Doctoral School in Civil, Environmental and Mechanical Engineering

Research subjects proposed for the 36th 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 PhD Program in Civil, Environmental and Mechanical Engineering, **preferably** on one of the following research subjects:

Civil and Environmental Engineering (Curriculum A)

- *Reference person:* Alberto Bellin

Title: Risk analysis in surface and subsurface water bodies

Contamination by chemicals such as pesticides, pharmaceuticals and metals, represents one of the main environmental challenges the society and the ecosystem is facing. In 2010 the global value of the chemical industry was of 4.12 10^{12} US$ with an increase of 54% in the previous decade. While the most used chemicals change with time their direct and indirect impact on the environment and the ecosystem is difficult to exert and far reaching. The far reaching impact of chemicals on ecology and wildlife, and therefore on the humans as last part of the food chain, has been described in a recent publication by Saaristo et al. (2018). Water is an important carrier that brings into contact contaminants with the ecosystem, the wildlife and humans. Accidental spills, modern agriculture which makes a massive use of fertilizers and pesticides, and diffused pollution in the urban areas are the main entry points of most contaminants in the environment. Their fate and transformation is key to evaluate their potential impact and damage they can cause. However, fate and particularly transformations of the most relevant contaminants are difficult to assess because of the extreme heterogeneity of the environment where their transport and transformation occurs. In addition to that, recent studies showed that the transformation is often localized in space and in time, where the conditions for such a transformation are actually developing.

In this research program we will develop a stochastic framework for modeling transport of contaminant in heterogeneous environments. Stochastic techniques will be combined with Artificial Intelligence (AI) in order to better reproduce the main environmental properties, such as the distribution of lithofacies in aquifers, controlling transport and transformation of contaminants in surface and subsurface water bodies. Artificial intelligence will be used as a way to filter out heterogeneities that influence only marginally the fate of the target contaminants.

References:

- Diamantini, E., Mallucci, S., and Bellin, A. (2019): A parsimonious transport model of emerging contaminants at the river network scale, Hydrol. Earth Syst. Sci., 23, 573-593, https://doi.org/10.5194/hess-23-573-2019, 2019.
- Diamantini, E., Lutz, S. R., Mallucci, S., Majone, B., Merz, R., & Bellin, A. (2018). Driver detection of water quality trends in three large European river basins. Science of the Total Environment, v. 612, p. 49-62. DOI: http://dx.doi.org/10.1016/j.scitotenv.2017.08.172
- Fiori A, Zarlenga A, Bellin A, Cvetkovic V and Dagan G (2019) Groundwater Contaminant Transport: Prediction Under Uncertainty, With Application to the MADE Transport Experiment. Front. Environ. Sci. 7:79. doi: 10.3389/fenvs.2019.00079
- Mandaric, L., Diamantini, E., Stella, E., Cano-Paoli, K., Valle-Sistac, J., Molins-Delgado, D., Bellin, A., Chiogna, G., Majone, B., Diaz-Cruz, S., Sabater, S., Barcelo, D., & Petrovic, M. (2017). Contamination sources and distribution patterns of pharmaceuticals and personal care products in Alpine rivers strongly affected by tourism. Science of the Total Environment, 590, 484-494. DOI: https://doi.org/10.1016/j.scitotenv.2017.02.185
- Kracun-Kolarevic, M., Kolarevic, S., Jovanovic, J., Markovic, V., Ilic, M., Simonovic, P., Simic, V., Gacic, Z., Diamantini, E., Stella, E., Petrovic, M., Majone, B., Bellin, A., Paunovic, M., Vukovic-Gacic, V. (2016). Evaluation of genotoxic potential throughout the upper and middle stretches of Adige river basin. Science of the Total Environment, 571, 1383–1391. DOI: http://dx.doi.org/10.1016/j.scitotenv.2016.07.099
- Saaristo M et al. (2018) Direct and indirect effects of chemical contaminants on the behaviour, ecology and evolution of wildlife. Proc. R. Soc. B 285: 20181297. http://dx.doi.org/10.1098/rspb.2018.1297

Expected research outcomes are: publications in peer review journals (about 3) and presentations at international congresses (three; one per year); proposals for public policy and regulations.

- *Reference person:* Bruno Majone

Title: Hydropower generation in the Italian Alpine region under a changing climate (A1 - scholarship on reserved topics)

Simulating hydropower generation is a challenging task requiring the simultaneous consideration of the long-term climate-dependent evolution of hydrological fluxes and electricity prices. A deeper understanding of the mutual interplay between these elements is urgently needed by hydropower managers and policy makers, as well as by the scientific community.

Hence, the main aim of this phD project is to investigate the long-term evolution of hydropower generation in the Italian Alpine region by integrating the explicit simulation of (i) streamflow generation, (ii) human infrastructures present in the hydrological system, and (iii) electricity prices. The perspective PhD student will benefit from the existence of the large-scale hydrological model HYPERstreamHS recently developed by the Hydrology group of the University of Trento, a model which adopts a holistic approach to simulate hydrological processes in large river basins with streamflow altered by hydraulic infrastructures such as reservoirs and diversions.

The expected outcomes of this activity are the following:
The development of an adaptive hydropower management optimization model for water storage reservoirs, aiming at maximizing the expected revenue under the installation constraints. The model will be tested by comparing aggregated results at regional scale with historical data of energy production
Scenario analyses of climate change impact on hydropower potential in the Italian Alpine region including uncertainty analysis. In addition, the evaluation of different management strategies of storage reservoirs will be performed.
Effect on hydropower production of the evolution of the energy market as fostered by the development of new storage technologies, projected changes in wind and solar energy production or implementation of different energy policies.

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

- Bellin, A., Majone, B., Cainelli, O., Alberici, D., and Villa, F., 2016. A continuous coupled hydrological and water resources management model. Environmental Modelling and Software, 75, art. no. 3541, pp. 176-192, doi:10.1016/j.envsoft.2015.10.013.
- Gaudard, L., Gilli, M. and Romerio, F. (2013): Climate change impacts on hydropower management. Water Resources Management, 27(15), 5143–5156. doi:10.1007/s11269-013-0458-1.
- Gaudard, L., Romerio, F., Dalla Valle, F., Gorret, R., Maran, S., Ravazzani, G., Stoffel, M. and Volonterio, M. (2014): Climate change impacts on hydropower in the Swiss and Italian Alps. The Science of the Total Environment, 493, 1211-21. doi:10.1016/j.scitotenv.2013.10.012.
- Laiti, L., Mallucci, S., Piccolroaz, S., Bellin, A., Zardi, D., Fiori, A., Nikulin, G. and Majone, B. (2018): Testing the hydrological coherence of high-resolution gridded precipitation and temperature data sets. Water Resour. Res. 54 (3), 1999–2016. https://doi.org/10.1002/2017WR021633
- Majone, B., Villa, F., Deidda, R., and Bellin, A., 2016. Impact of climate change and water use policies on hydropower potential in the south-eastern Alpine region. Science of the Total Environment, 543, pp. 965-980, doi:10.1016/j.scitotenv.2015.05.009.
- Piccolroaz, S., Di Lazzaro, M., Zarlenga, A., Majone, B., Bellin, A., and Fiori, A. 2016. HYPERstream: a multi-scale framework for streamflow routing in large-scale hydrological model. Hydrol. Earth Syst. Sci., 20: 2047–2061, doi:10.5194/hess-20-2047-2016.

- Reference person: **Luigi Fraccarollo**

Title: Airborne radar technology and entropy theory applied in laboratory and field sites to measure sediment-transport and its impact on bio-sensor activity
(A2 - scholarship on reserved topics)

The overall objective of the proposal is the use of advanced technologies, such as airborne radar, biological sensors, hydrodynamic tools, and innovative theoretical methods, that allow to predict the river flows also during high floods as well as the impact of hydrodynamic processes on the river biotic communities. This research is matching the targets of a national Prin Project, “ENTERPRISING”, started in November 2019 end ending in November 2022, where DICAM is among the partners. This project aims to face a twofold challenge; the first is that raised by World Meteorological Organization to identify advanced techniques for discharge monitoring at high flow, of interest to control extreme events; the second challenge is that of the European Biodiversity Strategy to 2020 (EU COM 244, 2011) for a better protection of ecosystems along with the contribution to averting global biodiversity loss. To distinguish between the Doctoral program and the Prin Enterprising Project we will refer hereafter by using the acronyms DP and PEP, respectively.
The integrated use of advanced technology and a refined eco-hydraulic modeling, exploiting bio-sensors, will lead to new insights on discharge monitoring and ecosystem-river processes. To achieve the target, PEP is articulated in different levels of activity and concerns: 1) the monitoring of river flow by developing innovative no-contact technology; 2) the identification and modeling of interaction mechanisms between hydrodynamics processes and biotic communities; 3) the use/development of advanced technologies for monitoring the response of biotic communities to hydro-morphological changes with the testing in laboratory and field; and 4) the evaluation of the effects of hydrodynamic processes on river ecosystem communities in different environments as a base for the development of an effective Biological Early Warning System (BEWS). These aims will merge to reach a way to understand modifications of the biotic environment in correlation with hydrodynamics, and geomorphological complexity, through a synergistic approach in which the expertise spans from fluvial processes to ecosystems sustainability.

The use of no-contact technologies is crucial to warrant a proper monitoring of key variables (water level, surface flow velocity) also during high flow conditions and when sediment transport is significant. Another key aspect of PEP is a deep understanding of disturbance and impact on target biotic components to be used as indicators of fluvial ecosystem health. Finally, novel theoretical insights on the mechanics of fluvial behavior is inspired by entropic analysis, which already proved to be applicable to geophysical flows in different setting, but still needs to comprehend the various regimes of sediment transport processes.

The DP will deeply operate within the DICAM unit to develop the specific tasks where the unit is involved and will further follow any autonomous route that the research will point out. In particular, the DP will develop experimental work in laboratory and in the full field.

In laboratory the experiments will be designed to host caged test organisms (mussels), and endow them with advanced valvometric techniques. The mussels, naturally exposed to hydro-morphological changes in their environment, will be tested through case studies in field and laboratory. The responses of organisms to well controlled hydraulic stressors, such as flow velocity and depth, or moving sediments of different sizes at different load, will be detected. The valvometric technique employs bivalves as sentinel organisms because of their sensitive and immediate responses to physical-chemical stressors which could threat the ecosystem biota. Behavioral parameters are 10–100 times more sensitive than survival parameters, and their measurements are both economical and practical. Since the first mussel monitors applied in 1992 on the River Rhine in Germany, till now, this method was shown to put a strain on invertebrates in studies mostly focused on low-flow conditions, for which measures can be easily performed. The use of no-contact technologies will allow to extend the analysis of hydro-morphologic implications on riverine biotic ecosystems also to otherwise prohibitive high-flow conditions.

The collected laboratory information will then be used to understand the physiological behavior of the organism in natural environments, and finally appoint them as reliable hydraulic bio-sensors (named BEWS, biological on-line early warning system). The fluvial system will be hydraulically described through the measurement of the water level, of the bathymetry and of the velocity distribution of the free surface transect. Relevant data will be acquired by Doppler, multi-frequency radar back-scattering or Frequency Modulated Continuous Wave radars [FMCW]. Miniaturized, low-cost radar sensors are nowadays possible, thanks to the progress of microelectronic technologies and to the growth of the automotive market and these make them appealing for applications onboard of drone thus making the monitoring of inaccessible fluvial sites. The DP will intervene to analyze and validate the radar data within the PEP groups. Its major target will be the design of the best accurate and robust methodology, within the available resources, to measure the sediment transport. Tracers, traps, turbidimeters, images and bathymetric data will be exploited, along with measurements, of grainsize distributions, roughness and bed forms, at local and meso scales.

Independent theoretical analysis of the sediment transport mechanics will trigger from the state-of-art knowledge of the mechanics of the process. Validation and improvement of the theories still need to expand the analysis to the case of ordinary bed-load and to complex bed topography and grain arrangement. Besides the statistical mechanics, the novel and promising approached based on entropy concepts, familiar to some of the PEP participants, will be encompassed to assess its skill to deal with sediment transport flows in rivers, a unexplored topic, yet. Development and validation of the entropy theory will consider, at first, available experimental data and will move then to applications in the selected situ of the PEP.
Numerical tools of various types, reasonably with limited need of development, will be exploited to check the interpretation and show model outcomes.
Beyond research papers, the outcomes of this DP will be disseminated in a wide range of stakeholders and a strong knowledge network will be built, also through a devoted website platform. Promising professional chances are expected and will be looked for after as most of the results will be coming.

- Reference person: **Ivan Giongo;**
Participants: Maurizio Piazza

Title: Novel strengthening techniques for URM structures based on lime-based composites (A3 - scholarship on reserved topics)

The project focus will be on strengthening methods for unreinforced masonry (URM) structures that see the use of lime-based composite coatings to increase the in-plane and out-of-plane seismic capacity of URM walls.
Steel reinforced concrete coatings to strengthen/repair URM buildings were firstly introduced in Italy in the early ‘80s (e.g. Circolare n.21745, 1981), after the Irpinia and Gemona earthquakes. The technique involves jacketing the “weak”/damaged wall on both sides by using a few-centimeter thick layer of cast-in-place concrete, reinforced with a steel mesh. Concrete-masonry load transfer and wall monolithic behavior are enhanced by inserting transversal steel ties that connect the reinforced concrete layers to each other. The result of the intervention is a significant increase in wall strength but also in stiffness. The considerable wall stiffening can in some cases prove detrimental to the overall building response, especially when the strengthening does not involve all of the load-bearing walls. Additionally, examples of local damage due to deformation incompatibility between the masonry and the concrete coating have been observed in the post-event reconnaissance missions that took place after the earthquakes that struck Italy in the late ‘90s and early 2000s. Concrete degradation with spalling of the concrete cover and corrosion of the steel reinforcement have also been frequently reported.
The recent development of high-performance lime mortars with resistance values comparable to those of cement mortars makes them a viable option to create coatings that combine strength, sustainability, and compatibility with historical masonry, from both the mechanical and chemical-physical point of view. Alternative reinforcements, different from the traditional steel meshes, will be investigated to maximize the durability of the intervention (e.g. glass-fiber or basalt meshes).
As concerns the system applicability/usability, the recent publication of the guidelines for the certification of Composite Reinforced Mortar (CRM) systems by the Italian government in 2019, has generated a notable momentum that renewed the interest of industry and academia towards developing structural coatings and reinforced plasters. As a result, new products have been introduced in the market, expanding the possibilities but also raising questions on their actual performance given the diversity of potential applications.
Therefore, the experimental characterization of the mechanical performance of lime-based CRM solutions applied to different type of masonry (i.e. stone masonry, brick masonry) and structural applications (e.g. walls, columns and arches), will constitute a central part of the project. The experimental program will include small-scale and full-scale laboratory tests. The experimental data will provide the necessary evidence for the optimization of the strength modification parameter currently adopted by NTC2018 to account for the wall-strengthening via concrete jacketing. The introduction modification parameters tailored on the performance of the novel lime-based CRM solutions will enable the adoption of such techniques and, as a consequence, more efficient and targeted interventions.

Among the research objectives there is also the development of sound and reliable analytical design approaches to supersede the extremely simplified NTC2018 approach for jacketing and enable practitioners to further exploit the advantages of adopting lime-based CRM strengthening techniques.

- Reference person: **Alfonso Vitti**

Title: GNSS and SAR for Earth surface and ground characterization in environmental monitoring of water resources
(A4 - scholarship on reserved topics)

Recent development in GNSS (Global Navigation Satellite Systems) technologies, including full operation Galileo system and the development of an operational multi-constellation scenario along with the availability of high-performance low-cost technology, wide the possibility to exploit GNSS signals for conventional positioning, navigation and timing applications and for unconventional applications such as direct displacement determination, atmosphere sounding and interferometric reflectometry for retrieval of ground physical characteristics.
The Sentile-1 mission of the ESA Copernicus programme provides open SAR (Synthetic Aperture Radar) observations to the scientific community that can be exploited for deformation monitoring, velocity determination and for soil moisture and snow pack characterization.

The project aims at the integration of GNSS and SAR techniques for monitoring of water resources in environmental sciences. In particular the candidate will focus on combined applications of GNSS multi-frequency interferometric reflectometry and back scattering SAR models for soil moisture and snow pack characterization.

Spatial-temporal variability of surface and ground characteristics can be investigated at very high resolutions using SAR data. On the other hand, analysis of GNSS data permits point-wise retrievals of physical quantities of interest. GNSS based point-wise and SAR based retrievals will be investigated both for consistency and complementarity given the different radio bands of the two space signals. Eventually, interferometric SAR models can be considered as a further source of information contributing to widen the knowledge about water resource
parameters under investigation.

The outcomes of the projects include publication of research results on scientific journals and identification of technology with corresponding processing procedures suitable for applications in real cases.

- Reference person: **Giuseppe Formetta**

Title: Assessment of social and economic impacts caused by natural hazards in mountain regions
(A5 - scholarship on reserved topics)

Death tolls and economic losses from natural hazards continue to rise in many parts of the world. Only in 2018 they caused almost 12000 deaths across the world and over 130 US billion dollars of economic losses (CRED, 2018). European states are experiencing a continuous and significant burden from multiple natural disasters (Wolfgang et al., 2019): in 2016 Germany, Belgium, and Switzerland have been hit by a series of flash floods and storms causing over $2.2 billion in losses; in 2013 Storm Xaver caused to northern Europe at least 15 fatalities, dozens of injured, and more than €800 million total economic losses (e.g. Rucińska, D., 2019); the July-August 2003 European heat wave that caused a total of 70,000 deaths (e.g. Russo et al., 2019; Bouchama, 2004).

A combination of several factors contribute to explain the increasing social and economic toll caused by natural hazards: increase in exposed assets, i.e. rising population and capital at risk (e.g. Visser et al., 2014), effects of anthropogenic climate change on climatic extremes (e.g. Donat et al., 2016; Bouwer, 2011), better impact reporting procedures (e.g. Doktycz and Abkowitz, 2019).

International agreements on disaster loss reduction (Sendai Framework for Disaster Risk Reduction 2015–2030) explicitly recognizes the benefits of multi-hazard early warning and forecasting systems (MHEW&F-S)". In 2017 Member States of the United Nations stated the deemed need of MHEW&F-S and agreed on its the definition as integrated system that "address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur alone, simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects" (UNISDR, 2017). Here the term early warning (EW) is extend with the term forecasting (&F) to explicitly acknowledge that each hazard have a specific forecast lead time which can varies from minutes/hours for flash-floods, days for pluvial floods or heat/cold waves, to months for drought hazard. The scientific community also agree in the need of novel approaches and local scale models for assessing impacts caused by climate change (e.g. Schewe et al., 2019). In order to answer to this call and to move towards a rigorous framework for multi-hazard risk assessment in this project I propose to implement a novel local scale multi-hazard impact-centered forecasting system. It aims to:
• Quantify the three fundamental component of the risk, i.e. hazard, exposure, and vulnerability, and to combine them in a multi-hazard framework, exploiting the most recent dataset and the more appropriate models;
• Provide timely effective warnings (not just of the hazards but also) of the most probable sectorial impacts that may be triggered by multiple hazard conditions.
The system will be unique and novel because it will be the first operative system for multi-risk quantification including:
• a local high-resolution meteorological forecasting system with operationally runs at 1 km resolution capable to explicitly model convective phenomena;

• a detailed and component-based open-source framework for multi-hazard quantification, locally and automatically calibrated for estimating the probability of occurrence of floods, droughts, shallow-landslides/debris-flow, heatwave/coldwaves and windstorms;
• a new set of exposure and vulnerability layers variable in space and time to account for accounting of socio-economic changes in the risk analysis;
• an innovative framework based on a probabilistic graphical model (Bayesian Network) dynamic in time and variable in space, which consider all the risk components (hazards, exposure, and vulnerability as in Formetta and Feyen, 2019) as stochastic variables and models all their possible interactions using probabilistic expressions. The latter will be inferred using a Bayesian learning process involving: 1) a database of reported impacts (fatalities and economic losses) occurred in the past (1980-2018) in the study area specifically organized in the project and 2) the corresponding hazard probabilities, exposure, and vulnerability at the time of the reported event (computed by using points ii and iii).
The CLARIFY project study area is the Trentino Alto-Adige region located in the eastern Italian Alps. The choice of the area is motivated by different reasons: i) there is no such a system currently running (this is also valid for all the others Italian regions); ii) in the near future mountain regions will be even more exposed to the occurrence of climatic extremes due to climate warning. The selected geographical domain is only a test-bed where the framework will be implemented, set up, tested, and verified against observed data for each single component, i.e. meteorological forecasting skills (against rainfall or air temperature measurements), hydrological calibration and validation (against historical measured river discharge), hydrological forecasting skills (against observed river-discharge using forecasted meteorological forcing data), historical and forecasted impacts (against reported fatalities and economic losses

References Bouchama, A. (2004). The 2003 European heat wave. Intensive care medicine, 30(1), 1-3. Bouwer, L. M. (2011). Have disaster losses increased due to anthropogenic climate change?. Bulletin of the American Meteorological Society, 92(1), 39-46. Donat, M. G., Alexander, L. V., Herold, N., & Dittus, A. J. (2016). Temperature and precipitation extremes in century-long gridded observations, reanalyses, and atmospheric model simulations. Journal of Geophysical Research: Atmospheres, 121(19), 11-174. Doktycz, C., & Abkowitz, M. (2019). Loss and Damage Estimation for Extreme Weather Events: State of the Practice. Sustainability, 11(15), 4243. Formetta, G., & Feyen, L. (2019). Empirical evidence of declining global vulnerability to climate-related hazards. Global Environmental Change, 57, 101920. Rucińska, D. (2019). Describing Storm Xaver in disaster terms. International journal of disaster risk reduction, 34, 147-153. Russo, S., Sillmann, J., Sippel, S., Barcikowska, M. J., Ghisetti, C., Smid, M., & O'Neill, B. (2019). Half a degree and rapid socioeconomic development matter for heatwave risk. Nature communications, 10(1), 19. Schewe, J., Gosling, S. N., Reyer, C., Zhao, F., Ciais, P., Elliott, J., ... & Van Vliet, M. T. (2019). State-ofthe-art global models underestimate impacts from climate extremes. Nature communications, 10(1), 1-14

- Reference person: **Marco Tubino**
Participants: Marco Redolfi; Chris Paola (SAFL)

Title: Investigating fundamental morphodynamic processes in multi thread-rivers
(A6 - scholarship on reserved topics)

Multi-thread rivers, such as braided, wandering, anabranching, and anastomosing channels represent the natural state of most gravel-bed systems worldwide, and they provide a rich environment that can sustain a high biodiversity. Channelization and rectification of rivers, as well as human alteration of the hydrological and sedimentological regime have highly reduced the number of multi-thread rivers in most developed areas. On the other hand, many river restoration projects aim at recovering morphologically rich states through interventions like local channel widening, building of vegetated islands, dams removal and in-stream reintroduction of sediments. Channel bifurcations represent key unit processes for the morphodynamic evolution of multithread rivers, as well as of a variety of fluvial environments, such as deltas and alluvial fans, as they determine how water and sediment are downstream distributed. Understanding their dynamics is therefore important for managing water resources and the flooding risk, predicting the long-term morphological evolution of channel networks and evaluating the effectiveness over time of river restoration projects aimed at reactivating a multi-thread configuration. Bifurcation dynamics also control instream processes in meander bends that mitigate the development of channel sinuosity through the occurrence of short cuts through point bars. River bifurcations have been extensively studied through laboratory-scale physical models and mathematical models based on 1D (Wang et al., 1995; Bolla Pittaluga et al., 2003; Kleinhans et al., 2013; Salter et al., 2018), 2D (Edmonds and Slingerland, 2008; Siviglia et al., 2013; Lee et al., 2018) and 3D approaches (Kleinhans et al., 2008). Along with field observations (e.g., Zolezzi et al., 2006; Kleinhans et al., 2012), these studies highlight the almost invariable tendency of bifurcations to produce an uneven distribution of flow and sediment transport, which results in a strong asymmetry of the channel width and bed elevation of downstream anabranches. This type of unbalanced configuration is often promoted by various forcing effects that drive the bifurcation towards an unbalanced state, sometimes leading to the complete closure of one of the anabranches. Forcing factors include both upstream and downstream effects. Upstream effects comprise mechanisms that feed the bifurcating node with a topographically-driven uneven distribution of flow and transport rate, like the curvature of the upstream channel (Kleinhans et al., 2008; Hardy et al., 2011; Sloff and Mosselman, 2012) and the occurrence of migrating bars (Bertoldi et al., 2009; Bertoldi, 2012) or steady bars (Lee et al., 2018). Downstream effects include mechanisms that provide a slope advantage to one of the distributaries (Edmonds, 2012; van Dijk et al., 2014; Zhang et al., 2017; Salter et al., 2018). Therefore, understanding the morphodynamical response of bifurcations in complex fluvial systems and the role of changes of external controlling variables is indispensable for a successful and sustainable management of multi-thread rivers, able to meet the different needs of protection against flooding risk and environmental preservation, within a scenario increasingly affected by climate change. Theoretical, experimental and numerical studies produced so far have provided a much better understanding of the basic mechanisms that determine the stability of a single bifurcating node.
However, minor attention has been devoted to investigate bifurcations as a part of a network of channels characterized by a variety of different processes and by a large number of degrees of freedom, as in the case of multi-thread rivers. Moreover,

there is a significant lack of information on the behaviour of bifurcations under unsteady flow conditions, where the relative importance of different mechanisms and the associated timescales can vary significantly, depending on the water stage.

With this proposal, the candidate will address the following research questions:
• What is the influence of downstream boundary conditions, such as confluences, on the equilibrium states of bifurcations and on their stability?
• What is the response of the bifurcation in a multi-thread river, characterized by a large number of degrees of freedom and by different processes acting on similar timescales?
• What is the effect of the temporal variability of the forcing factors on the bifurcation morphodynamics?
• What is the effect of the uncertainties associated with geometry and boundary conditions?

Effectively tackling these questions is made possible by three key factors: (i) the recent theoretical development on bifurcations morphodynamics; (ii) the availability of a large data-set from remote sensing (e.g., Tagliamento River); (iii) the increasing capabilities of numerical models to simulate morphodynamic processes. The candidate will be asked to first address the problem from a mathematical point of view, by extending and analysing existing models. As a second step, the candidate will examine field and remotely sensed data through image processing techniques and statistical methods. The multidisciplinary character of the research will allow interactions with different research groups at international level. The ideal candidate will have a background in Environmental Engineering, River Geomorphology or related fields. Candidates should also possess strong computer, scientific, and analytical expertise, have excellent communication (oral and written) skills, have the ability to work independently and as part of a team, self-motivation, adaptability, and a positive attitude. Since foreseen activities include model development, the candidate is required to have computational proficiency (or the will to pursue it) preferably in Fortran, R/python/Matlab and GIS products.
Suggested references: Bertoldi, W. (2012), Life of a bifurcation in a gravel-bed braided river, Earth Surface Processes and Landforms, 37 (12). Bertoldi, W., and M. Tubino (2007), River bifurcations: Experimental observations on equilibrium configurations, Water Resources Research, 43 (10). Bertoldi, W., L. Zanoni, S. Miori, R. Repetto, and M. Tubino (2009), Interaction between migrating bars and bifurcations in gravel bed rivers, Water Resources Research, 45 (6). Bolla Pittaluga, M., R. Repetto, and M. Tubino (2003), Channel bifurcation in braided rivers: equilibrium configurations and stability", Water Resources Research, 39 (3). Miori, S., R. Repetto, and M. Tubino (2006), A one-dimensional model of bifurcations in gravel bed channels with erodible banks, Water Resources Research, 42 (11). Redolfi, M., G. Zolezzi, and M. Tubino (2016), Free instability of channel bifurcations and mor- phodynamic influence, Journal of Fluid Mechanics, 799. Redolfi, M., G. Zolezzi, and M. Tubino (2019), Free and forced morphodynamics of river bifurcations, Earth Surface Processes and Landforms, 44 (19). phodynamic influence, Journal of Fluid Mechanics, 799.

Mechanics, Materials, Chemistry and Energy (Curriculum B)

- Reference persons: **Paolo Baggio; Alessandro Prada**

Title: The energy FLEXibility of enhanced HEAT pumps for the next generation of sustainable buildings (CUP E64I19001180001)
(B1 - scholarship on reserved topics)

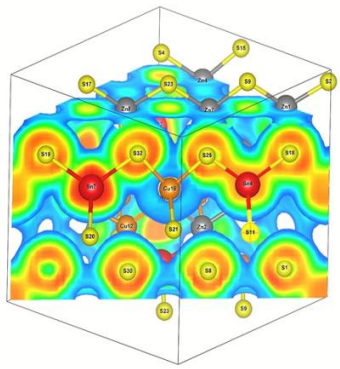
The project aims at giving a breakthrough contribution to the reduction of the carbon footprint due to energy consumption for buildings heating and air conditioning (HVAC), through an integrated approach that goes beyond the state of art.
The use of heat pumps (HP) is a key enabler to promote the use of renewable energy in buildings air conditioning. Even though air source heat pumps are the most widespread typology, there is still a need for suitable control paradigms for overcoming the inherent drawback due to the thermal power delivery curve which is opposite to environmental conditions and for a smart grid integration. A safe option for reducing annual energy consumption is the use of multisource HPs that are poorly investigated in comparison to air source HPs. Besides, the integrated simulation models of the building and the energy systems offer considerable opportunities for managing complex systems such as multisource HP.
The project will be based on an extensive experimental activity collected in laboratory and on reference buildings equipped with heat pump systems. The candidate is expected to perform the data analysis in order to assure the quality of the measurements and to post process the data about the building and HVAC operation.
A numerical model of the building and the HVAC systems is another expected output of the research. This model has to be calibrated and validated against experimental data in order to be used for designing enhanced control strategies such as rule based and model predictive control. The research outputs are expected to be published in relevant sector journals.

***- Reference person*:** **Paolo Scardi**

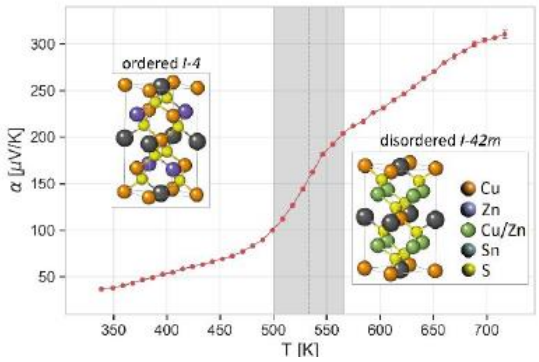
Title: Disordered Materials for Advanced Thermoelectric Devices
(B2 - scholarship on reserved topics)

While thermoelectric (TE) generators 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 inito* modeling techniques based on density functional theory (DFT) using high performance computing (HPC) facilities.
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 TE materials, starting from the current paradigm of Phonon Glass Electron Crystal (PGEC) materials and potentially culminating in the most challenging and promising topological insulators.
The thesis project is open to being experimental and/or theoretical/modeling-based, with a necessity to understand both aspects, in order to cover the full breadth of topics and make available all the necessary tools for a research group dedicated to the themes of TE materials. Ultimately, this can also be decided on the basis of the candidate's best attitudes and propensities.
Part if 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



Experimental measurement of Seebeck coefficient of kesterite in temperature, showing the steep increase at the order-disorder transition
Isotta et al., J. Phys. Chem. C 2020, 124, 7091−7096

Ideal candidates should be motivated towards an international research thesis, and have a background in Physics, Chemistry, or (Materials, Energy, Industrial) Engineering. For more details, see also: *energymaterials.unitn.it*

- *Reference persons*: Nicola Maria Pugno; Barbara Mazzolai (IIT Pontedera)

Title: Nanofabrication of multifunctional biomimetic structures inspired by natural organisms (B3 - scholarship on reserved topics)

Evolution has brought to the development of fascinating biological structures. Nanofabrication technologies provide valuable tools to fabricate artificial biomimetic materials with properties that imitate the natural structures.
This project aims at developing novel multifunctional biomimetic artifacts by merging nanofabricated materials with tailored mechanical properties and microfluidic structures, fabricated by two photon lithography, with functional electrospun fibers and 3D printed multi-materials.
Several biological properties and functionalities will be investigated as models to develop artificial systems embedding sensing and actuation abilities. In particular, plants and soft invertebrates will be the focus of such research.
Due to their low density and impressive mechanical properties, plants provide examples of lightweight but robust structures (e.g., bamboo). These characteristics are achieved thanks to a hierarchical structure that combines porous architectures with density gradients and hollow parts to increase the flexural stiffness while keeping a lightweight. Soft invertebrates (e.g., octopus) have a soft body that can bend, elongate, and squeeze while their skin adapt to each movement providing at the same time camouflage properties. Camouflage is obtained by chromatophores activated by light, resulting in a skin that combines sensing and actuation properties both at the microscale. The above biological properties represent some of the research activities will be proposed within this project.
In summary, the expected work spans from biological investigation to design, fabrication, and characterization of the resulting prototypes. The expected outputs are patents and publications on high impact journals on the field.

Modelling and Simulation (Curriculum C)

- *Reference persons: Andrea Piccolroaz; Francesco Dal Corso*

Title: Ultra-resistant microstructured materials

Constitutive modelling and rational design are the key to attain architected materials with effective mechanical properties beyond those of their constituents and to realize materials with enhanced stiffness, strength, and toughness.
Discrete structural models will be developed to capture statics and dynamics of linear and nonlinear elastic material subject to mechanical and thermal loadings. Floquet-Bloch techniques and numerical strategies will be used to analyse two- and three-dimensional metamaterials with two main purposes. First, to provide the genuine structural behaviour before the homogenization approximation and, second, to analyse all the phenomena that remain undetected when homogenization is applied. Examples of undetected phenomena are local bifurcations occurring in a lattice, higher-order effects from stiff inclusions in a compliant matrix.
Then, following a continuum mechanics approach, thermoplasticity will be used to describe the mechanical behavior of materials in a cohesive state, such as ceramics or slurries. The approach will open the possibility of treating material compaction and sintering in an unified approach.

The achievement of these extreme materials would open new challenging possibilities, for instance to transmit and propagate highly localized signals, or to design materials with tunable properties, or to analyze materials during thermal shocks.

- Reference person: **Michael Dumbser**
Participants: Ilya Peshkov

Title: Semi-implicit and explicit finite volume schemes for incompressible and weakly compressible three-phase flows
(C1 - scholarship on reserved topics)

This research topic concerns the development of new staggered semi-implicit and high order accurate explicit finite volume schemes for the numerical simulation of incompressible and weakly compressible multi-phase flows. In particular, we are interested in three-phase flows containing a liquid, a solid and a gas phase, such as, for example, free surface water flows that interact with moving solid bodies and air.

The objective of the present research is to represent the domains covered by the fluid, by the solids and by the surrounding void (or air, depending on the level of modelling detail) via scalar volume fraction functions for each phase, according to the so-called diffuse interface approach. The underlying mathematical models will be a generalization of the incompressible and compressible Navier-Stokes equations in moving domains. In order to improve computational efficiency, appropriate vectorization and parallelization of the developed computed codes should be carried out, and large-scale simulations of some example problems should make use of modern High Performance Computing (HPC) infrastructure.

During this thesis, a stay abroad and the achievement of the Doctor Europaeus label is highly recommended.

As outcome of this research we expect not only a substantial contribution to the fields of applied mathematics, computational mechanics and scientific computing, but also the development of a new and efficient computer software where the proposed schemes will be implemented. We furthermore expect several publications in leading international journals of the fields of scientific computing, applied mathematics and computational physics.

- Reference person: **Michael Dumbser**

Title: Novel semi-implicit finite volume schemes for fluid-structure interaction problems related to moving ships in rivers
(C2 - scholarship on reserved topics)

The research topic concerns the development of new efficient staggered semi-implicit finite volume schemes for the numerical simulation of fluid-structure interaction problems, in particular concerning moving ships in rivers. The free surface flow in the river will be described at the aid of the shallow water equations or the hydrostatic free surface Navier-Stokes equations with single-valued free surface. The ship geometry will be described at the aid of nonlinear volume functions based on a subgrid model, while the ship dynamics is described by rigid body motion that is governed by a system of nonlinear ordinary differential equations for the translational and rotational degrees of freedom. The resulting mildly nonlinear algebraic system is going to be solved via the nested Newton method of Casulli and Zanolli. An appropriate coupling of the ship dynamics and the free surface flow needs to be provided. The resulting scheme is supposed to be mass and momentum conservative.

We expect the development of a new and efficient computer software for the simulation of two and three-dimensional problems, making also use of high performance computing (HPC) techniques.

During this thesis, a stay abroad and the achievement of the Doctor Europaeus label is highly recommended. We expect not only substantial contributions to the fields of applied mathematics, computational mechanics, computational physics and scientific computing, but also several publications in leading international journals in these fields.

- Reference person: **Lorenzo Giovannini**

Title: Simulation of turbulent transport and exchange processes in the atmospheric boundary layer over mountain regions
(C3 - scholarship on reserved topics)

The quality of weather forecasts strongly depends on the performance of numerical weather prediction models and areas of complex and mountainous terrain prove to be particularly challenging for numerical models. One of the reasons is that large spatial variations can occur within the atmospheric boundary layer, that is, the lowest layer of the atmosphere. The large heterogeneity of the terrain and differences in vegetation and land use at varying altitudes affect the partitioning of the solar radiation received at the surface and, subsequently, the transport of heat and moisture between the ground and the atmosphere. The transport of heat from the ground is, however, a major driving force for the temperature field within the boundary layer and spatial variations can lead to local wind circulations within mountainous terrain. A correct representation of the exchange of heat, moisture, and also momentum between the land surface and the atmosphere and within the boundary layer is thus crucial for successful model simulations. In numerical models this exchange between the land and the atmosphere and within the atmosphere is handled by the land surface model and the turbulence parameterization, respectively. Potential issues with respect to the performance of these parameterizations in mountainous terrain have been identified. For example, the parameterizations were generally developed based on observations from flat terrain and may thus not be entirely adequate for complex, mountainous terrain. Studies evaluating the performance of the parameterizations in mountainous terrain, however, are scarce.
The present research subject aims at evaluating turbulence and land surface parameterizations in mountainous terrain and to identify potential issues with respect to these parameterizations that have a large impact on the model results. Improvements of these specific issues can thus be expected to have a comparatively large positive impact on numerical model simulations and consequently weather forecasts. To evaluate the model performance, model simulations will be performed of individual case studies for different Alpine regions, the Austrian Inn Valley near Innsbruck, the Italian Adige Valley, and the mountain slopes near Bolzano. For these regions, several years of high-quality observational data are available for comparison with the model. The model's sensitivity to changes or potential errors in the turbulence and land surface parameterizations will be evaluated also by means of idealized simulations, that is, certain parameters are modified systematically to quantify their impact on the model results.
The candidate will work in the framework of the Euregio project "ASTER – Atmospheric boundary-layer modelling over complex terrain", in strict connection with research groups at the University of Innsbruck and at the Free University of Bolzano. The results of the present project will be presented at international conferences, such as the EGU annual meeting, 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: **Davide Bigoni;**
Participants: Francesco Dal Corso; Andrea Piccolroaz

Title: Micromechanics & Stability of Materials
(C4 - scholarship on reserved topics)

Modelling and simulation of the mechanical response of composites near the border of ellipticity loss is the new challenge in the design and realization of materials with extreme properties. The purpose of the research activity is the design of a material in which shear banding and other instabilities may occur well inside the elastic range and far from failure. A material that can be tailored to exhibit shear bands with a desired inclination, or in which shear bands are the first instability occurring at increasing stress, or in which the anisotropy (not imperfections) allows the formation of only one shear band. This material will be characterized by rigorously determined elastic constitutive laws (thus avoiding complications such as the double branch of the incremental constitutive laws of plasticity) and would be, at least in principle, a material realizable (for instance via 3D printing technology) and testable in laboratory conditions. This material will be ideal not only to theoretically analyze instabilities, but also to practically realize the 'architected materials' which are preconized to yield extreme mechanical properties such as foldability, channeled response, and surface effects [1,2].

References:
[1] Bordiga, G., Cabras, L., Piccolroaz, A., Bigoni, D. (2019) Prestress tuning of negative refraction and wave channeling from flexural sources.
Applied Physics Letters, 114, 041901.
[2] Bordiga, G., Cabras, L., Bigoni, D., Piccolroaz, A. (2019) Free and forced wave propagation in a Rayleigh-beam grid: Flat bands, Dirac cones, and vibration localization vs isotropization.
International Journal of Solids and Structures, 161, 64-81.

- Reference person: **Oreste S. Bursi**
Participants: Marco Broccardo

Title: Analysis and risk assessment of petrochemical tank farms endowed with innovative metamaterials based on Gaussian process regression
(C5 - scholarship on reserved topics)

The Ph candidate will develop and apply risk-based methodology for assessing critical tank farms composed of broad and slender steel tanks of a typical petrochemical plant. Therefore, he/she will consider the tank farms subjected to a systematic list of top events and accident conditions caused by hazards on tank components leading to a loss of containment or physical damage owing to seismic loading. Thus, performance levels and critical scenarios for seismic events will be quantified. Then, a framework that relies on high-fidelity models for unanchored tanks based on 3D finite element (FE) models set in the ABAQUS software and uses low-fidelity demand models based on Gaussian process regression models, i.e. Kriging models, which allows for cheaper simulations of the system model is set and applied.

The novel concept of periodic metamaterials or metastructures will be applied to the vibration mitigation of tank farms of a petrochemical plant subjected to both seismic volumetric and surface waves. In greater detail and with regard to vibrations due to the impulsive components of the contained fluids, new tank farms will be conceived with novel periodic smart -mass and mass- foundations endowed with resonators; whilst existing tanks will be equipped with periodic resonators. Moreover, tanks will also be treated as resonating systems by themselves. These novel design concepts will also be explored for other examples of important finite lattice structures, like tanks used in regasification stations or reactors of nuclear power plants.

***- Reference person:* Luca Deseri**
Participants: Nicola M. Pugno; Massimiliano Fraldi (Università di Napoli-Federico II)

Title: Mechanobiology of coronaviruses uptake across the cell membrane
(C6 - scholarship on reserved topics)

Although lipid rafts are extensively studied for laboratory-made monolayers and bilayers [1], very recent findings in mechanobiology allow for explaining why certain ligand-receptor activity triggers lipid raft formations across the cell membrane [2]. Common and established knowledge is that ligand-receptors complexes form only by allowing conformational changes of the active receptors, no matter what such proteins are. The investigation in [2] is performed for G-Protein Coupled Receptors (GPCRs), an ubiquitous and very large family of receptors populating mammalian cells. Lipid rafts are predicted to nucleate, grow and evolve through receptor's activity and their interactions with pairing proteins. This arises through the interplay of (i) mechanical balance (involving elasticity, chemical potentials of the interacting species and their remodeling), (ii) tendency of the membrane to evolve towards minimal (free chemo-mechanical) energy configurations and (iii) reaction-diffusion dynamics of species (governed by their mobilities and by the gradient of their chemical potentials) regulated by interspecific interactions. In particular, it is found how rafts are stress relaxed and more compliant hosting zones of the cell membrane than raft-free sites. The required conformational changes for activating GPCRs hence relies upon the formation of such hosting zones.
The role of lipid-rafts as ligand's entry-mediators within cells can be key for providing a real understanding and fighting efforts against viruses uptake. Indeed, there exists a very compelling evidence that lipid rafts do serve as an entry port for viruses, such as the SARS-CoV of the 2002-2004 outbreak [3]. The findings in [1] and [3] (among other experimental results) strongly suggest that a general feature for hosting sites enabling receptors activity are stress relaxation and compliance. A quantitative predicting approach characterizing the space-time changes of the entry ports for CoV-2 can in fact contribute to the attempts of testing/designing new or existing drugs by selectively controlling (hence limiting) the mechanical properties mentioned above [4]. To this end, a non-trivial research allowing for a mechanical and multiphysics understanding of the remodeling and conformational changes needed for both the SARS-CoV and CoV-2 receptor Angiotensin-Converting Enzyme 2, ACE2, is needed through the investigation of energetics and the interspecific interactions.

References
[1] Deseri L., Zurlo G. (2013), The stretching elasticity of biomembranes determines their line tension and bending rigidity. Biomechanics and Modeling in Mechanobiology, DOI 1007/s10237-013-0478-z
[2] Carotenuto A., Lunghi L., Piccolo V., Babaei M., Dayal K., Pugno N. M., Zingales M., Deseri L.*, Fraldi M., (2020), Mechanobiology predicts raft formations triggered by ligand-receptor activity across the cell membrane, accepted for publication on the Journal of the Mechanics and Physics of Solids (*Corresponding Author)
[3] Lu Y., Liu D. X., Tam J. P. (2008), Lipid rafts are involved in Sars-CoV entry into vero e6 cells. Biochemical and Biophysical Research Communications, vol. 369, no. 2, pp. 344–349
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***- Reference person:* Nicola Maria Pugno**
Participants: Massimiliano Fraldi (Università di Napoli-Federico II); Luca Deseri

Title: Nanomechanics of wrinkling
(C7 - scholarship on reserved topics)

Wrinkling has recently attracted an increasing interest by suggesting a number of unforeseeable applications in many emerging materials science and engineering fields, in particular with respect to non-planar surfaces patterned at micro- and nano-scales. If guided and somehow designed, wrinkles formation could be for instance used as an alternative 3D printing way for realizing complex surface geometries and thus employed as an innovative bottom-up process in the fabrication of nano- and micro-technological devices. The prediction of wrinkles of films adhering on flat as well as on 3D-shaped compliant substrata is thus a challenging task, the genesis and the development of the phenomenon being not yet completely understood when thin membranes are coupled with soft supports, in cases where the geometry of the surfaces are characterized by complex three-dimensional profiles as well as in man-made films and graphene sheets, for which how underlying micro- or nano-structures influence magnitude, wavelengths and shape of wrinkling is still an open issue. Motivated by the above mentioned applications and by possible uses of wrinkled substrata for analyzing and orienting migration and adhesion of cells, the present project proposal is aimed to ask to the PhD candidate of investigating the experimental formation of new intriguing wrinkled patterns achieved on 3D periodic structures of micro/nano structured films, by adopting both analytical and numerical strategies, by also supporting experimental activities at the laboratory related to the construction and testing of specific prototypes conceived to analyze the effect of the underlying structural geometry on the wrinkling formation. Within the framework of ongoing biomechanical research activities, the candidate will be additionally involved in the study of

the functional relationships existing among growing cells adhering and moving on wrinkled surfaces and durotaxis, with the purpose of enhancing the basic understanding of the mechanobiology of living cells and envisaging applications in medicine.

- Reference person: **Daniele Zonta**

Title: Monitoring-based risk management of civil infrastructure
(C8 - scholarship on reserved topics)

BACKGROUNG
Extreme events can jeopardize the efficiency of the civil infrastructure and have an immediate impact on the community and its recovery time. There is the need to develop tools to predict possible damage scenarios resulting from these events and, in the event, to provide real time information on the state of the infrastructure to allow the public authority to react and undertake countermeasures.
Prediction of damage scenarios is based on formal risk analysis, which includes evaluation of the hazard of the event and the vulnerability of the individual components of the infrastructure network. The vulnerability of a component is usually described through fragility curves [1], functions representing the probability that the component undergoes a particular damage state for a given level of demand.
Sensor and communication technologies offer the possibility to assess real time the state of an infrastructure component (such as a bridge, a building or a link), yet monitoring an entire infrastructure network is economically unsustainable. A way to overcome this limitation is to install monitoring systems on a limited number of critical components and use a probabilistic approach to extend this information to the entire network.
The idea is to represent the state of the infrastructure through a set of random variables and to use Bayesian networks to model their conditional dependencies [2]: immediately after an event, monitoring observations are used to probabilistically infer the posterior distribution of the state variables.

OBJECTIVE
The two students selected will develop a probabilistic framework to support emergency management in the aftermath of an extreme event based on the information recorded by monitoring systems. Hazardous events considered includes: floods and earthquakes. The system will estimate a posteriori the condition state of an infrastructure network in a post-event scenario based on the state of individual components, appraised through instrumental monitoring. The same framework will also serve as an early warning system, providing alert to the community and decision support to the public authority.

METHOD
- Analyze the state of the art of monitoring-based decision-making.
- Model correlation in hazard and vulnerability among different infrastructure components, with focus on bridges, using Bayesian networks.
- Investigate and analyse monitoring system technologies for real time damage detection of bridges; in-field case studies will be provided by Autostrade per l'Italia.
- Develop methods for updating fragility curves and state variables of the Bayesian network based on information from monitoring systems.
- Propose a Decision Support System for early warning and emergency management.
- Validate the method on a number monitored bridges, provided by Autostrade per l'Italia.

[1] I. Ioannou, J. Douglas, and T. Rossetto. "Assessing the impact of ground-motion variability and uncertainty on empirical fragility curves." Soil Dynamics and Earthquake Engineering 69 (2015): 83-92.
[2] M. T. Bensi, A. Der Kiureghian and D. Straub. A Bayesian network methodology for infrastructure seismic risk assessment and decision support. Pacific Earthquake Engineering

Architecture and Planning, Landscape (Curriculum D)

- Reference person: **Enzo Falco**
Participants: Davide Geneletti

Title: Regulatory Planning for Nature-based Solutions implementation in cities

Regulatory planning in the form of command and control procedures have characterized urban planning practices for decades. Over the last two decades, market-based tools such as Transfer of Development rights (TDR) have spread across the world to achieve various objectives, ranging from increased equity among landowners and between landowners and society at large, preservation of agricultural land, acquisition of land by public authorities to form a reserve of publicly-owned areas (Falco and Chiodelli, 2017). The latter, together with the need to recapture the increase in the value of land generated as a consequence of the planning activity, is fundamentally linked to the provision of public services, open and green areas. The availability of such areas is of paramount importance for the planning of nature-based solutions (NbS) and the supply of urban ecosystem services (UES) (Harman and Low Choy, 2011; Almenar et al., 2019). UES (e.g. air purification, run-off mitigation and flood control, global climate regulation) serve, therefore, an essential role in the planning of the sustainable city and for tackling the causes and effects of the current climate crisis and increased environmental issues (e.g. air pollution, floods) at the local and global level (Geneletti et al., 2020).

According to the candidate profile, the research may address one (or a combination) of the following topics:

- International development of TDR practices and their potential to favour the implementation of nature-based solutions and the supply of UES;
- Inclusion of NBS in market-based and performance-based urban planning practices;
- Flexibility of TDR tools and land-value recapture practices compared to typical command and control procedures;
- Analysis of selected case studies, their regulatory and tools and legislation in relation to TDR, NbS and UES;
- Modelling NbS and TDR scenarios in a selected case study to determine UES supply.

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

1) Literature review: TDR's state of the art for NbS and UES.
2) Case study analysis: TDR NbS and UES.
3) Modelling and assessing of NbS and UES contribution in selected case studies.

References:
Almenar, J.B., Rugani, B., Geneletti, D., and Brewer, T. (2018) Integration of ecosystem services into a conceptual spatial planning framework based on a landscape ecology perspective. Landscape ecology, 33 (12), 2047-2059.
Falco, E. and Chiodelli, F. (2017). The transfer of development rights in the midst of the economic crisis: Potential, innovation and limits in Italy. Land Use Policy, 72, 381-388.
Geneletti, D. Cortinovis, C., Zardo, L. and Esmail, B.A. (2020) Developing Ecosystem Service Models for Urban Planning: A Focus on Micro-Climate Regulation. In Planning for Ecosystem Services in Cities, 31-42. Cham: Springer.
Harman, B. and Low Choy, D. (2011) Perspectives on tradable development rights for ecosystem service protection: lessons from an Australian peri-urban region. Journal of Environmental Planning and Management, 54(5), 617-635.

- Reference person: **Giovanna Massari**

Title: INTERFACE MODELS. Access strategies to BIM technologies

The new technologies adopted by the construction sector offer the opportunity to manage at the same time several aspects related to the project, with various levels of detail and complexity. This technological implementation should allow not only to optimize time and costs, but also to reduce environmental impacts related to each phase of the life cycle, through a holistic vision and according to circular economy logics.
The introduction of these new technologies is an important challenge especially for professionals asked to operate on existing buildings and to deal with architectural heritage. Given the strong singularity of geometry and craftsmanship of construction techniques, most of existing buildings are difficult to categorize within predefined standards, but it's still possible to record and describe them through digital models. The definition of good practices for the creation of models as interface with the built environment could be an important reference not only for facility management, but also for reuse or restoration projects. In this regard, a significant increase in projects on the built environment is expected, both to reduce soil consumption and to adapt the existing buildings to the new standards of internal comfort, energy consumption and environmental emissions.
In order to avoid losing most of the advantages offered by new technologies, it is necessary to pay attention to interface and interoperability issues between the actors involved during the life cycle of a building. For instance, it is crucial to distinguish between interface requirements, i.e. communication between different actors, and interoperability requirements, i.e. cooperation between different specialists, which also includes the possibility of sharing and re-elaborating previously modelled data.
Not each actor involved in the life cycle of a building needs to re-elaborate all modelled information, for some it is enough to read or view it, as well as not everyone needs have access to all the available data. For the purposes of an effective and efficient information exchange, it may therefore be useful to develop strategies to access data through special interface models, capable of optimizing communications and interactions between two or more involved parties.
Working on existing buildings requires the acquisition of data, through geometric survey and thematic analysis, and their subsequent processing for specific design purposes. A real case study can be an opportunity to develop interfaces useful for several project phases, supporting involved actors (designers, producers, administrators, owners, etc.) to access to specific information. Starting from the collected data, simulations of the projects during its life cycle can also be developed. With the involvement of multidisciplinary know-how and experiences of local specialists, it would be possible to define standards useful both to interface with existing buildings and to improve the exchanges between involved actors, with the aim of obtaining economic and environmental benefits. According to the case study, specific disciplinary areas can be selected and further investigated.

- Reference person: **Rossano Albatici**

Title: Performance-based design and machine learning tools for the energy and indoor living quality optimization in the building design process
(D1 - scholarship on reserved topics)

The need to design NZebs with high energy performances and environmental values has led to the use of increasingly complex tools mainly based on dynamic simulation, but recently the limits of such approach are getting more and more evident: the outputs can be used to perform diagnosis of existing buildings or to compare possible solutions, but their predictive power may be limited. In the field of digital design support, performance-based tools are beginning to emerge, coupled with on-site monitoring experiences, but still usually restricted to energy related parameters.

The research project concerns the development of a methodology based on optimization algorithms for the design of sustainable buildings with particular attention to IEQ (Indoor Environmental Quality) and HE (Healing Environment) issues. Based on the analysis of users' needs, of different building systems features and of energy performance indicators, the goal is to realize an optimization system based on machine learning algorithm (taking advantage from key concepts and issues applied on performance-based design in architecture), and to define proper object functions to obtain information about the design features influencing the desired/optimum results. Also exploiting the potential of generative computational design, this process is connected to the possibility to obtain a wider vision of design opportunities, almost unlimited possibilities of possible choices investigation and subsequent faster selection process of best choices. At the same time, the realization of an informed database of case studies becomes an important support from the very beginning of the design process.

The main issues to be faced are:
1. the proposal of a general approach to define the users' needs connected to different social, environmental and economic context, towards an IEQ-HE integrated vision;
2. the definition of a concept framework to be used for the optimization of living modules (mainly residential and tertiary) both for energy and indoor quality issues;
3. the development of a methodology for simulation, optioneering and visualization design process with the definition of a proper database of possible solutions (also based on monitoring campaign on existing buildings);
4. the development of a performance-based tool exploiting the potential of machine learning processes.

Expected research outcomes:
1. literature review on generative computational design, performance-based design in architecture and machine learning tools;
2. definition and analysis of the most important features and parameters connected to energy performance and indoor living quality issues to be implemented in machine learning processes;
3. tool based on machine learning for the prediction of the best choices related to energy and IEQ-HE parameters, also based on suitable case studies analysis;
4. papers on international journal and participation to conferences.

References
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- T. Wortmann and T. Schroepfer, "From Optimization to Performance-Informed Design," SimAUD2019, no. April, 2019.
- P. Hoes, J. L. M. Hensen, M. G. L. C. Loomans, B. de Vries, and D. Bourgeois, "User behavior in whole building simulation," Energy Build., vol. 41, no. 3, pp. 295–302, 2009, doi: 10.1016/j.enbuild.2008.09.008.
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- Reference person: **Sara Favargiotti, Giovanna A. Massari**

Title: Reality vs multi-dimensional modelling: landscape and architectural heritage exploration and design – PRIN 2017
(D2 - scholarship on reserved topics)

Building three-dimensional (3D) models and photorealistic visualizations of environment is important in many applications ranging from virtual representation of natural and built heritage to analysis and monitoring of land cover/use, architectural qualities as well as landscape and urban management, planning and design.
The new technologies adopted by the construction sector offer the opportunity to manage at the same time several aspects related to the project, with various levels of detail and complexity. This technological implementation should allow not only to optimize time and costs, but also to reduce environmental impacts related to each phase of the life cycle, through a holistic vision and according to circular economy logics.
The introduction of these new technologies is an important challenge especially for professionals asked to operate on existing buildings and to deal with architectural heritage but also for reuse or restoration projects. Even more challenging is the approach of these technologies to analyse and support local administrators to the landscape management and design.
In order to avoid losing most of the advantages offered by new technologies, it is necessary to develop strategies to access data through special interface models, capable of optimizing communications and interactions between two or more involved parties, even more when referred to local administrations among different regions.

Research focuses
The research will focus on two interoperability scales: the landscape and the architectural heritage, focusing on small villages in inner areas. On the one hand, a significant increase in projects on the built environment is expected, both to reduce soil consumption and to adapt the existing buildings to the new standards of internal comfort, energy consumption and environmental emissions.
On the other hand, the aim of 3D modelling of landscape is to produce according to the user needs sufficiently reliable and accurate digital three-dimensional model of the earth's surface that can be visualized dynamically through selected software or can be used to produce static cartographic or presentation products. Basic data in 3D modelling includes GIS datasets for relief, land cover, hydrography, buildings, roads and tourist infrastructure, as well as remote sensing data such as satellite and orthophoto images, Radar, LiDAR, etc.
The research will specifically address the topic on the Trentino region as a testing ground, compared and confronted with national and international case studies. Selected pilot areas in Trentino will be the opportunities to develop interfaces useful

for several project phases, supporting involved actors (designers, producers, administrators, owners, etc.) to access to specific information. With the involvement of multidisciplinary know-how and experiences of local specialists, it would be possible to define standards useful both to interface with existing buildings and to improve the exchanges between involved actors, with the aim of obtaining economic and environmental benefits.

Expected research outcomes
The doctoral candidate will address the following research topics: a) comparison and evaluation of 3D models (dynamic or static), digital technologies, tools and software for landscape and architectural heritage; b) knowledge background acquisition, database overview and analysis, data elaboration; c) generation of a 3D model of terrain with the basic data for landscape and hamlets (geology, soil, vegetation, hydrography, buildings, etc.) of specific selected pilot cases in small villages in inner areas in Trentino; d) simulations of the projects' dynamics during its life cycle at the different scale and with a multidisciplinary approach.

Note
The doctoral candidate will be involved in the research project "[B4R] BRANDING4RESILIENCE. Tourist infrastructure as a tool to enhance small villages by drawing resilient communities and new open habitats" PRIN 2017. The candidate research will support the analyses of specific territories and give inputs for co-designing actions and co-visioning scenarios. The doctoral candidate will address the architectural survey and digital modelling disciplines (ICAR/17) with an emphasis on landscape architecture (ICAR/15) and architectural heritage (ICAR/14).

Research project: MIUR PRIN 2017 Favargiotti
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