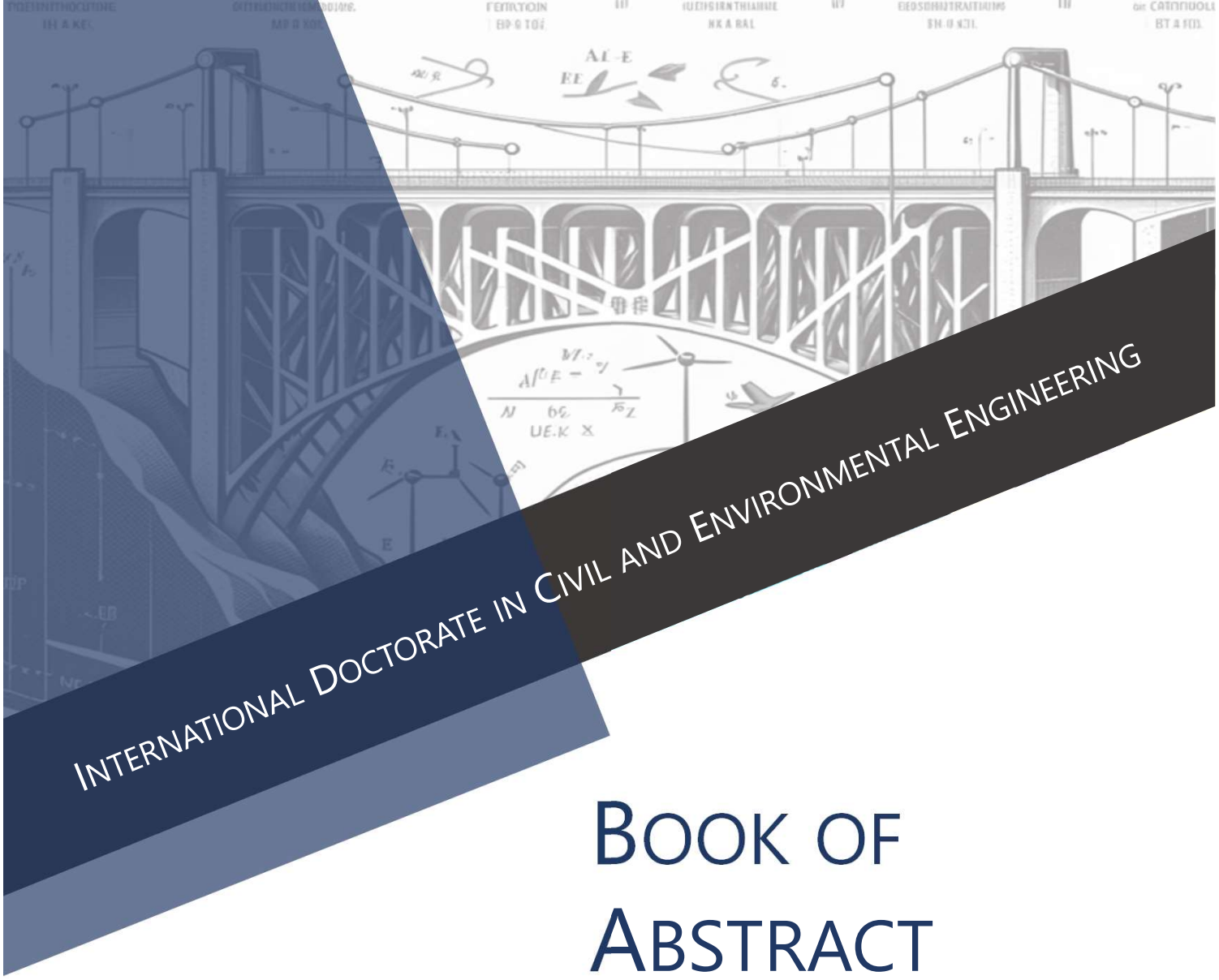

INTERNATIONAL DOCTORATE IN CIVIL AND ENVIRONMENTAL ENGINEERING

BOOK OF ABSTRACT

46th Plenary Meeting
Monday 28th October 2025
Tuesday 29th October 2025

Pisa - School of Engineering
Largo Lucio Lazzarino, 56122, Pisa, Italy

Firenze - School of Engineering
via di S. Marta 3, 50139, Firenze, Italy

UNIVERSITÀ DEGLI STUDI FIRENZE

UNIVERSITÀ DI PISA

Technische Universität Braunschweig

Proceedings of the 46th Plenary Meeting

28/29 October 2025 – Pisa/Firenze

International Doctorate in Civil and Environmental Engineering

Book of Abstract

Doctorate Course Coordinator: Prof. Luca Solari, Prof. Klaus Thiele

Secretariat: Margherita Mellini

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46th Plenary meeting program

28
October
2025

Location:
Aula Pacinotti, Polo A,
Largo L. Lazzarino, 1
Pisa

PROGRAM

09:30 *WELCOME GREETINGS*
10:00 PRESENTATIONS BY ENROLLED PHD STUDENTS
Session A1 - TRANSPORTATION INFRASTRUCTURES AND MATERIALS
11:30 COFFEE BREAK
12:00 PRESENTATIONS BY ENROLLED PHD STUDENTS
Session A2 - RELIABILITY OF STRUCTURES AND INFRASTRUCTURES AGAINST NATURAL HAZARDS
13:00 *LUNCH BREAK* (Foyer at the second floor)

14:00 PRESENTATION OF THE **NEWLY ENROLLED PHD STUDENT XLI CYCLE**
14:30 PRESENTATIONS BY ENROLLED PHD STUDENTS
Session A3 - STRUCTURAL MECHANICS
16:00 **Session A4 - INSIGHT ON THE CONSERVATION OF CULTURAL HERITAGE**
17:30 END OF THE MEETING

Session A1 – Transportation Infrastructures and Materials ***28/10/2025 H 10,00-11,30 Aula Pacinotti*** *Chair: Chiara Riccardi, PhD*
• Daniele Conte (XXXVIII) 15min • Chenxi Wang (XXXVIII) 15min • Giannelli Roberto (XXXIX) 12min • Sakanlou Farhad (XXXIX)12min • Luddi Maria Giulia (XXXIX) 12min • Dong Hongjun (XL) 10min

Session A2 - Reliability Of Structures And Infrastructures Against Natural Hazards ***28/10/2025 H 12,00-13,00 Aula Pacinotti*** *Chair: Agnese Natali, PhD*
• Alireza Duzandeh (XXXIX) 12min • Giulia Pierotti (XXXIX) 12min • Costanza Guarducci (XL) 10min • Hamza Tahat (XL) 10min • Saverio Zingarelli (XL) 10min

Session A3 – Structural Mechanics ***28/10/2025 H 14,30-16,00 Aula Pacinotti*** *Chair: Roberto Alessi, PhD, & Marco Picchi Scardaoni, PhD*
• Farshad Rahmani Karkevandi (XXXVIII) 15min • Nicolò Guiducci (XXXVIII) 15min • Yasaman Salahshour (XXXIX) 12min • Michele Coppedè (XXXIX) 12min • Paolo Pagni (XL) 10min • Alessandro Montanino (XL) 10min

Session A4 - Insight On The Conservation Of Cultural Heritage ***28/10/2025 H 16,00-17,30 Aula Pacinotti*** *Chair: Filippo Landi, PhD*
• Andrea Bongini (XXXVIII) 15min • Dario Billi (XXXIX) 12min • Martina Colapietro (XXXIX) 12min • Saghar Jamshidiaval (XXXIX) 12min • Francesca Meligeni (XXXIX) 12 min

UNIVERSITÀ DEGLI STUDI FIRENZE

UNIVERSITÀ DI PISA

Technische Universität Braunschweig

29 October 2025

Location:
Aula Caminetto,
Via S.Marta 3
Firenze

Link meet:

PROGRAM

8:30 **PREDEFENSES XXXVII Cycle**
11:45 *COFFEE BREAK*
12:00 PRESENTATIONS BY ENROLLED PHD STUDENTS
Session B1 - RIVER/COASTAL DYNAMICS AND POLLUTION
13:15 *LUNCH BREAK*

14:30 PRESENTATIONS BY ENROLLED PHD STUDENTS
Session B2 - SUSTAINABLE WASTEWATER TREATMENT
15:30 **Session B3 – MULTI-RISK AND NATURE BASED SOLUTIONS**
17:00 *COFFEE BREAK*
17:30 **Academic Board** - reserved to the members
18:30 END OF THE MEETING

Pre-defenses XXXVII Cycle PON

29/10/2025 H 8,30-12,00 Aula Caminetto

Chair: Prof. Luca Solari

8.30 **Mahtab Shiravi** - Double title with **NTNU**
"Multi-risk Analysis of Wind and Rain on Trees in Urban Environments"
9.05 **Jan Pietro Czellnik** - Double title with **UAB**
"Developing Granular Sludge Technologies for the Transition to Biorefineries of Municipal Wastewater Treatment Plants"
9.40 **Melissa Yozy Kepdib** - Double title with **NTNU**
"The Use of Low Enthalpy Geothermal Energy through the Installation of Micropiles"
10.15 **Stefano Fiaschi** - Double title with **UAB**
"Optimisation of municipal solid waste collection to enhance materials recovery"
10.50 **Alex Ricoveri** - Double title with **UAB**
"Biological treatment of synthetic hypersaline wastewater by conventional sequencing batch reactor (SBR) and integrated fixed film activated sludge reactor (SBR-IFAS)"
11.25 **Riccardo Angelini** - Double title with **UPC**
"Coastal Environment Monitoring through Satellite, Terrestrial, and Airborne Remote Sensing"

Session B1 - River/Coastal Dynamics And Pollution ***29/10/2025 H 12,00-13,15 Aula Caminetto*** *Chair: Marco Lompi, PhD & Irene Simonetti, PhD*
• Nisa Bahadıroğlu (XXXVIII) 15min • Ayalew Shura Kasa (XXXVIII) 15min • Rebecca Agati (XXXIX) 12min • Shoaib Ameer (XXXIX) 12min • Amanda Zannella (XXXIX) 12min

Session B2 – Sustainable Wastewater Treatment ***29/10/2025 H 14,30-15,30 Aula Caminetto*** *Chair: Lorenzo Innocenti, PhD & Benedetta Pagliaccia, PhD*
• Marta Di Bianca (XXXVIII) 15min • Daniele Sartirano(XXXVIII) 15min • Alessandro Alberti (XL) 10min

SESSION B3 - MULTI-RISK AND NATURE BASED SOLUTIONS ***29/10/2025 H 15,30-17,00 AULA CAMINETTO*** *Chair: Marco Lompi, PhD & Irene Simonetti, PhD*
• Alemayehu Shanko (XXXVIII) 15min • Tommaso Giordano (XXXVIII) 15min • Gabriele Bertoli (XXXVIII) 15min • Noemi Mannucci (XXXIX) 12min • Moradimirabadi Reza (XL) 10min

A Machine Learning approach to incorporate SARS-CoV-2 subvariant effect in wastewater

Daniele Sartirano

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Doctorate Cycle: XXXVIII

Co-tutelle University: University of Hasselt

Supervisors: Claudio Lubello, Niel Hens

Doctorate Thesis: Wastewater-based epidemiology: linking SARS-CoV-2 RNA and clinical tests in Tuscany

Keywords: Wastewater, machine learning, epidemiology, temporal effects

Abstract:

In our study on the feasibility of wastewater-based surveillance in Tuscany, we observed that the correlation between SARS-CoV-2 RNA concentrations in wastewater and clinically confirmed COVID-19 cases varied over time. Our analysis indicated that the primary factors driving this temporal variation were shifts in the prevalence of viral subvariants and changes in the accuracy of clinical testing. In this presentation, I will describe our efforts to apply machine learning methods to account for these factors and to reestablish a robust relationship between wastewater and clinical data. I will present regression models that provide valuable retrospective insights into pandemic dynamics, as well as a classification-based approach that reformulates wastewater surveillance as a predictive task. Finally, I will discuss how this framework reveals key limitations and sources of uncertainty within our dataset.

Saint Venant-Kirchhoff constitutive equation for a beam whose cross section deforms in its plane

Nicolò Guiducci

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Doctorate Cycle: XXXVIII

Co-tutelle University: University of Granada

Supervisors: Roberto Paroni, Roberto Palma

Doctorate Thesis: Geometrically exact theory of beams undergoing finite displacements

Keywords: Beam, cross section, constitutive equation

Abstract:

In this presentation we compare the behaviour of a beam under the two different hypotheses of a rigid cross section or of a cross section which deforms in its plane according to the Saint Venant-Kirchhoff constitutive equation. In fact, the assumption of a cross section rigid in its plane introduces an internal constraint in the behaviour of the beam which unrealistically improves its stiffness. To remove this undesired effect, we modify the deformation gradient tensor due to the rigid cross section hypothesis so as to allow the cross section itself to deform in its plane according to the constitutive equation. Nevertheless, we continue to consider the cross section as rigid out of its plane. Subsequently, we derive the modified strain tensors relative to the modified deformation gradient tensor, that is the right and left polar decompositions, the right and left Cauchy-Green strain tensors, and the Green-Saint Venant strain tensor, and compare them with those derived from the rigid cross section hypothesis. After that, we compute the stress tensors consistent with the constitutive equation, that is the second Piola stress tensor, the first Piola stress tensor, and the Cauchy stress tensor. The results obtained are in accordance with the behaviour we expect for stresses in a beam, and constitute the reason why we removed the hypothesis of a cross section rigid in its plane. Finally, we compute the stress vector acting on the cross section and derive from it the constitutive equation in terms of the internal resultant force and moment.

Development and Optimization of a Bio-Extender from Biomass-Derived Hydrophobic Fractions for Sustainable Bitumen Substitution

Roberto Giannelli

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Doctorate Cycle: XXXIX

Co-tutelle University: Université Gustave Eiffel

Supervisors: Massimo Losa e Emmanuel Chailleux

Doctorate Thesis: Development of high-performance carbon-neutral biomaterials and bio-circular binders for road applications

Keywords: biomass, hydrothermal liquefaction, bio-extender, sustainable materials

Abstract:

The study focused on optimizing the extraction of a hydrophobic liquid phase from pretreated biomass. Initially, Soxhlet extraction was optimized, yielding 11 wt% of a hydrophobic lipidic fraction. The residual biomass from this process underwent hydrothermal liquefaction (HTL), which fully converted the feedstock into solid, liquid, and gaseous products. The gaseous phase contained biofuel-relevant molecules such as methane and hydrogen. The liquid fraction was further separated into hydrophilic and hydrophobic components. The hydrophobic liquid phase showed high chemical compatibility with conventional bitumen (grade 50/70) and was tested as a partial bio-based substitute. Preliminary trials achieved a 5% replacement of petroleum bitumen, with the target of reaching 20%, leading to the formulation of a "bio-extender" a plant-derived material capable of maintaining the same rheological properties as conventional bitumen. This hydrophobic fraction can also be combined with the Soxhlet extract directly obtained from biomass to enhance performance. Ongoing experiments involve incorporating biopolymers to further improve the rheological behaviour of the bio-extender. These polymers are sustainably produced from waste biomass via bacterial fermentation, ensuring environmental compatibility. The ultimate goal is to develop an optimized bio-extender composed of the most effective combination of hydrophobic extracts and bio-based polymers, maximizing the replacement of petroleum-derived bitumen while maintaining comparable mechanical and rheological properties.

AI and CV methodologies for the digital transition and the optimization of archival 2D/3D data of cultural heritage, acquired with integrated geomatic techniques: MILo

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Doctorate Cycle: XXXIX

Co-tutelle University: INSA University of Strasbourg

Supervisors: Pierre Grussenmeyer, Arnadi Murtiyoso, Gabriella Caroti, Andrea Piemonte

Doctorate Thesis: AI and CV methodologies for the digital transition and the optimization of archival 2D/3D data of cultural heritage, acquired with integrated geomatic techniques

Keywords: MILo, GaussianSplatting, 2DGaussianSplatting, 3DGaussianSplatting,

Abstract:

Traditional Structure-from-Motion (SfM) and multi-view reconstruction methods often face significant challenges when dealing with complex visual and geometric conditions. Reflective or metallic surfaces, transparent materials, homogeneous textures, non-Lambertian reflections, underwater environments, and thin geometries frequently result in incomplete or inaccurate reconstructions due to loss of essential visual cues. To address these limitations, the Mesh-In-the-Loop Gaussian Splatting (MILo) framework has been introduced (Anttwo/MILo). MILo enhances the Gaussian Splatting paradigm by differentiably extracting a mesh from the splats during training, enforcing consistency between volumetric and surface representations. This integrated approach yields more accurate, detailed, and compact surface reconstructions, effectively bridging the gap between point-based and mesh-based representations. Preliminary results demonstrate substantial improvements in both geometric fidelity and computational efficiency.

Linking Cumulative Anthropogenic Pressures to Microplastic Distribution along the Spanish Mediterranean Coast and Balearic Islands

Rebecca Agati

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Doctorate Cycle: XXXIX

Co-tutelle University: Universitat de les Illes Balears UIB

Supervisors: Luca Solari, Carlo Brandini, Carme Alomar Mascarò

Doctorate Thesis: Microplastic Dispersion in the Northwestern Mediterranean: Modelling and Sampling Strategies in Acquatic and Estuarine Systems

Keywords: Microplastics, Mediterranean Sea, Anthropogenic Indicators, Cumulative Impacts, Plastic Hotspots

Abstract:

Microplastic (MP) pollution is a major threat to marine ecosystems, and the Mediterranean Sea is particularly vulnerable. Human activities influence MP pollution, yet the relationship between anthropogenic pressures and MP abundance remains poorly understood. This study assesses MP abundance in the Balearic Islands and along the eastern Spanish coast by combining surface MPs and anthropogenic indicators including wastewater treatment plants, agriculture, aquaculture, maritime traffic, ports, river mouths, blue flag beaches, urban centres, waste management, coastal proximity. Four spatial buffers (0, 1.5, 3, and 5 km) were analysed for each anthropogenic indicator to examine effects of distance from sources. Generalized Additive Models (GAMs) identified coastal proximity, waste management, and ports as key indicators for MPs pollution. Indicators were weighted to generate a Cumulative Impact Map, and an interpolation on MP abundances was obtained to produce continuous distribution maps through Inverse Distance Weighting. The overlap between the cumulative impact map and interpolated MP abundance highlighted hotspots at Ebro Delta, Castellón, and Palma de Mallorca. Cities such as Barcelona and Valencia showed medium human impact without MP hotspots, while Girona was a hotspot of MPs pollution despite low impact. These results reveal spatial mismatches and emphasize importance of considering both oceanographic factors and human pressures to guide monitoring, mitigation measures.

Linear one-dimensional models for tape spring by Γ-convergence

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Doctorate Thesis: Linear one-dimensional models for tape spring by Γ-convergence

Keywords: Tape spring, one-dimensional model, Γ-convergence

Abstract:

Here, we present three one-dimensional models for tape spring devices, derived through Γ-convergence starting from a shell model. Tape spring devices, due to their geometry, can be classified as thin shells characterized by a curvilinear cross-section. These devices are generally slender, making it interesting to study them and deduce beam models from shell models, thus obtaining simpler models than the shell ones. We consider a domain $\omega_{\varepsilon} \subset \mathbb{R}^2$, where $\varepsilon \leq 1$ is a positive parameter that will tend to zero. The cross-section of the device is described by the function $w_0(x_2)$, and the thickness is h_{ε}. Once the functional F, which describes the elastic energy of the device, is assigned, we proceed to linearize it. Since the domains of definition of the energy are infinite, one for each value of ε, we can refer to a domain ω independent of ε, through the transformation $\mathbf{r}_{\varepsilon}$. It is also assumed that $h_{\varepsilon} = \varepsilon^{\alpha}h$, where h is a reference value for the thickness, and the exponent $\alpha \ge 1$, so that the thickness tends to zero at a rate greater than or equal to the width of the device. Through this procedure, we arrive at the definition of the functional F_{ε}, for which we aim to determine the Γ-limit for different values of the exponent α. By studying F_{ε}, we determine the Γ-limits for: $\alpha = 1$, $1 < \alpha < 2$, and $\alpha = 2$.

Remote Sensing and Machine Learning for the Characterization and Dynamics of Water-Related Systems in a Changing Environment

Noemi

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Co-tutelle University:

Supervisors: Enrica Caporali, Margherita Azzari

Doctorate Thesis: Remote Sensing and Machine Learning for the Characterization and Dynamics of Water-Related Systems in a Changing Environment

Keywords: Small Agricultural Reservoirs (SmARs); remote sensing; Sentinel-2; drought resilience; agricultural water management; climate adaptation; water storage.

Abstract:

Water-related ecosystems deliver crucial services such as water purification, climate regulation, and biodiversity conservation, yet they are increasingly threatened by climate change and human pressure. Among these, Small Agricultural Reservoirs (SmARs) represent a critical but often overlooked component, providing local water storage, irrigation supply, and drought mitigation. Their small size and fragmented distribution make them difficult to detect systematically, resulting in knowledge gaps in national inventories and ecosystem service assessments. This research addresses these gaps by developing scalable methodologies that integrate satellite remote sensing and machine learning for the monitoring and characterization of SmARs within broader landscape and ecosystem perspectives. A first achievement is the nationwide inventory of SmARs in Italy, produced within the PRIN project CASTLE. Using Sentinel-2 imagery processed in Google Earth Engine, combined with ESA WorldCover and OpenStreetMap datasets, we generated a geospatial database of over 77,800 reservoirs, including surface area and estimated storage volume. This constitutes the first consistent baseline for evaluating SmARs' contribution to irrigation supply, drought mitigation, and hydrological processes. A second research line focuses on the optimal siting of water-related Nature-Based Solutions (NBS), tested at the municipal scale in Pontedera (Italy). By combining hazard data, land-use constraints, and ecosystem service analysis, results show that allocating NBS in priority zones enhances both flood risk reduction and ecosystem service provision. In parallel, the project also contributes to the international initiative DOWES, aimed at mapping

wetlandscapes as connected hydrological-ecological systems. Future work will refine detection methods by integrating optical and radar data (e.g., COSMO-SkyMed), enabling the analysis of temporal dynamics such as seasonal storage variations and responses to climate extremes. Overall, the ambition is to deliver a scalable and transferable methodology that supports evidence-based water management, strengthens the role of NBS, and contributes to long-term water security and ecological resilience

Oxygen Penetration Depth as a Tool to Predict Nitrous Oxide Emissions from Granular Partial Nitritation Wastewater Treatment Systems

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Doctorate Cycle: XL

Co-tutelle University:

Supervisors: Tommaso Lotti, Claudio Lubello

Doctorate Thesis: Pitfalls in Granular Sludge Wastewater Treatment Processes

Keywords: Wastewater Treatment, Partial Nitritation, Nitrous Oxide Emissions

Abstract:

The effort in developing efficient processes for nitrogen removal from wastewater has intensified research on strategies to achieve Partial Nitritation (PN) in the mainstream line of Wastewater Treatment Plants (WWTPs). PN is a biological process in which Ammonium Oxidizing Bacteria (AOB) oxidize ammonium to nitrite instead of nitrate, allowing for reduced aeration energy consumptions and resulting CO_2 emissions compared to Conventional Activated Sludge (CAS). However, some studies suggest that PN could lead to increased emissions of Nitrous Oxide (N_2O), a greenhouse gas with a GWP of 274. The emission factors (EF) reported in literature are highly variable and difficult to predict, as they heavily depend on several environmental conditions. Developing a reliable method to predict N_2O emissions from PN systems based on operational conditions would be crucial to quantify the actual overall environmental advantage of PN over CAS, and to optimize the systems' design parameters. With this objective, six Nitrous Oxide emission tests, corresponding to combinations of three dissolved oxygen and two temperature levels, were performed on a lab-scale granular Partial Nitritation reactor. Emission factors ranged from 0.60 to 2.97 % of the Ammonium Oxidation Rate, and were negatively correlated with granules' estimated oxygen penetration depths (δ). The ratio between anoxic and aerobic granule volume, easily derivable from δ, was linearly correlated with EF (R^2=0.91), and was therefore proposed as a tool to predict N_2O emissions from PN granules. This study lays the foundations for future works aimed at refining the proposed EF prediction method.

Economic and environmental analysis of city logistics solutions based on Urban Distribution Centers in Lucca using SUMO

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Doctorate Cycle: XXXVIII

Co-tutelle University: TU Braunschweig

Supervisors: Alessandro Farina, Marino Lupi, Lars Schnieder

Doctorate Thesis: Analysis and Design of Innovative City Logistics Solutions Based on Urban Distribution Centers and the Evolution of the Two-Echelon System with Automated Vehicle Platoons

Keywords: Van-platooning system, UDC localization problem, last mile city logistics, SUMO simulation

Abstract:

Although Urban Distribution Centers (UDCs) are widely recognized as an effective strategy to mitigate the negative externalities of city logistics, their implementation is often hindered by the localization problem. To overcome this limitation, the Van Platooning System (VPS), an evolution of the traditional two-echelon (2E) model, has been proposed as an innovative approach. In the VPS, platoons of automated vehicles operate in the first echelon and, upon reaching designated Split-Up Locations (SULs), separate to continue their routes independently in the second echelon. This system also reduces time losses associated with additional transshipment operations compared with conventional 2E systems. Previously, the VPS was tested in Lucca, Italy, focusing on overall system functionality and providing a general overview. The present study extends this work through a more comprehensive and realistic evaluation, incorporating detailed economic and environmental assessments and a comparison with conventional direct UDC deliveries. Unlike the initial study, which assumed that the UDC handled the entire demand, this study conducts a detailed demand analysis to identify which product categories can be effectively managed by a UDC, evaluating both best and worst case scenarios. Methodologically, the study advances from a static network representation in QGIS to a high-fidelity dynamic simulation in SUMO, which incorporates real road network characteristics and explicitly models vehicle behavior. Moreover, while the previous framework required additional computations to derive performance indicators, SUMO directly outputs key metrics such as emissions, fuel

consumption and travel time, enabling a more accurate evaluation of system performance, operational efficiency, and environmental impact.

Enhancing Molecular Simulation Accuracy and Aging Representation in Bitumen

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Doctorate Cycle: XXXIX

Co-tutelle University: RWTH Aachen

Supervisors: Massimo Losa, Alessandro Marradi, Marco Pagliai, Alvaro Garcia-Hernandez

Doctorate Thesis: Study of the aging mechanisms in conventional and bio-based bitumen and their relationship with chemical, rheological, and molecular characteristics

Keywords: Bitumen aging, Molecular dynamics simulation, Molecular composition optimization,

Abstract:

Molecular dynamics (MD) simulation of bitumen is an effective method for predicting its properties. However, achieving realistic molecular representations remains challenging, and aging can further alter both the molecular count and chemical structure of bitumen, complicating accurate modeling. This project introduces a systematic approach to estimate the molecular composition of bitumen and construct a more representative MD simulation. To this end, a suitable algorithm was first employed to determine the optimal types and quantities of molecules based on experimental data from Chromatographic Column Test (CCT) and Elemental Analyzer (EA) analyses. Then, different possible configurations were generated by varying the initial molecular arrangements for comparison. The results demonstrate that the proposed algorithm provides a more reliable and adaptive approach than conventional trial-and-error techniques, achieving closer agreement with experimental SARA fractions while maintaining correct elemental compositions obtained from EA. Variations in heteroatoms such as oxygen content significantly influenced molecular configurations and MD behavior, highlighting their importance in simulating both aged and unaged bitumen. Furthermore, the initial molecular arrangement affected system initialization, as unequal distances from the origin influenced simulation consistency. Ensemble-averaged RDF analysis showed shorter intermolecular distances in some scenarios, suggesting higher molecular agglomeration even when the material composition was the same. Moreover, MSD results revealed increased diffusion coefficients, indicating notable changes in the dynamic behavior of the same sample. Finally, incorporating quantum chemistry offers a more accurate framework for determining oxygen placement during oxidation, enhancing the molecular representation of aged bitumen.

Data-Driven Approaches for Traffic Safety Analysis: From Crash Severity Modeling to Real-Time Risk Estimation

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Doctorate Cycle: XXXVIII

Co-tutelle University: Université Gustave Eiffel

Supervisors: Massimo Losa, Thierry Serre

Doctorate Thesis: Advanced Traffic Analysis and Conflicts Control at Grade-Separated Intersections on Highway

Keywords: Traffic safety, Machine learning, Crash severity, Real-time risk estimation, SHapley Additive exPlanations, Extreme Value Theory, Last Time to Brake

Abstract:

This study focuses on developing data-driven approaches to analyze and predict road traffic risks through the integration of interpretable machine learning and statistical modeling. Using large-scale French crash and pre-crash trajectory datasets, the study investigates how environmental and vehicle-related factors jointly affect injury severity and near-crash probabilities. A hybrid framework combining Random Forest, SHapley Additive exPlanations (SHAP), and Partial Proportional Odds models identifies key determinants of crash severity, revealing that safety equipment, lighting conditions, and fixed obstacles are the most influential factors. Meanwhile, the surrogate safety indicator Last Time to Brake (LTTB) is embedded within an Extreme Value Theory (EVT) model to estimate real-time collision risk. Results show that LTTB outperforms the traditional Time to Collision (TTC) by effectively distinguishing near-crash conditions. Moreover, threshold analysis reveals that when LTTB falls below 0.7 seconds, the probability of a crash increases sharply, and collisions become almost unavoidable below 0.3 seconds, confirming the indicator's sensitivity to critical risk transitions. The integrated framework enhances both interpretability and predictive robustness. Future work will focus on incorporating these findings into ramp metering strategies to improve safety in highway merging areas. By coupling crash risk estimation with dynamic control, the framework aims to support real-time decision-making for traffic management systems and enhance highway safety under diverse traffic conditions.

Integrating hydrodynamic modelling and System Dynamics: A Framework for Assessing the Dynamic Resilience of Socio-Economic Systems to Flooding

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Doctorate Cycle: XXXVIII

Co-tutelle University: Florida International University

Supervisors: Fabio Castelli, Assefa Melesse

Doctorate Thesis: Development of an Urban Flood Resilience Model and Simulation of Future Scenarios for a Cultural City: The Case of Florence, Italy

Keywords: Resilience, System Dynamics Model, HEC-RAS, Coupling

Abstract:

This study applies System Dynamics (SD) modeling to investigate urban flood resilience. The model identifies key indicators organized across social, economic, environmental, organizational, and infrastructural dimensions. Causal loop diagrams explore the intricate cause-and-effect relationships between parameters, focusing on two primary feedback mechanisms. The first loop examines the negative relationship between flood damages and economic activity, where damages reduce economic output, thereby increasing community vulnerability. Conversely, the second loop investigates how direct flood impacts can enhance community awareness, compelling authorities to invest in resilience-enhancing infrastructure and thus lowering vulnerability. This dynamic framework is applied to the city of Florence, Italy. To provide a realistic hazard input, a 200-year return period flood was simulated using the U.S. Army Corps of Engineers' HEC-RAS hydrodynamic model. The resulting inundation depths were then integrated into the SD model. This coupled methodology enables a robust analysis of the dynamic response of socio-economic systems to flood-induced disruptions and their subsequent recovery processes. The framework is instrumental in quantifying short-term resilience capacities (economic, infrastructural, organizational, and social), offering a valuable tool for proactive urban planning and disaster management.

Integration of hydrothermal carbonisation, pyrolysis and chemical leaching for stabilised municipal sludge and aerobic granular sludge valorisation

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Doctorate Cycle: XXXVIII

Co-tutelle University: Université Grenoble Alpes (UGA)

Supervisors: Riccardo Gori, Andrea Maria Rizzo, Geert Haarlemmer, Hary Demey Cedeno

Doctorate Thesis: Recovery of carbon and critical raw materials from civil sludges through integrated thermochemical processes

Keywords: sewage sludge, aerobic granular sludge, hydrothermal carbonization, pyrolysis, chemical leaching, phosphorus, biocoal, recovery

Abstract:

The integration of chemical leaching, slow pyrolysis and hydrothermal carbonization (HTC) could provide a solution for the challenge of sewage sludge valorisation, thanks to the possibility of simultaneously recovering phosphorus and a carbon. In this context, the "fast" HTC of stabilised conventional activated sludge (CAS) was studied at different temperatures prior to hydrochar pyrolysis. HTC tests were performed by a 300 mL autoclave, at 210-270 °C and 0-60 min holding time. When both increased, the hydrochar yield decreased from 79.5% to 69.6%, without substantial effect of holding time. Sludge filterability resulted improved, except for the 210 °C at 0 min test. The trend of the pH with holding time and temperature, causing a different solubilization of some inorganics, including phosphorus, is useful to define the valorisation pathway of the HTC aqueous phase. A second activity consisted in the HTC (by autoclave) and pyrolysis (by thermogravimetric analyser) of aerobic granular sludge (AGS). 39%-55% and 47%-58% of AGS carbon was recovered in the pyrochar and in the hydrochar respectively. Batch methylene blue adsorption tests were conducted on the pyrochar and on the biocoal from pyrochar leaching, with the latter showing improved performances compared to the untreated pyrochar. The studies showed that (i) holding time can be reduced without affecting hydrochar and carbon yield, (ii) around 40-60% of AGS carbon can be recovered in the solid HTC or pyrolysis product and (iii) chemical leaching is beneficial on the adsorption behaviour of the AGS-pyrochar.

Physics-Informed Neural Networks for Turbulent Flow Simulation in Wind Engineering: A Case Study (high rise building)

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Doctorate Cycle: XXXIX

Co-tutelle University: Ruhr universität Bochum, (RUB)

Supervisors: Luca Facchini, Ruediger Hoeffer, Anina S. Glumac

Doctorate Thesis: Development of neural networks based on data for non-Gaussian autoregressive processes constrained by balance equations

Keywords: Navier-Stokes equations, Physic Informed Neural Networks, turbulent flow, Wind induced pressure.

Abstract:

Predicting wind flow over tall buildings has always been a critical and challenging issue in wind engineering. Until now, wind tunnel tests, computational fluid dynamic and machine learning techniques have been used to predict wind induced pressure distribution on the building's surface. However, experimental and numerical approaches are expensive and time consuming. On the other hand, machine learning techniques in this field usually suffer from a lack of data. To overcome these drawbacks, Physics-informed neural network (PINN) is implemented in the current study. PINN has attracted considerable attention for solving partial differential equations, especially the Navier-Stoke (NS) equation. However, most research has focused on solving the NS equation for laminar flow. The aim of this research is to present a strategy for simulating the flow field using physics-informed neural networks for turbulence flow. The loss function consists of supervised and unsupervised parts, which uses the validated data from the LES model and the residual of the governing equation, respectively. It should be noted that only data related to the boundaries and building surface was used. The results obtained show that this method can be effective in predicting wind flow around buildings. Consequently, PINN can be surrogate of CFD and wind tunnel test, which are expensive and time consuming.

Analytical Model and FE Model for FRCM-Retrofitted Masonry

HAMZA ABDULSALAM ALI TAHAT

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Doctorate Thesis: Structural consolidation interventions using innovative materials for the preservation of historical and monumental masonry buildings

Keywords: masonry strengthening, FRCM reinforcement, Interface bond–slip behavior, sawtooth model, FE simulations.

Abstract:

This presentation presents an analytical and numerical framework to describe the debonding behaviour of fibre-reinforced cementitious matrix (FRCM)-reinforced flat masonry elements under direct shear tests. A sawtooth shear stress–slip law, initially developed for SRG systems in the litrature, is calibrated for a PBO-FRCM system based on the experimental results adopted from the litrature. The recent experimental data on flat masonry pillars serves to validate the model by capturing essential interface behaviours, including residual strength and pseudo-linear hardening. Furthermore, a finite element (FE) model of the specimens has been developed to simulate the interface response, allowing for a comparison between numerical predictions and experimental results. The sawtooth law is implemented directly in commercial FE software without the need for custom coding. Results show good agreement among experimental observations, the sawtooth analytical model, and FE simulations, confirming the model's accuracy and applicability.

Quantitative assessment of seismic risk for built heritage structures

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Doctorate Thesis: Quantitative assessment of seismic risk for built heritage structures

Keywords: Seismic Vulnerability, Masonry Churches, Data Clustering, Abaqus Modelling, Sensitivity Analysis, Fragility Curves

Abstract:
This presentation presents the methodological workflow developed for the seismic vulnerability assessment of historical masonry churches. The research begins with the analysis and classification of damage and typological post-earthquake survey data from the Observed Damage Database (Da.D.O.), which can lead to the identification of representative church archetypes through statistical clustering. Three main clusters were identified. The chosen archetype is then simulated in Abaqus software, from which automated scripts provide construction of geometry, material definitions using the Concrete Damaged Plasticity (CDP) model, boundary conditions, and ground motion records. Static and modal analysis are performed initially for model validation, followed by dynamic nonlinear time-history analysis to determine the behaviour of the structure under seismic loading. Sensitivity analyses are conducted using Latin Hypercube Sampling (LHS) to explore the influence of material and geometric uncertainties on the dynamic response parameters. The resulting dataset provides the foundation for the preliminary derivation of analytical fragility curves for the representative archetype. These findings represent a key step toward portfolio-scale vulnerability and risk assessment of cultural heritage assets.

Clean Bitumen and Sustainable Pavements

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Doctorate Thesis: Clean Bitumen and Sustainable Pavements

Keywords: Emissions, clean bitumen, pavements

Abstract:

Emissions from bitumen and pavements contribute to a range of public health, environmental, ecological, and climate concerns. Preliminary studies indicate that specific modifiers in bitumen can effectively suppress bitumen fume emissions. Notably, different modifiers exhibit considerable specificity and selectivity.

GRAVEL AND SAND PROCESSES ON DYNAMIC COBBLE BERM REVETMENTS: SCALED LABORATORY EXPERIMENTS

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Doctorate Thesis: Gravel Structures for Coastal Protection: Physical Processes of Sand and Gravel interaction

Keywords: Coastal Protection, Dynamic Revetments, Gravel Structures, Sediment Processes, Sand and Gravel

Abstract:

Dynamic cobble berm revetments are structures that mimic natural composite beaches by placing a large volume of cobbles in the backshore of a sandy beach. Artificial gravel beaches built on sandy beaches have also been used and proved to play a significant role in protecting coastal areas from storm sea states The adaptability of these structures to increasing water level and energetic wave conditions shows efficiency on coastal protection and has raised new questions on design and construction strategies, as these structures are often considered a "nature-based" or soft-engineering solution preferred to commonly used hard structures. Only few studies have been carried out so far, to determine design parameters for these gravel structures, including the use of laboratory experiments for empirical equations of run up, and morphodynamics prediction of gravel beaches, often neglecting their dynamic interaction with sand. A 1:6 scaled laboratory experiment was constructed and expanded to explore the sand and gravel interactions processes and impact on the behavior of the structure within accretive and erosive conditions. Preliminary results show an increase of run-up elevation in similar wave conditions after every accretive condition, associated with the loss of infiltration within the revetment. Additionally, loss of volume and offshore movement of the gravel on the face of the structure above the sand accretive line that created a slip surface where gravel travelled downward resulting in a continuous loss of volume.

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Doctorate Thesis: Methods of evaluation to support the planning of Nature-Based Solutions for sustainable water management

Keywords: Nature-Based Solutions (NBS),Sustainable Water Management,Planning Support,Urban water systems,Ecosystem services

Abstract:

As cities grow and climate change occurs, water management in modern cities is becoming increasingly difficult due to aging and deteriorating infrastructure. Grey infrastructure systems, such as wastewater treatment plants and surface water drainage, often do not work well enough to cope with problems such as flooding, heavy rain, and increasingly problematic water quality. Nature-based solutions (NBS) are another way to deal with these problems. The proposal makes natural processes and ecosystems more resilient to these stresses and also has beneficial effects such as better air quality, better urban aesthetics, and the protection of biodiversity. In NBS techniques, green structures, permeable surfaces, and wetlands at the city level can be beneficial for the environment and are long-term ways to manage urban water. Legal support for these schemes, active and effective public participation and supportive frameworks are essential for the successful planning and implementation of NBS. Research has shown that implementing green and blue infrastructure in urban development strategies is effective in improving the resilience and sustainability of cities, as well as sustainability in the water management sector. Furthermore, integrating NBS with conventional systems to create hybrid "grey-green" infrastructures is essential to renovate old urban systems to withstand the impacts of climate change. For this purpose, the effectiveness of NBS is assessed using qualitative and quantitative criteria that encompass ecological, social, and economic dimensions. Comprehensive assessment frameworks, such as biodiversity enhancement, equitable access for all, and community participation, should be used to ensure that NBS projects are viable in the long term. The research illustrates the importance of adaptive management, participatory evaluation, and

integrated methodologies in the creation of sustainable and resilient urban water systems via the use of nature-based solutions (NBS).

Innovative management tools to increase the resilience of public buildings against natural risks

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Doctorate Thesis: Innovative management tools to increase the resilience of public buildings against natural risks

Keywords: Climate change, Climate adaptation, Vulnerability assessment, Optimization, Public buildings

Abstract:

The increasing frequency and magnitude of extreme climate events, combined with the outdated construction techniques in the built environment, highlights the urgent need for innovative tools to support adaptation and risk management strategies. To address this challenge, a methodological framework that integrates the Climate Vulnerability Assessment (CVA), in accordance with the latest EU guidance on adapting buildings to climate change, with multi-objective optimization models has been developed. Through this integration, the framework provides a powerful decision-support tool for enhancing the resilience of public buildings. The proposed approach is aligned with the European BUILDCHAIN project, whose objectives include improving the management of large building stocks and their climate resilience. For this reason, a vulnerability index that can be used to support decision-making in adaptation planning is derived by evaluating building exposure, sensitivity, and adaptive capacity to extreme events such as heat waves and heavy precipitation. To complement the assessment, an optimization process based on the Invasive Weed Optimization (IWO) algorithm is implemented, aiming to minimize total vulnerability and adaptation costs under a defined budget constraint. To demonstrate the applicability and scalability of the model, a set of school buildings located in the city center of Florence was selected as a case study and, preliminary results confirm the framework's potential. Looking ahead, future work will focus on extending the methodology toward a comprehensive risk assessment and on integrating agent-based models to support autonomous and adaptive decision-making.

3D documentation and indices for simplified seismic vulnerability estimation of Parish Churches in Lunigiana

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Doctorate Thesis: INNOVATIVE METHODS FOR THE DOCUMENTATION AND PRESERVATION OF THE PARISH CHURCHES OF LUNIGIANA

Keywords: Parish Churches, Vulnerability indices, SLAM technology

Abstract:

Knowledge of the state of conservation, supported by metric and thematic documentation, is fundamental for the protection of historic buildings. This study aims to optimize the analysis procedures to evaluate the seismic vulnerability of parishes. The approach adopted is multidisciplinary, multiscale, and multisensor, and is based on the integration of geomatics and structural expertise to construct a rapid and low-cost workflow to support vulnerability analyses. Two evaluation methods are applied: - Analysis of collapse mechanisms, according to a qualitative approach (LV1 level); - Calculation of numerical indices (γ_1, γ_2, γ_3) derived from geometric building parameters. Both evaluation methods depend on the quality and availability of historical, geometric, and structural documentation. The documentation takes on a central role not only in the preliminary analysis phase, but also in the critical verification of the results obtained through the indices. In this context, the new rapid and low-cost survey device based on SLAM technology is tested, which proves effective in the analysis of a large sample of buildings and useful for both calculating indices and identifying structural irregularities. The use of SLAM-based devices allows you to obtain more objective, detailed, and replicable evaluations, strengthening the reliability of analyses conducted with simplified methods. On the other hand, some limits are related to the 3D model resolution, which is related to the chance to interpret small details relevant for structural studies. The study confirms the importance of digitization, of the systematization of data into structured databases for an effective and preventive management of the architectural heritage.

Climate resilient structures: proposal for a climate change-based assessment of structural reliability

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Doctorate Thesis: Climate resilient structures: proposal for a climate change-based assessment of structural reliability

Keywords: Climate Change, Climatic Actions, Resistance, Reliability, Change Factors

Abstract:

Climate change poses a serious threat to the built environment. Expected exacerbated climatic actions and reduction in structural resistance, due to the acceleration in material degradation processes, may contribute to a reduction in structural performances. In this context, it is necessary to assess climate change impacts on reliability and durability of structures, currently designed under stationary climate conditions. In accordance with the semi-probabilistic limit state approach, statistically representative values of the parameters governing the design should be reassessed. The aim is to meet the safety concept expressed in EN 1990, stating that during the design life of the construction the probability that action effects do not exceed the structural resistance, is below a reference value, usually associated with a target reliability index. The main goal is the development of a general methodology for assessing structural reliability over time, combining probabilistic models for actions with those for resistance, duly implementing the hypothesis of non-stationary climate conditions. In this framework, the factors of change method is adopted to describe the evolution of statistics of climatic variables. In parallel, time-dependent models are investigated to represent the degradation of different building materials, allowing a consistent combination of both effects in the overall reliability assessment. In this sense, this method will provide a first answer to the need of developing guidelines to mitigate the effects of climate change on structures. The main perspective is to contribute to the development of a population of resilient buildings, in accordance with the objectives of the latest European policies.

Response of free alternate bars to unsteady flow

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Doctorate Thesis: Modeling sediment transport and large-scale bedform dynamics in rivers

Keywords: Alternate bars, Sediment, Rivers, Unsteady flow

Abstract:
Rivers naturally experience highly variable flows due to seasonal changes and flood events, yet the response of alternate bars to such unsteady conditions is still not well understood. Existing analytical solutions often focus on single-flow events and may not capture the cumulative effects of repeated flow variations. This study combines laboratory experiments with analytical modeling to investigate bar evolution under sequences of triangular hydrographs with periods ranging from 20 to 120 minutes. Experiments were conducted in a 15.6 m long and 0.45 m wide flume, where high-resolution bed topography was measured during the falling limb of each hydrograph. Key bar properties such as height, wavelength, and migration velocity, were evaluated over multiple flow cycles to assess long-term behaviour and the conditions under which a recurring morphodynamic equilibrium is reached. The analytical model for weakly nonlinear and weakly unsteady flow was evaluated against experimental observations to test its predictive capability over successive hydrographs.

An integrated modelling approach using Big data for urban and social dynamics

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Doctorate Thesis: A new integrated transport/territory planning process to make conurbations sustainable by achieving carbon neutrality, zero pollution and environmental resilience

Keywords: transport modelling, agent based model, integrated approach, big data, urban policies, travel choices, social and urban dimensions

Abstract:

An integrated approach between urban, social and transport dimensions is essential to create increasingly realistic models that enable the simulation of populations and their travel choices. The main objective is to move beyond traditional models that consider mobility demand as a static variable, and to obtain agent-based models that can be adapted to the chosen study reality. The lack of large-scale national surveys has therefore made it necessary to develop an alternative approach to reconstruct the inputs required by agent-based models, but above all to model different mobility choices in novel and innovative ways. The methodology developed involves the use of various types of big data to recreate the behaviours and chains of activities of network users in a profound and realistic way. The data used consists mainly of big data such as mobile phone cell data and Floating Car data, and discrete data such as population and activity census data. The populations thus created reflect the mobility choices of the entire population studied and for entire days of simulations, not just representative of peak hours. The agent-based models obtained make it possible to simulate the real effects of the introduction of urban policies across the entire Metropolitan Area of Florence, even simulating the reasons behind modal choices conditioned by the social characteristics of the population and the urban forms in which it moves. Institutions therefore have a valuable tool for the introduction, implementation and realisation of increasingly targeted and effective policies for each urban and social reality.

Exposure and vulnerability to heatwaves and air pollution: assessments in urban environments

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Doctorate Thesis: Exposure and vulnerability to heatwaves and air pollution: assessments in urban environments

Keywords: Risk assessment, air pollution, urban heat, modelling, mitigation

Abstract:

The impacts of heat stress and air pollution are both related to severe health risks for citizens. Complexity and heterogeneity of urban systems can lead to some residents being more exposed than others, possibly exacerbating social inequalities. Whilst the impacts of heath stress and air pollution on population health are known, their relationship with socioeconomic vulnerability has been less investigated. In this work, an integrated risk assessment framework for a mid-size city (Prato, Italy) was developed by combining information on concurrent hazards (summer heat stress and winter air pollution), socioeconomic vulnerabilities indices (Income deciles and Deprivation Index), and demographic exposure (elderly population fraction). Multiple data sources were merged through a novel approach incorporating observed measurements of air temperature and air pollution (PM10 and PM2.5 concentrations) at fine time and spatial resolution through a dense IoT sensor network. Although the IoT sensor network covered many areas of the city, some zones still remained without observations. This part of the presentation focuses on modelling air temperature during an exceptionally warm summer day in the city of Prato integrating the IoT measurements with three distinctive remote sensing predictors: Land Surface Temperature (LST), Sky View Factor (SVF) and Vegetation Fraction Cover (VFC). Finally, effective mitigation strategies should be implemented to tackle urban heat. This part of the presentation focuses on assessing the potential cooling of irrigating urban parks as mitigation strategy against urban heat at city scale through ENVI-Met software.

Dynamics of Rocking Bodies

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Doctorate Thesis: Mechanical interpretative schemes of the dynamic behavior of masonry structural elements subject to seismic actions

Keywords: rocking, block, aspect ratio, overturning, impact, coefficient of restitution, zero strength configurations

Abstract:

Understanding the rocking motion phenomenon is crucial to describing the dynamic response of masonry elements and assessing their actual vulnerability to seismic events. Although the first pioneering studies regarding rigid body rocking date back to the late 19th century, this topic still presents some points to be clarified. The analytical basis was laid by Housner (1963), who proposed a simple but effective model for slender blocks subjected to various types of dynamic loads; later works demonstrate, using experimental results, that energy loss is overestimated by the analytical model and that the impact event needs to be studied in a deeper way. The nonlinear equations of motion for non-slender blocks have been later studied numerically but, due to the chaotic features of the motion, this topic is far from being fully understood. During the first year of the PhD the study addressed some of the contributions considered most representative available in the recent literature. An important point that clearly emerged from the survey of the literature is that even small differences in the initial conditions may easily lead to very large differences in the rigid block motion, hence greatly complicating the analytical analysis. By a critical re-examination of the limit condition for the stability of the rocking body (i.e., the overturning condition, also called "zero strength configuration") we also showed that a wider admissible domain can be found for the initial conditions, which shape depends on the block size, slenderness and loss of kinematic energy during impact.

A new efficient and accurate isogeometric analysis approach to the simulation of shape-changing artery stents—towards patient-tailored 4D printed stents

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Doctorate Thesis: A new efficient and accurate isogeometric analysis approach to the simulation of shape-changing artery stents—towards patient-tailored 4D printed stents

Keywords: Thermo-viscoelasticity, Shape-memory polymer, Generalized Maxwell model, Isogeometric analysis, Geometrically exact beams

Abstract:

We present a thermo-mechanical formulation for geometrically exact beams and beam systems made of shape memory polymers (SMPs). The model combines transient heat transfer with beam kinematics to reproduce temperature-driven shape programming and recovery. Constitutive behavior is described with a viscoelastic Generalized Maxwell model together with the Time–Temperature Superposition Principle (TTSP), which accounts for the evolution of relaxation properties with temperature. This rheological law is applied directly to one-dimensional stress and strain measures, yielding a primal formulation that does not require additional internal variables compared to elastic beams. The equations are solved using isogeometric collocation, discretizing the strong form directly. This approach preserves exact geometry, achieves high-order accuracy, and avoids element-wise integration. The model can handle arbitrarily curved and complex geometries, with time integration performed using the trapezoidal rule. Numerical examples demonstrate that the proposed formulation can accurately and efficiently capture shape morphing in SMP beams. As a first step toward potential applications, we also fabricated patient-specific vessel geometries and stent-like structures. The combination of simulation results and prototype fabrication demonstrates the potential of this approach and opens the path toward adaptive structures, smart materials, and patient-specific biomedical devices such as cardiovascular stents.

From BIM to DT. Data integration in life cycle information management of existing assets

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Doctorate Thesis: From BIM to DT. Data integration in life cycle information management of existing assets

Keywords: BIM, IoT, Linked Data, FM

Abstract:

The operational phase of real estate assets accounts for about 80% of total life-cycle costs. Space management and monitoring of building systems are crucial to ensure user well-being. The AECO industry is shifting towards data-driven processes, with BIM serving as a dynamic repository for comprehensive data integration. This study, part of the BIM2DT project at the University of Florence, aims to develop a data processing framework to implement Digital Twins of existing buildings by integrating BIM platforms with IoT technologies. The aim is to support decision-making in operations and maintenance by combining static and dynamic data. Following a thorough literature review and collaboration with the University's Building Area, a BIM Guide based on best practices was developed, and a mapping between university asset databases and BIM objects is ongoing. Two IoT integration workflows are explored: (a) LoRaWAN sensors linked to the Niagara Framework to enhance Building Management System interoperability, and (b) LoRaWAN sensors connected via Node-RED, InfluxDB, and Grafana for flexible data capture and visualization. Crucially, an interoperable semantic layer has been created connecting heterogeneous static and dynamic data sources, structured using Linked Data technologies and ontologies including BOT, BOP, and SS/SOSA. This layer ensures semantic interoperability and enables complex queries. The research contributes to dynamic Digital Twin development that enhances facility management, optimizes energy efficiency, and promotes sustainability across the University's estate, aligned with national digital transformation goals.

Performance Evaluation of CMEMS Hindcast Data through Comparison with Wave Buoy for a site in the Mediterranean Sea

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Doctorate Thesis: Influence of Climate change on Ocean Wave Characteristics

Keywords: Significant wave height, Peak period, Hindcast, Wave buoy, Extreme waves

Abstract:

Wave parameters play an essential role in the design of offshore structures, the study of coastal dynamics, and the evaluation of climate change impacts. A variety of numerical wave hindcast datasets are available to provide such information; however, their site-specific reliability must be verified using in situ buoy observations. This study assesses the performance of the Copernicus Marine Environment Monitoring Service (CMEMS) reanalysis dataset by comparing it with measurements from a wave buoy deployed off the coast of Crotone in the Mediterranean Sea over the period 2010–2013. The analysis focuses on significant wave height (Hm0), spectral peak period (Tp), and mean wave direction (Dirm), employing statistical indicators such as Root Mean Square Error (RMSE), Pearson's correlation coefficient (R), Scatter Index (SI), and Bias to evaluate CMEMS accuracy. Results show a clear correlation for Hm0, with noticeable deviations observed for waves exceeding 4 m. The RMSE increases with higher Hm0, indicating reduced agreement under extreme conditions. Generally, CMEMS slightly underestimates Hm0, as reflected by a bias of –4.4%. In contrast, Tp demonstrates only moderate correlation, with greater uncertainty observed for longer wave periods of more than 10 sec, suggesting reduced reliability in extreme event conditions. Furthermore, the extreme wave analysis based on the Peak Over Threshold (POT) method reveals that the CMEMS dataset exhibits increasing underestimation with higher return periods. Overall, the findings emphasize the importance of site-specific calibration of numerical hindcast data to improve the accuracy of climatological wave time series and enhance extreme event assessment.

Definition of informed Digital Twins to optimise the maintenance and renovation of the public buildings

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Doctorate Thesis: Definition of informed Digital Twins to optimise the maintenance and renovation of the public buildings

Keywords: Bayesian learning, Cultural heritage buildings, Finite element models, Operational modal analysis

Abstract:

The preservation of Cultural Heritage structures requires non-invasive strategies to assess their structural condition and support long-term conservation. Among these, Bayesian inference represents a powerful tool for evaluating model reliability and assessing their resilience. However, its implementation typically requires a large number of model evaluations to construct the posterior distribution. To address this computational demand, the finite element (FE) model is often replaced by a surrogate model that allows for fast evaluations. The drawback is that surrogate models may not only introduce inaccuracies but also behave as black boxes, limiting physical interpretability. In this work, a simplified physics-based FE model is proposed, achieving a balance between accuracy and low computational cost. The methodology is applied to a sixteenth century heritage building in Granada (Spain) as part of the European BUILDCHAIN project, combining ambient vibration data with a reduced FE model. The analysis highlights the model's sensitivity to specific features, guiding a refined geometry selection process. This informed simplification enhances the model's sensitivity to key parameters and supports a more efficient and meaningful calibration process. Overall, the proposed framework lays the foundation for a Digital Twin by combining experimental data, physics-based modelling and probabilistic inference. It provides a scalable, generalisable tool for assessing the structural health of heritage assets.

Development of Innovative Tools for Real Estate Asset Management to achieve a smarter and resilient built environment

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Doctorate Thesis: Development of Innovative Tools for Real Estate Asset Management to achieve a smarter and resilient built environment

Keywords: Digital Building Logbook (DBL), Building Asset Management, Seismic Risk Assessment, Petri Nets, Maintenance Modelling

Abstract:

This research aims to develop innovative digital tools, specifically Digital Building Logbooks (DBLs), to optimize real estate asset management. It defines a holistic approach to building asset management, encompassing both long-term planning and the operational dimension, from extraordinary to ordinary maintenance. Aligned with EU strategies, the research addresses sustainability, resilience to natural hazards, and the preservation of building heritage. In collaboration with the Horizon Europe BUILDCHAIN project, it contributes to the development of DBLs through a framework that integrates seismic assessment, maintenance modelling, and economic analysis to support informed decision-making in building management. In this perspective, Petri Net modelling is introduced as a powerful tool to represent buildings as systems of systems and to simulate maintenance processes, supporting predictive management strategies. The proposed framework will be tested on real case studies involving school buildings in Florence (Pilot 4 of BUILDCHAIN). The ongoing research aims to strengthen the role of Digital Building Logbooks as data-driven tools for sustainable, safe, and resilient building asset management, in line with European goals for digitalization and sustainability.

Experimental and Analytical Evaluation of Crest Modifications and Roughness Effects on Wave Overtopping

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Doctorate Thesis: Experimental and Analytical Evaluation of Crest Modifications and Roughness Effects on Wave Overtopping

Keywords: Wave overtopping, Crest modification, Overtopping reduction, Roughness effects

Abstract:

This research examines experimental and analytical methods for the prediction and reduction of wave overtopping on coastal defense structures, with a particular focus on modified coastal structure geometries. Four configurations were systematically tested under identical hydraulic conditions during the experimental phase: a plain vertical seawall, a sloping armoured (composite) seawall, a Stilling Wave Basin (SWB) crest modification, and SWB layouts equipped with parapet walls. The results showed that the combined application of armoured slopes, SWBs, and parapets is capable of eliminating overflow in several tested conditions, resulting in overtopping reductions of up to 90%. These findings offer valuable insights for the development of coastal protection systems in urban areas where it is not feasible to raise the crest elevation. The analytical component of the study was dedicated to the evaluation of the predictive accuracy of empirical formulas that are frequently employed to calculate the mean overtopping discharge. It specifically examined the roughness factor and its relationship to slope and permeability. Four formulations, including a revised model developed for 1:2 composite slopes in this study, EurOtop (2018), Eldrup et al. (2022), and van Gent et al. (2022), were assessed against both CLASH reference datasets and newly acquired laboratory data. The comparison underlined the necessity of considering structural permeability in overtopping prediction and the constraints of slope-dependent corrections when applied to semi-permeable geometries. In general, the results enhance the development of overtopping assessment methods and direct the development of resilient coastal structures by providing experimentally validated performance insights.

Prediction of Mechanical Properties of Masonry Walls by means of Visual Inspection

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Doctorate Thesis: Prediction of Mechanical Properties of Masonry Walls by means of Visual Inspection

Keywords: Structural Assessment, Masonry, Composites, Homogenization, Neural Network, CNN, Finite Element Method, Programming

Abstract:

This research develops an integrated methodology to estimate masonry mechanical parameters directly from the exterior leaves (textures) of existing structures, enabling realistic finite-element analyses and safety assessments of historical masonry buildings. Masonry is treated as a heterogeneous composite whose meso-scale arrangement governs the global response. The approach couples AI-based segmentation (ANN/CNN) to identify phases and quantify their geometric and statistical traits with strong homogenization and stiffness optimization via static condensation to obtain equivalent properties (E, G, fm, tau0, fv0). This overcomes limitations of Reuss–Voigt–Hill and purely energetic schemes, which may yield inconsistent or non-physical estimates. A MATLAB-based FEM tool has been implemented to analyse both heterogeneous and homogenized panels, showing perfectly matching displacement, strain, and stress fields with commercial solvers. Within the same environment, a static-condensation procedure delivers the derivation of equivalent elastic parameters, forming the core of the proposed homogenization framework. The framework also enables exploration of plastic behavior via appropriate stiffness-reduction strategies, extending applicability to non-linear response assessment. The current phase focuses on consolidating the strong-homogenization pipeline and refining CNN segmentation for automatic dataset generation. Future work includes extension to frame-level analysis, experimental calibration of phase properties, and a targeted resolution of the Poisson's-ratio issue in masonry homogenization. The expected outcome is a fast, reliable, and physically sound workflow for mechanical characterization from visual data, bridging laboratory observations and everyday engineering practice.

Definition of informed Digital Twins to optimise the maintenance and renovation of the public buildings

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Doctorate Thesis: Definition of informed Digital Twins to optimise the maintenance and renovation of the public buildings

Keywords: Bayesian learning, Cultural heritage buildings, Finite element models, Operational modal analysis

Abstract:

The preservation of Cultural Heritage structures requires non-invasive strategies to assess their structural condition and support long-term conservation. Among these, Bayesian inference represents a powerful tool for evaluating model reliability based on updated information about the structural behaviour of the building.. However, its implementation typically requires a large number of model evaluations to obtain the posterior information of the uncertain model parameters. To address this computational demand, the finite element (FE) model is often replaced by a surrogate model that allows for fast evaluations. The drawback is that surrogate models may not only introduce inaccuracies but also behave as black boxes, limiting physical interpretability. In this work, a simplified physics-based FE model is proposed, achieving a balance between accuracy and low computational cost. The methodology is applied to a sixteenth century heritage building in Granada (Spain) as part of the European BUILDCHAIN project, combining ambient vibration data with a reduced FE model. The analysis highlights the model's sensitivity to specific features, guiding a refined geometry selection process. This informed simplification enhances the model's sensitivity to key parameters and supports a more efficient and meaningful calibration process. Overall, the proposed framework lays the foundation for a Digital Twin by combining experimental data, physics-based modelling and probabilistic inference. It provides a scalable, generalisable tool for assessing the structural health of heritage assets.

Machine Learning Framework Enhances Short-term Flood Forecasting

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Doctorate Thesis: AI-Enhanced Flood Forecasting and Ecosystem-Based Flood Risk Assessment Toward More Resilient Territorial Systems

Keywords: Flood, forecasting, early warning system, Large Sample Hydrology, AI, Machine Learning

Abstract:

Reliable river flow forecasting is an essential component of flood risk management and early warning systems. It allows for a better emergency response coordination and it's critical for protecting infrastructures, communities and ecosystems from extreme hydrological events. Process-based hydrological models and purely data-driven methods are often underperforming during extreme events, struggling to forecast peak flows. To overcome this limitation, this study introduces a hybrid forecasting framework that couples Extreme Gradient Boosting (XGBoost) and Random Forest (RF). The approach is implemented in 857 catchments of the LamaH-CE dataset, using rainfall and discharge observations at 6-hour resolution. Results demonstrate consistently high skills, with 71% of catchments achieving a Kling-Gupta Efficiency (KGE) greater than 0.90. Peak detection reached 87%, and false-alarm rate is 13%. Compared to the European Flood Awareness System (EFAS), the framework achieves lower peak magnitude errors, fewer false alarms, and improved streamflow and peak flow forecasting accuracy. The proposed framework is computationally lightweight, scalable, and easily transferable across watersheds. Training takes only seconds on standard CPUs. The findings of this work highlight the potential of integrating hydrological understanding with efficient machine learning to improve accuracy and reliability operational flood forecasting, and outline future directions for hybrid hydrological-machine learning models development.

A Data-Driven Metamodeling Approach to Seismic Basin Response Analysis

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Doctorate Thesis: Integrating Numerical Modeling and Machine Learning-Based Metamodeling Algorithms for the Quantitative Estimation of Representation of Seismic Effects in Basins

Keywords: Aggravation Factors, Basin Effects, Machine Learning, Numerical Modeling, OpenSees, Seismic Site Response Analysis, SHAP Analysis

Abstract:

The seismic response of basins is challenging to predict due to the complex interaction of geometric, geotechnical, and seismic factors. This study focuses on the Parametric Study of Two-Dimensional Aggravation Factors in Basins from Numerical Site Response Analysis, which develops a framework for the quantitative prediction of two-dimensional (2D) aggravation factors (AGFs)—defined as the ratio of 2D to one-dimensional (1D) spectral pseudo-acceleration. Using an extensive series of numerical simulations conducted through OpenSees and Python-based automation, the research systematically explores a wide range of basin configurations and seismic inputs. The resulting dataset enables a statistical investigation of the relationships between AGFs and dimensionless parameters, providing a basis for simplified yet quantitative inclusion of basin effects in seismic design codes. Building upon this foundation, subsequent studies aim to develop and compare machine learning metamodels to efficiently approximate AGFs from numerical simulations, thereby reducing computational demands while preserving accuracy. Further work focuses on the interpretability of these metamodels through SHapley Additive exPlanations (SHAP) analysis, providing insights into the relative importance and interactions of geometric, geotechnical, and seismic features. Collectively, these studies contribute to advancing predictive, interpretable, and computationally efficient methods for the estimation and practical implementation of basin effects in seismic design engineering.