Doctoral Programme in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 38th cycle

A mandatory attachment of the application is **a description of the research project and statement of purpose** (max. 3 pages) relative to the research areas of the Doctoral Programme in Civil, Environmental and Mechanical Engineering, **preferably** on one of the following research subjects:

Curriculum A - Civil and Environmental Engineering

- *Reference person:* Alberto Bellin (UNITN/DICAM)

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 the availability of massive 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 two paradigmatic changes paved the way to the application of Machine Learning techniques in sectors, such as that of water resources and environmental pollution, traditionally addressed with process-based models and also plagued by data scarcity. One of the main challenges of environmental modeling is the need to represent complex phenomena with limited data availability and this increases uncertainty in modeling response, 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: the heterogeneity of the media or the environment 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. A large body of literature is available on the impact of uncertainty on the process-based models, but much less in the data-driven approach traditionally developed in fields in which the question to answer was simple with respect to the complexity and richness of the underlying processes, and in most cases representing the process leading to the observed complexity was not an objective of the analysis, as in image interpretation for example. In this case, uncertainty in the underlaying processes does not affect, or exerts a limited influence, the answer the modeler is seeking. Unfortunately, this is not the case in environmental applications, where the interest is on the full dynamics, which is decisively impacted by uncertainty.

The 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 and climate change on subsurface (groundwater) 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 groundwater resources. Groundwater is indeed a critical water resources, which is endangered by overexploitation and contamination;
2) Risk analysis and impact on human health of environmental contamination. This class of models are intended to identify 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 the different 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 is causing a boom of new hydropower systems with adverse effects on the streamflow and freshwater ecosystems that are expected to be relevant and for this reason they need to be explored. In the presence of significant alterations of the natural regime due to hydropower exploitation process-

based models show typically low performances, 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:

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 in- troductory 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, ‖ 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 person:* Lorenzo Giovannini (UNITN/DICAM)
Participants: Nadia Vendrame (UNITN/C3A), Dino Zardi (UNITN/DICAM)
A1 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM (Euregio project “IPN187” INTERFACE - CUP E65F21003390003)

Title: Investigating the role of local and mesoscale circulations in the surface energy balance closure over mountain areas

The surface energy balance, i.e. the partitioning of the energy exchange between the Earth’s surface and the atmosphere, plays an essential role in determining atmospheric processes in the planetary boundary layer. An accurate assessment of its components is therefore crucial for a variety of applications. However, measurements of the surface energy balance terms are still affected by uncertainties. In particular, turbulent heat fluxes measured with the eddy-covariance technique generally do not balance the available energy. Several studies claim that the main reason for this gap is connected to the advection induced by secondary circulations, which can be present even over homogeneous surfaces in convective conditions, but are more common over heterogeneous and complex terrain, as a consequence of differential heating. The systematic lack of closure of the surface energy balance, besides representing an important gap in our understanding of the available energy distribution and in the interpretation of observations, poses various limitations in the use of experimental data for several applications. For example, surface energy balance measurements are used to validate land surface parameterizations implemented in meteorological and climate models, where the closure of the surface energy balance is strictly imposed. Therefore, the comparison between model results and observations is plagued by the uncertainty in the experimental values. Different studies suggest that the uncertainty in the experimental measurements of the surface energy balance components is also critical for the estimation of CO_2 fluxes, with obvious repercussions on the evaluation of the carbon cycle. The non-closure of the surface energy balance is particularly important also for several agrometeorological applications, which adopt simple models to determine the potential or actual evapotranspiration. The present research project aims at evaluating the uncertainties connected to the measurement of the surface energy balance at different sites in the Alpine environment, where processes related to the lack of closure are expected to be particularly significant. Measurements at sites located in different contexts and climatic settings, thus differently influenced by advection, will allow to investigate the relationship between the non-closure of the surface energy balance, the surface heterogeneity and the consequent development of different types of local and mesoscale circulations. Data from different sites in Trentino, South Tyrol and Tyrol will be analyzed, covering various morphological and surface conditions, representative of different topography and land cover, providing a unique testbed to evaluate the role of advection in the closure of the surface energy budget. The outcome from this analysis is expected to be an evaluation of the rate of closure of the surface energy balance at the different sites and under different meteorological conditions, with the aim, in particular, of identifying possible connections with flow conditions (especially the development of local and mesoscale circulations) and with the topographic

context. It is expected that this research project will provide, for the first time, a systematic quantification of the non-closure of the surface energy balance at several Alpine sites, investigating in detail the role of local and mesoscale circulations at locations where such phenomena are a well-known and well-researched characteristic of the local flow conditions. The research hypothesis is that the surface energy balance non-closure for characteristic sites (valley floor, slope, high-altitude) is distinct, but similar among the characteristic sites under comparable conditions. The successful candidate will work in the framework of the Euregio project "INTERFACE – Investigating the surface energy budget over mountainous terrain", in strict connection with research groups at the University of Innsbruck and at EURAC. The research project will also benefit from an unprecedented combination of advanced methodologies in different fields, thanks to the adoption of a sophisticated UAV platform, and the use of large-eddy simulations over complex terrain, which will help in the interpretation of eddy-covariance data. The results of the project will be presented at international conferences, such as the EGU General Assembly, the International Conference on Alpine Meteorology, the AMS Conference on Mountain Meteorology and the AMS Symposium on Boundary Layers and Turbulence. Moreover, results are expected to be published in peer-reviewed high-ranked international journals.

- *Reference person:* Giuseppe Formetta (UNITN/DICAM)
A2 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM (WATERSTEM MUR PRIN 2020 project - CUP E63C22000420001, reference number 20202WF53Z)

Title: Coupling vegetation dynamics, hydrological models, and high-resolution remote sensing data to understand onset and propagation of hydrological droughts in mountain regions

Alpine mountainous basins provide critical water supply and ecosystem services, yet these environments are increasingly at risk due to anthropogenic stressors and competition for water across urban, agricultural and environmental demands. On the top of this, future climate projections suggest a drier and warmer Mediterranean with large increases in the frequency, duration, and severity of hydrological droughts (i.e., runoff and groundwater levels below than normal) with serious consequences for the management of water resources and natural ecosystems. In spite of the recent progress in land surface monitoring, current drought estimation in widely used operational products still largely relies on poorly parameterized potential evapotranspiration, in combination with simple hydrological bucket models (e.g., drought indices) which have shown to lead to questionable results. As hydrological systems are intrinsically intertwined with climatological and ecological systems, the propagation of meteorological droughts (i.e., precipitation below than normal and higher temperatures) through them is modulated by a variety of mechanisms which are linked to carbon and water cycle interactions and specifically to how different plant species i) access subsurface water storages and ii) respond to water stress, high CO2 and high evaporative demand. Ignoring the parameterization of these mechanisms is often the norm in state-of-the-art land surface and hydrological models and impacts water balance closure via incorrect representation of transpiration leading to uncertainties in hydrological drought prediction. The ultimate goal of the project is to unravel the interactions between vegetation and water cycles as to understand the modulating effect of the vegetation on water-supply deficit (as opposed to the more frequently addressed meteorological drought) and its impact on water resources and natural ecosystems in mountainous regions. The work plan will focus on the Adige and the Po river basins and will employ a novel combination of field monitoring (soil water content, soil suction, meteorological measurements), remote sensing, data assimilation and ecohydrological models. The objective is to envision and implement a novel conceptual framework that will be used to translate the acquired scientific knowledge into practices to support water resources and silvopasture management. From a scientific point of view the novel framework will advance understanding of: i) hydrological droughts, ii) episodes of vegetation mortality (e.g., forest dieback) and iii) optimal water resource allocation. Specifically, it will focus on unravelling water exchange mechanisms in the CZ during drought across several spatial scales (at the plant scale, the stand, and the basin scale) and ii) build an integrated ecohydrological model able to describe more realistically transpiration, vegetation water uptake from subsurface water pools. The development of an integrated ecohydrological model requires a baseline hydrological model able to test multiple working hypotheses easily and objectively, thanks to a flexible software architecture which allows to easily modify the code model structure, consider new parameterisations and ingest observations.The GEOframe system was created with this philosophy in mind and its overall structure has to do with the representation and modelling of the quantification of the role of interactions among compartments as well as their non-linear effects. To reduce model uncertainties due to errors in input data or parameterizations in this project we exploit the assimilation of remotely sensed Earth observations such as soil moisture, leaf area index, NDVI and evapotranspiration. A better representation of the entire soil moisture profile along the soil column and will in turn improve the representation of water accessible to vegetation via simple and more advanced data assimilation techniques like Evolutionary Particle Filter. Expected results of the project are: i) a more realistic estimation of each component of the hydrological cycle (i.e. transpiration, runoff and storages), which is able to provide a more robust (and reproducible) closure of the water balance at basin scale, and ii) explain how they covary with ecosystems/vegetation and the landscape; ii) a new generation of component-based

ecohydrological models, able to describe the vegetation-storage interactions during hydrological droughts, which nowadays are affecting more and more basins in the Alpine region; iii) improve the water resource optimization addressing competing water needs (e.g. agriculture, hydroelectric power plants) based on more accurate representation of both hydrological processes and vegetation dynamic.

- *Reference person:* Marco Toffolon (UNITN/DICAM)
Participants: Atle Harby and/or Ana Adeva Bustos, SINTEF (Norway)

A3 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM

Title: Modelling ice dynamics and environmental impacts in hydropower reservoirs with pumped-storage operations

Hydropower systems represent a crucial element in the strategy of decarbonising energy production and reducing greenhouse gas emissions. In fact, hydropower can effectively balance the intermittent renewable energy production and provide large-scale balancing services. In addition, pumped-storage operations can exploit temporary extra-production by renewable sources, which also reflect into low energy prices, to transfer large water volumes from downstream to upstream reservoirs, yielding an increase of potential energy stored for periods with insufficient available energy and high prices. Even though a single pumped-storage operation is not efficient in energetic terms, in a global perspective these systems allow for a more efficient management of the different energy sources. Nevertheless, exchanging large water volumes between pairs of reservoirs has an impact on the environmental conditions that must be carefully evaluated.

The research questions to be addressed during the doctoral studies are the following.

1. Which is the impact of pumped-storage operations on water quality, heat content, thermal stratification, and ice formation, in the upper and lower reservoirs?
2. How does climate change interact with hydropower demands, and can pumped-storage operations mitigate the undesired effects?
3. How is ice formation affected, and can the ice sheet resist to large and frequent water level fluctuations in winter?

The analysis will be largely based on modelling, with available observations being used to calibrate and validate the models. Depending on the specific task, different types of models (from 0D to 3D) will be considered to simulate the hydro-thermodynamics of the water bodies, selecting from existing ones (e.g., MyLake, CE-QUAL-W2, Delft3D) or developing new conceptualizations, for instance to determine the mechanical behaviour of the ice sheet subjected to large vertical deformations especially at the shores.
Case studies will be selected for the analysis within the large number of lakes and reservoirs utilised for hydropower production in Norway.

The research is partially funded by the project "HydroConnect – Impacts of connecting Norwegian hydropower to continental Europe and the UK" (https://www.sintef.no/en/projects/2021/hydroconnect/) led by SINTEF (https://www.sintef.no/en/) with the participation of the Norwegian University of Science and Technology (NTNU, https://www.ntnu.edu/). During the PhD, a research period will be spent in Trondheim, Norway, to establish a direct collaboration with SINTEF and NTNU.

References:

- Bonalumi, M., F.S. Anselmetti, A. Wüest, and M. Schmid (2012), Modeling of temperature and turbidity in a natural lake and a reservoir connected by pumped-storage operations, *Water Resour. Res., 48*, W08508, DOI: 10.1029/2012WR011844
- Kobler, U.G., and M. Schmid (2019), Ensemble modelling of ice cover for a reservoir affected by pumped-storage operation and climate change, *Hydrological Processes, 33*, 2676–2690, DOI: 10.1002/hyp.13519
- Kobler, U.G., A. Wüest, and M. Schmid (2019), Combined effects of pumped-storage operation and climate change on thermal structure and water quality, *Climatic Change, 152*, 413–429, DOI: 10.1007/s10584-018-2340-x
- Müller, M., G. De Cesare, and A.J. Schleiss (2016), Flow field in a reservoir subject to pumped-storage operation – in situ measurement and numerical modeling, *Journal of Applied Water Engineering and Research*, DOI: 10.1080/23249676.2016.1224692

- Reference person: Sebastiano Piccolroaz (UNITN/DICAM)
Participants: Ulrike Obertegger (FEM), Hugo Ulloa (Univ. Pennsylvania), Henk Dijkstra (Utrecht University, DICAM)

Title: near-Surface processes in High ALtitude Lakes – SHALL

Lakes and reservoirs are mutually linked with the surrounding environment through the fluxes that cross their boundaries, particularly across the lake-atmosphere surface boundary. Heat, momentum, and mass fluxes at the air-water interface are the main drivers determining the response of lakes to external seasonal and longer-term variability. Through the same surface fluxes, inland water bodies also modulate the local climate, and there is increasing evidence about their relevant role on the global carbon budget and, as such, on the planetary-scale climate. Being able to quantify surface fluxes of inland waters requires measuring, understanding and characterizing near-surface processes occurring in these water bodies. These processes include turbulent mixing, thermal stratification, and biological activity, just to cite some of the most important. While direct measurements of these processes in large lakes are relatively accessible, the same observations for high altitude lakes are scarce, mainly due to operational constraints in executing fieldwork in remote, difficult to access lakes. Hence, for these lakes the characterization of near surface physical processes and surface fluxes still poses major scientific challenges, making the understanding of their contribution to regional and global (e.g., energy, carbon) budgets uncertain. This research project aims to quantify near-surface processes in high altitude lakes, their mutual interactions and in particular how these processes determine the surface fluxes. The candidate in collaboration with the research team will do so through a combined experimental and modelling research activity. The experimental activity will be primarily carried out at the LTER (Long-Term Ecosystem Research) site Lake Tovel (1178 m a.s.l.), in collaboration with the site manager Ulrike Obertegger. The field work will focus on the acquisition of water transparency data, multiparametric profiles, surface CO2 fluxes, meteorological data. Nearsurface velocity data and/or turbulence microstructure profiles are also expected to be acquired, the last in collaboration with Henk Dijkstra. The data will be acquired with equipment already available at DICAM, FEM and Utrecht University. Monitoring at Lake Tovel will be done monthly, aimed at characterizing the seasonal patterns, but 24-hour and exceptional monitoring campaigns will be organized to get insights into diel dynamics and investigate the effect of pulse disturbances. Occasionally, spatially distributed measurements will be collected to characterize the spatial variability and other high altitude lakes characterized by more turbid waters will be monitored. The acquired data will be used to investigate relationships and interactions between near-surface processes and surface fluxes, also through the development of simple analytical and numerical models as a support to data interpretation (in collaboration with Hugo Ulloa and Henk Dijkstra). Specifically, the acquired data will be used to: i) - characterize and quantify seasonal, daily, and sub-daily near-surface processes, fluxes, and their interactions; ii) - investigate the effect of small-scale stratification, shortwave/surface cooling competition, and change in water transparency on near-surface mixing and surface fluxes (with a particular focus on CO2 fluxes); iii) - investigate the spatial and temporal scales of the aforementioned processes. A quantification of surface fluxes in high-altitude lakes may have substantial impact on establishing the role of these lakes in the global climate system, which is of primary relevance considering that these lakes have been found to be particularly sensitive to climate change. The candidate will work in synergy with a multidisciplinary, international and multi-generational team composed of engineers, physicists, and biologists

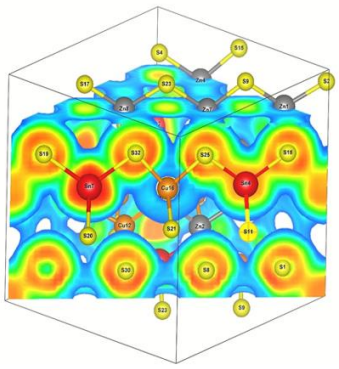
Curriculum B - Mechanics, Materials, Chemistry and Energy

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

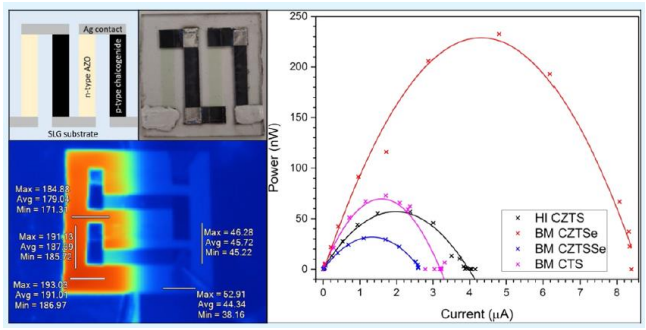
Title: Advanced Thermoelectric materials and generators

While thermoelectric generators (TEGs) have been known for decades for the recovery of waste heat and the general possibility of transforming thermal gradients into electricity, real applications require performances that are still far from what is allowed by traditional materials.
"Engineering" the structural disorder in semiconductor materials seems a promising solution that we have begun to explore: (i) experimentally, with the production of materials by high-energy reactive milling; (ii) by developing all necessary measurement and characterization techniques, and (iii) by means of the most advanced *ab initio* modeling techniques based on density functional theory (DFT) using high performance computing (HPC) facilities. The last challenge is (iv) to transfer all concept to working devices, especially thin film TEGs.
The thesis work involves a systematic exploration of the disorder introduced into chalcogenides (sulfides or selenides, in particular with 2,3 or more cations), to develop new, highly performing and sustainable thermoelectric materials. The last is

a strong point in the project, as we wish to consider materials and devices based on non-toxic, widely available and not expensive materials.
The thesis project is open to being experimental with a part theoretical/modeling-based, with a necessity to understand both aspects.
Part of the Thesis work can be carried out at the Max-Planck-Institut für Festkörperforschung of Stuttgart (D), in the group of Prof. R. Dinnebier; and other European large scale facilities.



Electron Localization Function (ELF) map calculated *ab-initio* (DFT), showing the disorder-induced inhomogeneity in kesterite (Cu2ZnSnS4) boosting the TE performance.
Isotta et al., Phys.Rev. Applied 14, 064073 (2020)



Thin film thermoelectric generators (TEG) based on (p-type) kesterite (CZTS or CZTSe) or Cu2SnS3 (CTS) and (n-type) Al-doped zinc oxide.
Syafiq et al., ACS Applied Energy Materials (2022)

Ideal candidates should be motivated towards an international research thesis, and have a background in Physics, Chemistry (or Materials, Energy, Industrial Engineering). Specific experience on thermoelectricity is highly considered. For more details, see also running activities on: energymaterials.unitn.it

Curriculum C - Modelling and Simulation

- *Reference persons:* Luca Deseri (UNITN/DICAM), Nicola Pugno (UNITN/DICAM)

Participants: Massimiliano Fraldi, Stefania Palumbo (Univ. Napoli-Federico II)

C1 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM

Title: Cells mechanotropism and tumor growth

This research aims to add a contribution to the multidisciplinary efforts to for helping cancer diagnosis and therapies. Indeed, there is still a very strong need for understanding mechanisms of cell polarization arising in processes like tissues morphogenesis, growth and remodeling. These are known to play a key role when cancerous cells aggregate reach critical masses to endanger single organs, sometimes spreading to metastasis overtime. In terms of tumor's targeted therapies, precision medicine earned a lot of attention in the last fifteen years, thereby calling for a better and quantitative understanding of the mechanobiology and multiphysics involved in cancer growth.
With the aim of contributing to deliver quantitative predictive methods for helping precision medicine against cancer, we propose to widen the studies performed in [1]. The latter is focused on the characterization of the interplay between cell's orientation and groups (named "fences") of given point forces. Indeed, cells interact with extracellular matrix by sensing external chemo-mechanical stimuli and then inducing formation of stress fibers mediated by polymerization/de-polymerization processes. These redesign the interplay between structural organization and contractility activities in the cytoskeleton, thereby tuning selected signal pathways governing many important cell's physiological functions like adhesion, migration and division. Previous evidence show that cells reorient by an almost pure mechanical response due to substrata geometrical changes arising during the processes mentioned above. In [1] this has been investigated essentially for single cells, by exploiting the interplay between cell's orientation and selected polygonal fences of prescribed point loads.
In the proposed research this methodology will be generalized to cell aggregates and to curved substrates, thereby owing more realistic geometries of tumors.

This method could be utilized for indirect AFM measurements of endogenous forces and stresses in the cell actin fibers. This would induce duplication or differentiation by favoring or enforcing homeostatic cells' stretches, and it could either envisage new mechanics-based markers for targeting cancer cells or it could allow for guessing pathological conditions from cells' mechanotropism.

References

[1] S. Palumbo, A.R. Carotenuto, A. Cutolo, L. Deseri, N. Pugno, M. Fraldi, Mechanotropism of single cells adhering to elastic substrates subject to exogenous forces, J. Mech. & Physics of Solids, 153, 2021,104475
[2] Yan, Y., Li, Y., Song, L., Zeng, C., 2017. Pluripotent stem cell expansion and neural differentiation in 3-D scaffolds of tunable Poisson's ratio. Acta Biomaterialia 49, 192–203.
[3] Zhang, W., Soman, P., Meggs, K., Qu, X., Chen, S., 2013. Tuning the Poisson's ratio of biomaterials for investigating cellular response. Adv. Funct. Mater. 23(25), 3226–3232.

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

C2 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM

Title: Logic of Monitoring System Design

BACKGROUND

When designing a structure such as a bridge or a building, a civil engineer follows a well-established, rational procedure, whereby the performance of the design concept is predicted through structural analysis and quantitatively assessed with respect to the target performance. On the contrary, when the same engineer designs a monitoring system, the approach is often heuristic with performance evaluation based on common sense or experience, rather than on quantitative analysis. The new Italian standards UNI/TR 11634:2016 Guidelines for Structural Health Monitoring [1] and UNI 10985 Vibrations on bridges and viaducts - Guidelines for performing dynamic tests [2] highlight the importance of designing structural health monitoring systems based on the performance to achieve. However, a commonly recognized procedure is still missing.

OBECTIVE

The objective of this doctoral work is to outline and formalize a rational procedure for the design of monitoring systems, keeping in mind an analogy between structural and monitoring design. Whereas the structural design objective is to achieve stability with an appropriate level of safety, the object of monitoring is to acquire knowledge with an appropriate level of confidence. The monitoring design process includes: definition of the target performance of monitoring (for example the accuracy of knowledge); calculation of the required accuracy of instrumental data, using a model; choice of sensor technology. The design is satisfactory if knowledge accuracy is equal or better than the demand. In logical terms, structural health monitoring is formally identical to the metrology problem of indirect measurement [3], where the measurand is indirectly estimated based on observation of other physical quantities linked to the measurand. In analogy with the metrology problem, in this we use error propagation technique, based on Bayesian logic [4], to judge a priori the covariance matrix of the target parameters a posteriori, an approach sometime referred to as pre-posterior analysis. It is expected that the PhD candidate will elaborate on this ground and formulate a general process for complex monitoring system design. The method will be demonstrated on one or more pilot case studies, including the Settefonti Viaduct on A1, whose monitoring system is currently operated by Autostrade Tech SpA. Particular attention will be devoted to the design of systems for dynamic monitoring, both for permanent monitoring under live loads and for shock and stepped sine tests.

EXPECTED RESULTS

- Method for monitoring system design.
- Pilot application to case studies.
- Validation of the approaches proposed in UNI 10985, currently under review.
- Scientific papers published in top quartile international journals.

REFERENCES

[1] L. Kirkup and R. Frenkel, An Introduction to Uncertainty in Measurement, Cambridge University Press, 2010.
[2] D. Sivia and J. Skilling, Data Analysis: A Bayesian Tutorial, Cambdrige University Press, 2006.
[3] UNI/TR 11634:2016 Guidelines for Structural Health Monitoring; Ente Italiano di Normazione: Milano, Italy, 2016.
[4] UNI 10985 Vibrations on bridges and viaducts - Guidelines for performing dynamic tests; Ente Italiano di Normazione: Milano, Italy, 2002 (currently under review).

- *Reference person:* Daniele Zonta (UNITN/DICAM)
C3 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM

Title: Decision support system based on data fusion from satellite and terrestrial structural health monitoring

BACKGROUND

Many bridges all over the world have passed their design life [1]. Their complete replacement in the short term is economically unsustainable; therefore, managers constantly check their safety with periodic visual inspections and give maintenance priority to the most degraded ones. Inspections cause traffic-jams, might not identify some defects (eg in the prestressing cables) or risk identifying them late [2]. The aging of the bridges makes this approach increasingly onerous.

More accurate and objective information could be acquired by structural health monitoring, with sensors (eg strain gauge, load cells) permanently installed on bridges [3]. However, the cost of a monitoring system is high (€ 50-200k compared to € 0.5-2k for an inspection) and it is impossible to install them to all bridges.

Innovative technologies and data analysis techniques may allow to overcome the problem. DInSAR satellite interferometry [4] 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. Bayesian networks can model the relationships between different structures and extend the results of a few monitored structure to the whole network [5].

As far as the management process, managers prioritize maintenance, repair, and replacement on their asset with their own experience, but the choice may be affected by heuristics and biases [6]. The expected utility theory [7] identifies the most rational allocation of resources by accounting for social, economic, and environmental impacts. The monitoring information could also be exploited for early warning systems that alert the community of impending environmental dangers, or directly act to reduce the risk. However, the application in civil infrastructure is still limited [8].

OBJECTIVE

The selected student will develop a decision support and early warning system for bridge management based on a combination of low-cost satellite technologies and terrestrial monitoring systems, which identifies structural damage, automatically regulates access to bridges depending on the risk level and provides operators with the optimal allocation of resources for the maintenance program.

The idea is to use DInSAR satellite technology, low cost but not very accurate, to continuously and extensively monitor the distortions of many bridges and integrate this information with data acquired by more accurate but expensive sensors installed on a few strategic structures and extend the results through a Bayesian network. In this way it will be possible to significantly increase the safety of many bridges with a reduced investment.

METHOD

- State of the art of satellite interferometry, Bayesian networks, decision support systems and ealy warning.
- Use of DInSAR satellite interferometry and TerraSAR-X data to obtain information on the behavior of bridges and data fusion with terrestrial monitoring.
- Development of a Bayesian network to extend the information acquired from a few of bridges to an entire stock and risk assessment.
- Development of the decision support and early warning system that identifies anomalous behavior of bridges in real-time and defines the optimal management of a stock.
- Validation of results by application to case studies.

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 satellite and terrestrial data, implements a Bayesian network for risk assessment, and identifies optimal management strategies based on the expected utility theory.
- Possible patent(s) on research outputs.

REFERENCES

[1] ASCE, «2021 Infrastructure Report Card» 2021. [Online]. Available: https://www.infrastructurereportcard.org/.
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- *Reference persons:* A. Siviglia (UNITN/DICAM), H.A. Dijkstra (Utrecht University affiliated to DICAM), M. Toffolon (UNITN/DICAM)

C4 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM

Title: Chaotic behaviour in Gravel Bed Rivers morphological models: analysis and implications for prediction skill of river trajectories

Background: River managers are challenged by the need to ensure flood protection, water resources availability, and ecosystem health in a changing environment. Predicting the interaction between riparian vegetation and river morphology is crucial to assess river trajectories under a changing climate, for flow regulation, and for river restoration scenarios. The development of ecomorphodynamic numerical models, which quantify the interaction of the relevant physical processes is crucial for predicting the morphodynamics of these areas and for planning sustainable restoration and flood mitigation measures. Recent work has shown that, owing to the interaction between vegetation growth and riverbed evolution, deterministic ecomorphodynamic models exhibit a sensitive dependence on initial conditions, the hallmark signature of chaos, implying that the skill of long-term predictions of river ecomorphodynamic trajectories may become low. However, simple estimates of the predictability horizon suggest that predictive skill is still acceptable on the time scale on the order of a few flood events.
Main aim of the project: In addition to chaotic behavior, also stochastic events may affect the results of ecomorphodynamic models. The goal of this project is to understand how stochastic events, such as stochastic flood disturbances and uprooting, affect predictive skill in such models.
Approach: This project will focus strongly on mathematical and numerical models of hydrodynamical and ecological processes. As a first step, we will explore the deterministic models in more detail by determining the characteristics of the chaotic behavior, more specifically by clarifying the route to chaos and its consequences for the predictability horizon. Next, we will consider the stochastic versions of these models, representating the unresolved processes either as additive or multiplicative noise, and study their dynamics and predictive capabilities.
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 ecomorphodynamics. **Characterization of the PhD candidate**: The successful candidate will have a strong mathematical background, strong programming skills (e.g. C++, FORTRAN, Python, MATLAB) and a desire 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:* Ivan Giongo (UNITN/DICAM)

Participant: Maurizio Piazza

Title: Timber vertical additions for improving seismic resilience of existing buildings

Background: Excessive land use is an extremely relevant issue within the EU community, with many countries aiming towards the goal of zero soil consumption by 2050 [1].
Use of vertical additions (VA) as a solution to obtain new housing volumes is becoming increasingly popular [2], both in the historical centres where the artistic-cultural value of the buildings requires the preservation of the original structures, and in the suburbs where the option of demolition/reconstruction can entail higher costs and sustainability issues. Load-bearing timber technology is often preferred to the other construction technologies due to: lightness, construction rapidity, prefabrication and sustainability [3].

However, in countries characterized by seismic risk and a vulnerable building-stock, the use of VA is hindered by the strictness of current codes which requires that the raised buildings exhibit the same seismic performance of newly constructed buildings [4]. This requirement results in considerable intervention costs and difficulties, which often lead to alternative, less sustainable strategies to increase housing availability.
Preliminary studies conducted at the University of Trento have shown that in some cases the addition of a wooden elevation constructed using current techniques to an existing building not only does not worsen the safety level (compared to the original as-built condition) but, on the contrary, can improve the global seismic response of the raised building.

Research goals

The aim of the project is to develop novel products, design methods and technical solutions that persistently transform timber elevations into tuned mass dampers [5], in order to increase the seismic safety of existing buildings while promoting sustainable development with regard to: 1) heritage preservation; 2) land-use; 3) carbon-footprint.

Methods

Interdisciplinary techniques will be integrated to overcome the complexity of addressing vintage buildings, heterogeneous in nature and with strong epistemic and aleatory uncertainty. Multi-level numerical modelling and multi-scale/hybrid experimental testing will be combined with soft computing and statistical methods.

Expected outcomes

Publication of the research results in highly regarded international scientific journals.
Preliminary suggestions on the updating of current codes and guidelines.
Possible patent(s) on research outputs.

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- *Reference person:* Davide Bigoni (UNITN/DICAM)

Participants: Andrea Piccolroaz (UNITN/DICAM), Francesco Dal Corso (UNITN/DICAM), Diego Misseroni (UNITN/DICAM)

Title: New loadings for structural elements and homogenization of elastic periodic materials

The combination between tensile bifurcation and non-holonomic constraints is planned to yield materials absorbing energy both for tensile and compressive strain cycles. The theoretical analysis of these systems is in its infancy, as only the PI and his co-workers have contributed to. However, the structures analyzed in these preliminary works are the simplest possible, while now the complexity has to be attacked. In fact, complexity becomes necessary to achieve structural elements representing the building blocks of the microstructure of an architected material with extreme characteristics. From a theoretical perspective, the chief methodology here is homogenization via Floquet-Bloch wave asymptotics. Periodic lattices of elastic rods will be analyzed, organized in parallelepiped geometries, axially loaded up to an arbitrary amount and then subject to incremental time-harmonic dynamic motion. How a structure is loaded is a concept of chief importance in determining its deformation capabilities. It will be investigated how to generate special forces in a microstructure that will become the basis for a material design, capable of attaining, surpassing, and exploiting bifurcations and instabilities. Control of loading on a structure which can suffer highly nonlinear deformation is a crucial but difficult task, a concept usually not given sufficient importance in mechanics. The search for new structural forces, will take the research into unexplored territory, linked to the design of soft fluidic robot manipulators, but also essential to analyse possibilities of extracting energy from interaction with a fluid or a gas, an important point in the quest for non-hyper-elasticity. A side result of this activity will be a new design of soft fluidic robot manipulators.
This PhD is related to the topic of my ERC AdG “Beyond”.
Outcomes: papers

Curriculum D - Architecture and Planning, Landscape

- ***Reference person:*** **Enzo Falco (UNITN/DICAM)**
Participant: Davide Geneletti (UNITN/DICAM)
D1 - scholarship on reserved topics

Funded by: University of Trento – Department DICAM (BIOVALUE project – CUP E63C22001420006)

Title: Furthering nature-based solutions and biodiversity values in spatial planning tools and practice

Recent international and European strategies have placed increasing emphasis on halting biodiversity loss in cities and urban environments through a series of policies, including spatial and urban planning (e.g., EU Territorial Agenda and Biodiversity Strategy). A transformative change is needed in terms of paradigms, goals, values and tools shaping current spatial development patterns and urban regeneration dynamics if such objectives are to be achieved. Spatial planning systems are able to create opportunities as well as challenges for the implementation of nature-based solutions and ecosystem services supply as fundamental drivers of change towards conservation and improvement of biodiversity. Potential failures, barriers and bottlenecks will be identified in view of mainstreaming biodiversity in spatial planning decisions. This research will be set within the BioValue EU Project, *Biodiversity value in spatial policy and planning leveraging multi-level and transformative change,* and will focus on understanding the main drivers of change within urban and peri-urban areas and different spatial planning systems for furthering biodiversity. Reference will be made to typologies of spatial planning systems as defined at the EU level to take a European comparative perspective which will be at the basis for achieving a systemic view and defining innovative tools and practices.

According to the candidate profile, the research may address a combination of the following topics:

- Mapping the European spatial planning systems and benchmark policy directions for biodiversity-inclusive spatial planning;
- Developing and applying innovative spatial planning and policy tools for mainstreaming Biodiversity;
- Testing Ecosystem Services (ES) mapping and assessment framework for mainstreaming biodiversity value in spatial planning-policy;
- International comparative analysis of 3 to 5 case studies.

The research will likely lead to three articles reflecting its main outcomes:

1) Literature review on European spatial planning systems in terms of biodiversity consideration and implementation.
2) Case study analysis for mainstreaming biodiversity values through ES Mapping and assessment.
3) Assessing innovative spatial planning tools and combination of a mix of policies in selected case studies.

- *Reference person:* **Rossano Albatici (UNITN/DICAM)**
Participant: Michela Dalprà (UNITN/DICAM)

Title: Energy retrofitting and decarbonization of existing buildings: interoperable workflows for the development of industrialized modular timber systems integrated with engineering plants

After the crisis that heavily affected the construction sector in 2008, in Italy there had been a slight recovery suddenly halted by the recent pandemic: -10.1 percent of investment in construction in 2020 in real terms compared to the previous year. Today, the continuing and increasing contraction of the new construction market is balanced by a sustainable attention for the regeneration of the existing building stock. Considering the main themes of the European Green Deal, the National Research Plan 2021-27 and the PNRR, the research aims to bring process and product innovation to an area (construction) in crisis, which tends to be conservative in the use of technologies (including digital ones) and expensive in environmental terms, improving the performance of the single building element/product as well as the overall performance of the buildings.

The research project concerns the identification of the production methodologies and the creation of an outlook on Industry 4.0 within the manufacturing process of industrialized modular timber systems for the retrofitting of existing buildings.
The main issues to be faced are:

1. Identification of off-site production methodologies for MMC (Modern Methods of Construction) in dry tech, based on the main systems used for panels production (CLT and/or framed wall), which aim to reduce the intensity of processing at the worksite to move it mainly to the factory;
2. Analysis of standard (timber) modules with some flexibility for easy adaptation to existing buildings in order to perform a circular and climate positive retrofitting;
3. Identification of BIM procedures for the standardization of the panel design process (to be fully compatible with production and control software, directly linked to client order handling, inventory management etc.);
4. Definition of an overall interoperable workflow for the development of industrialized modular timber systems integrated with engineering plants.

Moreover, concerning the intervention on existing buildings, the following issues will be considered as well: adoption of rigorous and expeditious 3D digital survey techniques (SLAM Laser Scanner, SfM and MVS algorithms), development of a unitary digital model with metric accuracy and its development for information management on existing conditions, usability of the same model for design simulation and for the control of the subsequent implementation phases, the introduction of dynamic and/or interactive (VR/AR) visualization for specialized and/or promotional purposes, the verification of Open Source alternatives to commercial products.

Expected research outcomes
1. Literature review on off-site production methodologies for MMC in dry tech
2. Definition of a BIM/HBIM procedure for the standardization of the (timber) panel design process
3. Definition of a resource efficient (pre) manufacturing & construction workflow
4. Proposal of a draft manual for onsite smart survey with advanced 3D digital techniques
5. Papers on international journal and participation to conferences

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- Reference persons: **Sara Favargiotti (UNITN/DICAM), Alessandra Marzadri (UNITN/DICAM)**
Participant: Mathilde Marengo (IAAC)

Title: Adaptive blueprint: responsive landscape and infrastructures for the transition of cities and territories

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 losing existing ecosystems (Dramstad et al., 1996, Munafò, 2020; European Union, 2012). 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 is essential in order to change direction.

“Adaptive blueprint” 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 young researcher will be able to manage innovative, interdisciplinary strategies for urban planning, integrating the aspects of biodiversity conservation, ecological connectivity with aspects related to the quantity and the quality of the water resource. These new “blueprint” strategies for urban drainage management are intended to implement green and blue infrastructures (hereafter Nature Based Solutions, NBS) into the built heritage (squares, streets, buildings) to ensure the compliance of regulatory constraints (i.e hydraulic and hydrological invariance) and to have benefits on ecosystem services and therefore on the well-being of the community and the environment (Huber 2010).

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

1. design and model, in different territorial areas, new intervention strategies aimed at maximizing their efficiency in reducing climate change effects;

2. develop new knowledge in the field of sensors to be applied to NBS to implement software systems that allow remote mapping, design and control of their efficiency in water management and to improve the collective well-being and the ecosystem services;
3. development of an integrated design strategy: landscape analysis + design and software implementation + sensing systems to evaluate the multiple benefits and effects of NBS at different spatial (i.e. single building or open spaces) and temporal scales.

The expected results of this PhD scholarship are extremely innovative and in line with the objectives and purposes of the REACT EU and the new themes envisaged in the Green Deal. The ideal candidate will have a background in Architecture and Planning, Landscapes as well as in Civil or Environmental Engineering or related fields. The position is intended to be co-tutored with dr. Mathilde Marengo with a research period abroad at the IAAC - Institute for Advanced Architecture of Catalonia in Barcelona. Candidates should possess a strong spatial design expertise and knowledge of GIS techniques (e.g. GRASS and QGIS) and of landscape representation (e.g. AutoCAD, Photoshop, Illustrator, InDesign or similar Open Source software e.g. GIMP). They also should 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 them) preferably. 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):

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