromagnetic characteristics. By incorporating reliability-based optimization into the design of metamaterials, engineers can account for uncertainties associated with their fabrication processes and material properties, ensuring that the resulting metamaterials meet the desired performance and reliability requirements. This approach allows for the exploration of optimal configurations, metamaterial compositions and microstructural designs that maximize reliability and functionality.

The application of reliability-based optimization to metastructures and metamaterials opens up exciting possibilities for designing innovative structures and materials in various industries based on the wave expansion method. In aerospace engineering, for instance, metastructures and metamaterials can be optimized to achieve lightweight yet robust aircraft components, leading to improved fuel efficiency and reduced emissions. In civil engineering, reliability-based optimization can be employed to design resilient structures capable of withstanding extreme weather events and seismic activities using the same wave-based approach.

Furthermore, in the automotive industry, this approach can contribute to the development of safer and more efficient vehicles through the design of crash-resistant metastructures and energy-absorbing meta-materials.

In sum, the innovative integration of reliability-based optimization techniques with metastructures and meta-materials represents a powerful approach for advancing the design and performance of complex systems. By accounting for uncertainties and maximizing structural reliability, engineers can create innovative and robust structures and materials that push the boundaries of what is achievable in terms of performance, efficiency, and safety. This interdisciplinary approach holds great promise for revolutionizing various industries and enabling the development of next-generation technologies.

Along these lines, the project aims to meet the following objectives:

- Implement the RBDO framework for deterministic metastructures and metamaterial subjected to random inputs
- Implement the RBDO framework for random properties of metastructures and metamaterials
- Implement the RBDO framework for meta-structures and metamaterials with spatial variability of material properties and time-variant stochastic inputs
- Write 2/3 papers
- Develop and integrate a computational toolbox for RBDO of metastructures and metamaterials.

- **Reference persons:** A. Siviglia (UNITN/DICAM), H.A. Dijkstra (Utrecht University affiliated to DICAM), M. Toffolon (UNITN/DICAM)

**A1 - scholarship on reserved topics**

Funded by: University of Trento – Department DICAM

**Title: Chaos and morphological predictions in fluvial and tidal systems**

**Background:**

Traditionally, hydraulic engineering has relied on deterministic models to predict the morphological evolution of rivers and tidal systems. However, recent studies suggest that the complex and nonlinear interplay between flow and sediment transport, particularly when vegetation is present, may lead to chaotic behavior. As a result, there is a growing need for further research to understand the processes and to develop novel approaches that include stochastic models and ensemble methods to quantify the uncertainty of the results, similar to what is done for numerical weather prediction.

**Research Questions:**

This PhD project aims to investigate the chaotic behavior that can occur in the morphological evolution of fluvial and tidal systems. The study will address the following research questions:

1. What are the mechanisms that lead to chaotic behavior in fluvial and tidal systems, especially when influenced by vegetation?
2. Can we develop models and tools to predict the morphological trajectories in fluvial and tidal systems and quantify the uncertainty?
3. Can we develop a common approach for fluvial and tidal systems?

**Methodology:**

The project will use a range of methods, including numerical simulations, laboratory experiments, and field observations, to investigate these research questions. We will use existing models and develop new ones to simulate the dynamics of fluvial and tidal systems influenced by vegetation. We will also use analytical tools from chaos theory to identify and quantify chaotic behavior in the models. Finally, we will validate the models and test their prediction skill using field observations.

**Approach:**

This project will focus on mathematical and numerical modeling of hydro morphodynamic and ecological processes. As a first step, we will explore the deterministic models in more detail by determining the characteristics of the chaotic behavior, specifically by clarifying the route to chaos and its consequences for the predictability horizon. Next, we will use the stochastic approach and ensemble methods to make predictions of the morphological evolution of both fluvial and tidal systems.

**Dissemination and Impact:**

Publications on the methodological aspects, in particular the results from the novel stochastic models, will mainly be in scientific journals. The identification and understanding of clear predictability barriers will have substantial impact on the field of geomorphodynamics.

**Characterization of the PhD candidate:**

The successful candidate will have an engineering, mathematical, or physics background, strong programming skills (e.g. C++, FORTRAN, Python, MATLAB), and the ability to perform model work at the interface between hydraulics and ecology.

Fluent spoken and written English, as well as good communication skills, are required.

**- Reference person: Alberto Bellin (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: Hybrid Machine Learning and Process-based modeling in environmental applications**

Modeling of natural processes has received a significant burst in the last years thanks to the escalating computational power and availability of data from satellite and near surface surveys, citizen science, new sensors and from large scale modeling of climate in environmental applications. Data are also accumulating on the impact of environmental pollution on human and freshwater ecosystems health. These paradigmatic changes paved the way to the application of Machine Learning algorithms in sectors, such as that of water resources and environmental pollution, traditionally addressed with process-based models.

One of the main challenges of environmental modeling is the interplay between physical and bio-geochemical processes occurring in a heterogeneous media or environment. Heterogeneity, combines with uncertainty, including unknown uncertainty, i.e. uncertainty that exists but cannot be identified (see Rubin et al., 2018). Uncertainty is unavoidable in modeling natural processes and it originates from two sources: media or environment heterogeneity in which the processes occurs and the inability of the model to fully capture process dynamics. Better parametrizations of the physical processes may alleviate the impact of the second source of uncertainty, but the first one is difficult to handle due to our limited ability to model the disordered spatial variability of media properties. The progressive increase of data availability and the development of data- driven methods open new perspectives in handling uncertainty in modeling natural processes and their interplay with the human activities.

The proposed research will focus on the different evolutions of the Neural Networks and will be developed along two main directions: 1) the inclusion of physical constraints into the ML algorithms with the objective of excluding unphysical connections among the neurons and the development of new activation functions compatible with the process under investigation; 2) development of hybrid models taking advantage of the capability to learn from the data of the ML algorithms and the respect of physical constraints typical of process-based approaches.

The research will be conducted in one or more of the following areas:

- 1) Impact of water (over)exploitation, droughts and climate change on water resources. Here a hybrid model combining the capability of process-based models with data-driven approaches is expected to provide enhanced modeling capabilities and provide reliable estimates of water resources. Focus will be here on groundwater which is indeed a critical water resources endangered by overexploitation, contamination and droughts;
- 2) Risk analysis and impact on human health of environmental contamination. This research aims at identifying the nexus between pollution indicators (possibly simple to determine) and human health in impacted areas. High levels of contamination with the most relevant impact on human health occur often at specific locations (hot spots) and specific time (hot moments) and identifying them requires new modeling paradigms;
- 3) Modeling the interplay between renewable energies and their effect on the timing of hydropower production leading to streamflow alteration. This theme is relevant because the energy crisis and the progressive transition to renewable energy sources renewed the interest on hydropower systems, which management is expected to change in view of the growth of other renewable sources (i.e., solar and wind). In fact, reversible (pump storage) systems are a valuable alternative to batteries for accumulating solar and wind energy when they peak. In the presence of significant alterations of the natural regime due to hydropower exploitation process-based hydrological models show typically low performances (because hydropower data are often not available), while data-driven approaches are more flexible and may help in identifying unknown nexuses among the data and provide new visions in this important energy compartment.

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

- Maria Grazia Zanoni, Bruno Majone, Alberto Bellin, 2022. A catchment-scale model of river water quality by Machine Learning, *Science of The Total Environment*, 10.1016/j.scitotenv.2022.156377.
- Xu, T., Liang, F., 2021. Machine learning for hydrologic sciences: An introductory overview. *Wiley Interdisciplinary Reviews, Water* 8, 1–29. doi:10.1002/wat2.1533.
- Nearing, G.S., Kratzert, F., Sampson, A.K., Pelissier, C.S., Klotz, D., Frame, J.M., Prieto, C., Gupta, H.V., 2021. What role does hydrological science play in the age of machine learning? *Water Resources Research* 57, e2020WR028091. doi:10.1029/2020WR028091.
- Thomas H. Miller, Matteo D. Gallidabino, James I. MacRae, Christer Hogstrand, Il Nicolas R. Bury, Leon P. Barron, Jason R. Snape, and Stewart F. Owen, 2018. Machine Learning for Environmental Toxicology: A Call for Integration and Innovation, *Environ. Sci. Technol.* 2018, 52, 22, 12953–12955, doi: <https://doi.org/10.1021/acs.est.8b05382>.

- Rubin, Y., Chang, C.-F., Chen, J., Cucchi, K., Harken, B., Heße, F., and Savoy, H.: Stochastic hydrogeology's biggest hurdles analyzed and its big blind spot, *Hydrol. Earth Syst. Sci.*, 22, 5675–5695, <https://doi.org/10.5194/hess-22-5675-2018>, 2018.



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

### **A3 - scholarship on reserved topics**

Funded by: iNEST - Interconnected Nord-Est Innovation Ecosystem (ECS00000043 – CUP E63C22001030007)

**Title: Water management and risk mitigation strategies to reduce the pollution associated to stormwater urban runoff by preserving the natural capital**

The point and diffuse sources of pollution of surface and groundwater environments linked to the presence of urban stormwater drainage networks are widely recognized as one of the main causes for the loss of ecosystem services (e.g. carbon sequestration, chronic chemical contamination, etc.) and biodiversity of cities and downstream connected areas (Marsalek, 1991, Petrucci et al., 1994, Müller et al., 2020). Within this context, it is expected that the extreme events associated with climate change (e.g. floods and droughts) may exacerbate these contamination levels by: i) increasing the atmospheric deposition during dry periods and ii) increasing the wash-off of atmosphere and the erosive capacity of the runoff during extreme rainfall events. Moreover, the growing presence of contaminants of emerging concern (CECs e.g. heavy metals, organic micropollutants, pesticides, polycyclic aromatic hydrocarbons (PAHs), microplastics) introduces new challenges in the management of urban runoff (e.g. Li et al., 2012; Gasperi et al., 2014, Werbowski et al., 2021). In the recent years, in the management of stormwater drainage networks, increasing attention has been given to the application of Nature Based Solutions (NBS) (e.g. Browder et al., 2019) with the idea of exploiting the potential of the “natural capital” to improve the stormwater quantity and quality management (European Commission 2015, Lique et al., 2016, Frantzeskaki 2019).

Starting from this background, the PhD student will develop and apply innovative models and tools at different spatial (i.e. neighborhood areas, streets and urban landscape) and temporal (e.g. storm event, seasonal and annual) scales to evaluate the benefits of integrating in the built heritage some Nature Based Solutions (e.g. existing or planned wetlands, green roofs, bioretention systems, etc.) to: i) reduce the losses of ecosystem services and biodiversity, ii) predict the presence and fate of CECs in the fluvial receptors and iii) mitigate the effects of climate change in terms of both water quantity and quality management.

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

1. design and model, in different urban areas, new intervention strategies aimed at reducing the hydraulic-hydrological risk associated with extreme rain events;
2. develop a modeling tool to characterize the quality of stormwater and the fate of the CECs along the stormwater urban drainage network;
3. implement suitable NBS to improve the quality of rainwater and propose strategies for its reuse;
4. propose optimization/management strategies to exploit the potential of these techniques to improve the management of water quality of urbanized catchments.

The proposed research ranks in the context of the Italian National Recovery and Resilience Plan and in line with the iNEST (Interconnected Nord-Est Innovation) project. The expected results of this PhD scholarship are extremely innovative and in agreement with the aims of the European Green Deal (European Commission, 2019) to prevent and reduce pollution and to promote a sustainable use of water.

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):



Browder, G., Ozment, S., Rehberger Bescos, I., Gartner, T., Lange, G.-M. 2019. Integrating Green and Gray: Creating Next Generation Infrastructure. Washington, DC: World Bank and World Resources Institute. © World Bank and World Resources Institute. <https://openknowledge.worldbank.org/handle/10986/31430>.

European Commission, 2015. Nature-Based Solutions and re-naturing cities. Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities.

Frantzeskaki, N., 2019. Seven lessons for planning nature-based solutions in cities. Environ. Sci. Policy 93, 101–111. <https://doi.org/10.1016/j.envsci.2018.12.033>.

Gasperi, J., Sebastian, C., Ruban, V., Delamain, M., Percot, S., Wiest, L., Mirande, C., Caupos, E., Demare, D., Kessoo, M.D.K., 2014. Micropollutants in urban stormwater: occurrence, concentrations, and atmospheric contributions for a wide range of contaminants in three French catchments. Environ. Sci. Pollut. Res. 21 (8), 5267–5281. <https://doi.org/10.1007/s11356-013-2396-0>.

Li, W., Shen, Z., Tian, T. et al. 2012. Temporal variation of heavy metal pollution in urban stormwater runoff. Front. Environ. Sci. Eng. 6, 692–700. <https://doi.org/10.1007/s11783-012-0444-5>.

Liquete, C., Udias, A., Conte, G., Grizzetti, B., Masi, F., 2016. Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. Ecosyst. Serv. 22, 392–401. <https://doi.org/10.1016/j.ecoser.2016.09.011>.

Marsalek, J. 1991. Pollutant loads in urban stormwater: review of methods for planning-level estimates. JAWRA Journal of the American Water Resources Association, 27: 283-291. <https://doi.org/10.1111/j.1752-1688.1991.tb03133.x>.

Müller A, Österlund H, Marsalek J, Viklander M., 2020. The pollution conveyed by urban runoff: A review of sources. Sci Total Environ. 709:136125. <https://doi.org/10.1016/j.scitotenv.2019.136125>. Epub 2019 Dec 18. PMID: 31905584.

Petrucchi, G., Gromaire, M.C., Shorshani, M.F., Chebbo, G., 2014. Nonpoint source pollution of urban stormwater runoff: a methodology for source analysis. Environ. Sci. Pollut. Res. 21 (17), 10225–10242. <https://doi.org/10.1007/s11356-014-2845-4>. Epub 2014 Apr 24. PMID: 24760596.

Werbowski, L.M., Gilbreath, A.N., Munno, K., Zhu, X., Grbic, J., Wu, T. et al. 2021. Urban stormwater runoff: a major pathway for anthropogenic particles, black rubbery fragments, and other types of microplastics to urban receiving waters. ACS ES&T Water, 1, p. 1420. <https://doi.org/10.1021/acsestwater.1c00017>.

## Curriculum B - Mechanics, Materials, Chemistry and Energy

- **Reference persons:** Maria F. Pantano (UNITN/DICAM), Alvis Bagolini (FBK)

**B1 - scholarship on reserved topics**

Funded by: University of Trento – [Fondazione Bruno Kessler](#) (FBK)

**Title: Development of high-performance MEMS inertial sensors**

Nowadays, microelectromechanical systems (MEMS) represent a well-established class of miniaturized devices integrating both mechanical and electrical components onto the same silicon board, fabricated together via photolithography-based process, which enables small device footprint, high sensing/actuating performances, low-power consumption, and mass production. MEMS devices, with particular reference to inertial sensors, are commonly applied in a variety of fields, ranging from consumer electronics to automotive industry, and have enabled novel functions and opportunities of the systems where they have been applied (e.g., screen rotation in mobile phones). However, they are still scarcely used in high-demanding applications, such as aerospace, because of insufficient sensitivity and stability, stemming from technological limitations affecting current fabrication strategies. In this research project, novel technological solutions and mechanisms will be sought to develop MEMS inertial sensors based on Silicon-On-Insulator (SOI) wafer micromachining to enable enhanced sensitivity and low noise, compared to standard devices. Different layouts will be developed and their mechanical and electromechanical performance compared through both analytical and numerical models, based on Finite Elements Method (FEM). The optimized layouts will be then fabricated and experimentally validated.

**Reference person: Oreste S. Bursi (UNITN/DICAM)**

Participants: Marco Broccardo (UNITN/DICAM), Giacomo Oliveri (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: Metamaterials and metasurfaces for mechanical or space applications**

The goal of this thesis is to introduce a holistic approach to the design of metamaterials and metasurfaces for mechanical and/or space applications. Wave focusing and energy harvesting at ultralow frequencies should be tackled. Nonetheless, electromagnetic issues for frequencies between 10 GHz – 20 GHz and both far- and near-field radiation control should be considered. Moreover, thermal, structural and random -geometrical and material - issues should be part of the design. In this respect, novel concepts are going to be explored, like structured fabrics that derive their properties both from the constitutive materials and their geometry. Therefore, their design can target desirable characteristics, such as wave focusing of mechanical waves, high impact resistance, thermal regulation or electrical conductivity. Also, multifunctional properties of chiral mechanical metamaterials can be explored in view of vibration attenuation and bandgap features, impact energy absorption and negative coefficient of thermal expansion.

By means of this approach, for instance, the control of the aperture field above the metasurface could be pursued to generate the desired radiation pattern. Thus, arbitrary aperture distribution could be generated with control on amplitude, phase and polarization. The objectives of this thesis are summarized below:

- 1- Use of structured fabrics for tunable mechanical properties
- 2- Adoption of chiral mechanical metamaterials for multifunctional applications
- 3- Metamaterials and metasurfaces capable of generation with arbitrary phase and amplitude distribution radiation patterns in the case of EM waves
- 4- Validation of the design procedure with numerical simulations and experiments capable of taking into account uncertainty issues.

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

**B3 - scholarship on reserved topics**

Funded by: Project HORIZON EUROPE ERC 2022 COG S-FOAM, GA n°101086644 – CUP E63C23000510006

**Title: Enhancing Self-Foldability and Shape-Morphing in Origami/Kirigami-Based Metamaterials**

We present a captivating opportunity for the best students to work in the field of architected materials and origami-based metamaterials. The objective is to implant origami/kirigami capabilities within architected cellular structures at different scales, paving the way for metamaterials with unparalleled mechanical performance. By combining multistability, control of localized deformation, and ellipticity loss, we aim to unlock a groundbreaking capability: self-foldability and shape-morphing induced by external stimuli. Through this innovative research, we will develop theoretical models, leveraging topological inhomogeneities in origami-based metamaterials, to achieve reprogrammable frustrate states, tunable mechanical properties, spontaneous buckling, and foldability. To advance our understanding, we will utilize Floquet-Bloch asymptotic homogenization as a powerful tool for determining a continuum equivalent to origami frustrated metamaterials. Furthermore, our investigation will involve rigorous numerical testing using both standard commercial finite element (FE) software and dedicated origami software. In summary, this research aims to create metamaterials with extraordinary mechanical properties. By integrating origami/kirigami techniques, we will unlock self-foldability and shape-morphing capabilities, enabling structures to adapt and respond to external stimuli.

## Curriculum C - Modelling and Simulation

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

### **C1 - scholarship on reserved topics**

Funded by: University of Trento – Department DICAM

**Title: Innovative methods in Monitoring and Uncertainty Quantification of critical bridges**

Candidates interested in this scholarship can develop their research project on one of the following sub-topics:

#### **Project 1 - Stochastic simulator-based uncertainty quantification for fluid induced seismicity**

Fluid-induced seismicity holds paramount importance in the context of energy production and carbon sequestration. As we strive to meet the increasing global energy demands and mitigate climate change, technologies such as hydraulic fracturing (fracking) for unconventional oil and gas extraction, as well as underground injection of carbon dioxide (CO<sub>2</sub>) for carbon capture and storage (CCS), have gained prominence. However, these activities can trigger seismic events due to fluid injection, extraction, and migration deep within the Earth's subsurface. Understanding and managing fluid-induced seismicity is imperative to ensure the safe and sustainable implementation of these energy and environmental practices. Applying stochastic simulators to fluid-induced seismicity allows for the quantification of uncertainties, providing a comprehensive framework for understanding and managing the risks associated with fluid injection. Uncertainty quantification is a crucial aspect of this approach, as it enables decision-makers to assess the reliability and confidence of the simulation results.

Stochastic simulators consider the inherent uncertainties and variations in the system by generating a range of possible outcomes. By conducting multiple simulations with different parameter settings and modeling assumptions, these simulators capture the probabilistic nature of fluid-induced seismicity. The resulting ensemble of simulations provides a distribution of possible seismic responses from which key statistical measures can be derived, such as mean values, standard deviations, and probability distributions.

Uncertainty quantification based on stochastic simulators encompasses both epistemic and aleatory uncertainties. Epistemic uncertainties arising from incomplete knowledge or understanding can be addressed through inversion techniques and data assimilation, as mentioned earlier. This process allows for the reduction of epistemic uncertainty by updating the uncertain parameters based on observed data.

Aleatory uncertainties, representing inherent variability, are expressed by means of spatial-temporal random fields, and they are irreducible by nature. Statistical analyses can be performed to characterize the variability in seismic responses and provide insights into the range of possible outcomes. This information is invaluable for decision-making, as it helps assess the likelihood of different levels of seismic activity and associated risks.

Uncertainty quantification based on stochastic simulators also enables sensitivity analysis, as mentioned earlier. By systematically varying input parameters and observing the resulting changes in the seismic response, the sensitivity of the simulation outputs to different factors can be assessed. This analysis aids in understanding the relative importance of different sources of uncertainty and guides the allocation of resources for further investigation or risk reduction measures.

In summary, the application of stochastic simulators to fluid-induced seismicity not only captures the inherent uncertainties and randomness of the process but also allows for their quantification through uncertainty quantification techniques. This comprehensive framework enhances decision-making by providing probabilistic information about the seismic risks associated with fluid operations. It promotes a better understanding of the uncertainties involved, assists in the optimization of operational strategies, and contributes to the development of robust risk management practices in the energy industries.

The project objectives are the following:

- Develop a physics-based stochastic simulator
- Develop a surrogate model for stochastic simulators
- Robust computation of fluid induced seismicity based on forward UQ analysis using stochastic simulators
- Sensitivity analysis with respect to fluid seismic risk to rank the critical parameters and related uncertainties
- Write 2/3 papers

#### **Project 2 - 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 person: Giacomo Oliveri (UNITN/DICAM)**

Participants: Andrea Massa (UNITN/DICAM), Paolo Rocca (UNITN/DICAM)

#### **C2 - scholarship on reserved topics**

Funded by: Project CN1 - "National Centre for HPC, Big Data and Quantum Computing, Spoke 7 (CN0000013 - CUP: E63C22000970007)

**Title: Innovative Wave-Manipulation Multiscale Metamaterial Design for the Smart Electromagnetic Environment**

The next-generation telecommunication systems are envisaged to fulfill unprecedented requirements in terms of data transfer speed, flexibility, coverage, reliability, and quality-of-service while relying on sustainable (i.e., energy-efficient and cost-effective) technologies. The need to meet such ambitious expectations is motivating a deep re-visitation of the paradigms currently adopted in the design and the deployment of wireless communication networks. As a matter of fact, the transition between subsequent wireless communication generations has traditionally consisted in upgrading the technological solutions of the user terminals as well as of the provider base stations and network. On the contrary, the propagation environment has been considered as a fundamental, but essentially uncontrollable, element/actor of the wireless scenario. This viewpoint is being completely overrun by the emerging paradigm of the Smart Electromagnetic Environment (SEME). The transformative SEME vision originates from the key idea that the wireless propagation can be partially controlled by properly "tailoring" the reflection by walls, buildings, and urban structures. In the SEME scenario, the environment is no longer an uncontrollable part of a wireless system, but rather it can cooperatively support the propagation to improve the coverage, the data rate, and the network reliability without the need to install additional base stations or access points. Within this framework, the research initiatives carried out by the members of the ELEDIA@UniTN team at DICAM have been focused on both (a) the opportunistic exploitation of the environment to increase the performance of existing wireless systems and (b) the design of ad-hoc solutions to enable the transition towards a SEME.

The objective of the PhD research activity will therefore be the study, modelling, design, and validation (both numerical and experimental) of innovative technological solutions enabling the SEME, focusing on the design of innovative 2D/3D wave-manipulation multiscale metamaterials able to reflect and/or transmit the electromagnetic (EM) waves in an arbitrary/desired way.

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 material engineering to advanced numerical modelling, as well as applications of optimization methods and machine learning techniques for their analysis and 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, partially in the framework of the project "National Centre for HPC, Big Data and Quantum Computing (CN HPC)" funded by the European Union - NextGenerationEU within the PNRR Program (CUP: E63C22000970007), Spoke 7 "Materials and Molecular Sciences".

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

1. Review and analysis of the literature on EM wave-manipulation materials, with focus on their functionalities and the design methods;
2. Study and development of novel techniques for the design of new 2D/3D wavemanipulation multiscale metamaterials for their use in the SEME context;
3. Design and numerical validation of static and reconfigurable multiscale metamaterials for tailoring the reflection and/or transmission of the EM waves;
4. Integration of the material design in 3. within SEME environment and simulation of the physical/EM and functional/communication behavior;
5. Development of selected prototype solutions and performance verification.

Suggested selected references:

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- [4] G. Oliveri, et al., "Holographic smart EM skins for advanced beam power shaping in next generation wireless environments," *IEEE J. Multiscale Multiphys. Comput. Tech.*, vol. 6, pp. 171-182, Oct. 2021.
- [5] P. Rocca, et al., "On the design of modular reflecting EM skins for enhanced urban wireless coverage," *IEEE Trans. Antennas Propag.*, vol. 70, no. 10, pp. 8771-8784, Oct. 2022.
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**- Reference persons: Andrea Piccolroaz (UNITN/DICAM), Davide Bigoni (UNITN/DICAM), Luca Deseri (UNITN/DICAM)**

### **C3 - scholarship on reserved topics**

Funded by: Project CN1 - "National Centre for HPC, Big Data and Quantum Computing, Spoke 7 (CN0000013 - CUP: E63C22000970007)

**Title: Exploring instabilities and bifurcations for advanced metamaterials**

The goal of the research project is to investigate instabilities and bifurcations in non-hyper-elasticity and their application in the design and development of advanced metamaterials. Non-hyper-elastic materials exhibit unique mechanical behaviors, such as flutter instability, Ziegler paradox, and self-oscillation, which can be achieved through instabilities and bifurcations.

The project will involve a combination of theoretical analysis, numerical simulations, and experimental validation. Theoretical models will be developed to understand the complex interactions between instabilities and nonlinear dynamics

in deformable structures. Numerical simulations will be conducted to analyze the behavior of two- and three-dimensional grids of elastic rods subjected to dynamic excitation and various types of constraints.

The research project aims to break the limitations of hyper-elasticity and push the boundaries of material deformability. By harnessing non-hyper-elastic effects, we seek to create metamaterials that can absorb and deliver energy to the environment, enabling applications in energy harvesting or dissipation. Furthermore, the control and manipulation of mechanical signals through non-hyper-elasticity will be explored, paving the way for the development of novel metamaterials capable of guiding and conditioning signal propagation.

The outcomes of this research project will contribute to the advancement of material science and the design of innovative metamaterials. The developed theoretical models, numerical tools, and experimental findings will provide valuable insights into the utilization of non-hyper-elasticity in various fields, including robotics, energy systems, and signal processing.



**- Reference persons: Oreste S. Bursi (UNITN/DICAM), Giacomo Oliveri (UNITN/DICAM)**

#### **C4 - scholarship on reserved topics**

Funded by: Project CN1 - "National Centre for HPC, Big Data and Quantum Computing, Spoke 9 (CN0000013 - CUP: E63C22000970007)

**Title: Innovative metamaterials and metastructures for risk reduction and fitness for service of special risk industrial plants**

To tackle the mitigation of natural-technological (NaTech) events, the PhD candidate has to propose innovative metamaterial-based solutions for disaster reduction in special risk facilities and methods to increase nearby community resilience. To achieve this scope, the relevant project builds upon the most recent innovative scientific and technological concepts developed within the research field of locally resonant phononic metamaterials. In particular, the feasibility of such metamaterial-based isolation concepts and systems has also been demonstrated across different low- frequency ranges, e.g. from seismic to acoustic waves. These general developments have further advanced through novel absorption and isolation concepts which can achieve negative effective mass and stiffness moduli in media and structures and through nonlinear mechanisms such as bistability. Also, impact-based mechanisms and relevant devices, e.g. nonlinear energy sink devices, can easily reduce vibrations via energy transfer to higher modes.

Therefore, the PhD candidate should try to conceive and develop: i) metamaterials and/or metastructures capable of rendering industrial plant equipment fully or partially isolated from the effects of incident waves impinging from all directions; ii) modelling and simulation procedures based on both high-fidelity and surrogate models (digital twins) for the quantification of fragility and recovery functions and the reduction of risks that derive from NaTech events and fitness for service; iii) periodic metamaterials and structures for energy harvesting in view of localized structural health monitoring of critical equipment.

## **Curriculum D - Architecture and Planning, Landscape**

**- Reference person: Claudia Battaino (UNITN/DICAM)**

**Title: Rehabilitate people and spaces of the city. The prison that does not yet exist**

### **Background**

In recent years, the space of detention, understood as the place of rehabilitation and socialization, which the prison is called to answer in its main purpose, is an emerging problem [1]. The limits, living conditions, overcrowding and age of Italian prisons make it necessary to evaluate the assets, the search for strategies and innovative project models [2]. In fact, the quality and adequacy of spaces affect the behaviour of prisoners and users, who even in confined spaces must have a dignified life [3]. The architectural quality of the prison is a complex issue that is intertwined with the urgency of recovering the existing heritage in a state of decay, and finally with the identification of creative policies of urban requalification and in line with European countries. The realization, or forecasting, removal of the project of new prisons, i.e. the choice of the greatest possible distance from urban centers, risks generating forms of marginalization and spatial and social isolation, which must be evaluated for the development of decision support to urban planning [4].

## Research goals

The aim of the research is to develop new guidelines, models and strategies for prison design in line with European and international regulations. Secondly, the development of knowledgeable strategies for prison's heritage, that can provide new opportunities for urban redevelopment [5].

## Methods

An interdisciplinary outlook will be applied for an innovative approach that leads to identify the characteristics and perception of detention spaces, possible architectural design strategies, and the heritage recovery project. The research will be conducted, in different territorial areas, in close contact with inmates and the population in order to intercept social needs and establish physical relationships with the real places of the city. The research will follow the "learning by doing" method through design experimentation and the direct involvement of people living and working in prison. The possibility of activating workshops between architecture students is envisaged.

The ideal candidate should have a strong spatial aptitude, at the architectural and urban scale, an excellent knowledge of the main graphic representation techniques, a background in Architecture and Building Engineering as well as motivations for personal growth and a positive attitude to invest in communities and cultural models that are not yet fully known or shared.

## Expected outcomes

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

- Comparative analysis of international case studies.
- Development and experimental application of strategies for the innovative design of detention spaces.
- Identification and evaluation of prison assets for the participatory recovery projects.
- Papers on international Journals and participation to conferences.

## References

- [1] AA.VV. (2016) "Technical guidance for prison planning. Technical and operational considerations base on the Nelson Mandela Rules", UNOPS, Copenhagen.
- [2] B.A.M., Hoffs, B.A.M. (2014) "Begin Again. New prison design which supports the process of rehabilitation", Eindhoven University.
- [3] L.Bernheimer, R. O'Brien et al.(2017), "Wellbeing in prison design. A guide", Matter Architecture, London.
- [4] E.Fransson, F.Giofrè (2018) "Prison architecture and humans", Datapage India, Coimbatore.
- [5] M. Biagi (2012) "Carcere, città e architettura. Progetti per il carcere di San Vittore a Milano 2004-2009", Maggioli Editore, Milano.

**- Reference persons: Rossano Albatici (UNITN/DICAM), Francesco Babich (Eurac Research)**

Participant: Simone Torresin (UNITN/DICAM)

**D1 – research fellowship on reserved topics**

Funded by: [Eurac Research](#)

**Title: Dynamic and multi-sensory variability in indoor environments to transform comfort-energy trade-offs into opportunities for more flexible and healthier buildings**

Buildings contributes to a large portion of global energy consumption and related CO<sub>2</sub> emissions. In recent years, research has focused on reducing energy consumption and environmental emissions, while at the same time ensuring environmental conditions conducive to occupants' health and well-being. However, while building occupants are simultaneously exposed to multiple environmental stressors dynamically changing in space and time, most of research has focused so far on single environmental stimuli (i.e., either thermal, acoustical, visual or air quality), mainly considered as steady stressors.

Research is needed to investigate how human multi-sensory response to dynamic environmental stimuli can be acknowledged in buildings' control to ensure comfort and healthy conditions while reducing energy consumption. The PhD project will include investigations in the following fields: i) human response to multiple environmental stimuli, with description of combined and cross-modal effects; ii) human response to dynamic environmental stimuli; iii) assessment methods of human perceptual response to environmental stimuli (e.g., soundscapes, smellscapes); iii) control logics for Building Automation And Control Systems (BACS) taking into account aspects related to (spatial and temporal) dynamic variability and multi-sensory exposures. The research will target a specific building use (e.g. residential) and at least two domains (e.g. acoustics and indoor air quality), which will be defined at the beginning of the project.



Specific objectives and expected outcomes include:

1. A literature review on occupants' response to dynamic environments
2. The development of perceptual methods to study the affective response of occupants to specific environmental conditions, when not already available in the literature
3. The investigation of human response to combined stimuli along dynamic patterns
4. The development of algorithms to be implemented in BACS, building on the developed knowledge on multi-sensory response to dynamic environmental stimuli.

The PhD research will include lab experiments at the Eurac Research's experimental facilities, field studies and energy simulations.

The ideal candidate has a background in either architectural or building engineering. Previous experience in carrying out environmental measurements (objective and subjective) and tests with participants is desirable.

Contract details: gross amount for Research Fellowship (working contract to be signed): Euro 21.000,00 per year.

Duration of Contract: 36 months.

Contribution to cover the expenses related to the participation of the student in research and training activities (research-related costs, meetings, conference attendance, training actions, etc.).

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

## References

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- Mishra, A. K., Loomans, M. G. L. C., & Hensen, J. L. (2016). Thermal comfort of heterogeneous and dynamic indoor conditions—An overview. *Building and Environment*, 109, 82-100.
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**- Reference persons: Gianluca Maracchini (UNITN/DICAM), Simone Torresin (UNITN/DICAM)**

Participant: Francesco Aletta (University College London - UCL)

**D2 – scholarship on reserved topics**

Funded by: [HEAD-Genuit-Stiftung](#)

**Title: Development of a "Noise Footprint" framework**

Noise pollution is a major public health and environmental challenge that affects both individuals and the natural environment (European Environment Agency, 2020). It is becoming a serious concern and global action is needed to mitigate this problem (Aletta, 2022).

Measuring and quantifying the impact of noise pollution can be challenging due to the complexity of noise sources, the dynamic nature of sound phenomena, and the intrinsic variability of human responses to sound stimuli. To have a broader understanding of the problem often requires a multi-disciplinary approach that combines both physical measurement, subjective reporting, and epidemiological analysis. While noise pollution can still be spatially "monitored", either locally or at scale (European Union, 2002), there are limited ways in which one could quantify the "impact" that individual persons, groups, and buildings have in terms of noise on the environment, over time, i.e., their "footprint".

A "carbon footprint" is a measure of the total amount of greenhouse gases that are emitted into the atmosphere because of human activities. A "noise footprint" framework could be similar to a carbon footprint in that it would aim to measure and understand the impact of human activities, buildings and personal/collective choices on the environment in terms of noise pollution (The Lancet Regional Health – Europe, 2023). It would involve measuring the total amount of noise that is emitted into the environment because of different activities and sources, in this case with a specific focus on the design of the built environment.

The scientific literature on the concept itself of a "noise footprint" is relatively limited (see, e.g., Cucurachi et al., 2019) compared to other environmental impact metrics such as carbon footprint. There is still much research that needs to be done to fully develop and implement such a framework.



A key research question is how the noise footprint can be reduced and what compensatory measures and interventions can be taken at the district, building and human scale. One answer comes from the soundscape approach (International Organization for Standardization, 2014), which considers the acoustic environment as perceived by humans in context. According to this perspective, sound stimuli are not necessarily a source of pollution (i.e., noise) but can also be a resource for the creation of healthier built (Aletta & Kang, 2019) and natural environments (Truax, 1978). In this context, soundscape interventions can not only reduce the noise footprint and provide compensatory measures, but even reverse the impact on the environment and society, generating positive outcomes (Steele et al., 2019). This novel perspective will be implemented in the development of a “noise footprint calculator”.

Specific objectives and expected outcomes are:

1. Conducting a scoping/narrative literature review on the concept of “noise footprint” – previous attempts, possible references, in both scientific and grey literature – with particular reference to the built environment. This will be accompanied by a workshop/focus group with relevant stakeholders;
2. Defining a “unit” to characterize the noise footprint;
3. Defining methodology/framework for calculating the Noise Footprint;
4. Prototyping a free web Noise Footprint calculator;
5. Testing/validating Noise Footprint calculation framework with real-world case studies (e.g., building design).

The ideal candidate has a background either in architectural and/or environmental acoustics or in environmental impact assessments, together with an interest in developing knowledge in acoustics related to the built environment.

## References

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