



DEPARTMENT OF MECHANICAL ENGINEERING

Master Thesis Topics 2026

55 open topics across the group's four research programmes. Each entry gives the contact address and, where the supervisor wrote one, a short description of the project.

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| 01 | Structural Integrity under Extreme Loads
Prof. Andrea Manes - 13 topics |
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| 02 | Digital Twins for Health & Usage Monitoring and SHM
Prof. Claudio Sbarufatti - 20 topics |
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| 03 | AI Applications for Structural Integrity & PHM
Prof. Francesco Cadini - 11 topics |
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| 04 | Metamaterials & Energy Absorption
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Source: SIGMA Lab thesis presentations, May 2026, updated in September 2026.
Applications and general enquiries: marco.giglio@polimi.it

01

Structural Integrity under Extreme Loads

Programme head: Prof. Andrea Manes | 13 topics

Machine learning for ballistic-limit prediction in multilayer protections

The design of ballistic protection systems for ground vehicles requires fast and reliable tools to assess the ability of multilayer configurations to stop high-velocity projectiles. Experimental campaigns and high-fidelity simulations are accurate but expensive and time-consuming, while the design space is extremely large. Machine learning models trained on numerical simulation databases can provide rapid predictions of ballistic performance and support early-stage design decisions.

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High-fidelity simulation of pristine and damaged ceramic/composite armor under ballistic impact

Modern body armor combines low weight with high stopping power thanks to ceramic and composite plates. Yet micro-cracks from everyday bumps or aging can weaken a panel before the next high-velocity hit. Virtual testing that predicts this residual strength is key to life-cycle optimization and safe re-use.

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Development and Validation of Advanced Joining Techniques for Titanium-Steel Hybrid Structures in High-Performance Mechanical Applications

Development of an innovative product featuring a titanium frame, with a weld joint between the titanium frame and specific steel components. This requirement introduces considerable complexity, as titanium and steel are dissimilar materials with significantly different physical, chemical, and metallurgical properties.

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Development and Validation of methods to increase survivability of gas turbine engine

Gas turbines are foundational to energy systems and transport capabilities, integrating high-power density with design flexibility. Gas Turbine are also widespread in highly demanding operational domain.

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Predictive Numerical Modelling of Underwater Explosions (UNDEX) on Structures

Many studies have been performed for air-blast scenarios, while readily available numerical frameworks for underwater explosions (UNDEX) are still limited due to the increased complexity associated with shockwave propagation, gas bubble dynamics and fluid-structure interaction phenomena. The development of reliable predictive tools is therefore crucial for the assessment and design of resilient naval platforms and onboard systems.

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Numerical approaches for modelling the ballistic impact onto metallic and ceramic protections

Evolving threat capabilities require an update of protective structures. Ballistic grade steels and ceramic armours have been developed in the last decades to increase the safety level of the platforms they are installed on. This thesis aims to build high-fidelity models of such protections under dynamical loading at high strain rates

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Prediction of structural response under confined explosions in composite panels

Accurate modelling of confined explosions is essential to predict the response of structures under internal blast loading.

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Predictive modelling of buried charge effects

Many studies have addressed air-blast and underwater explosions, but buried charges represent an intermediate and less explored configuration, where soil confinement strongly affects the pressure transmission and impulse duration. Accurate prediction tools are essential for assessing the response of structures and protective systems under these loading conditions.

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Development of numerical models to capture the failure modes of blast-loaded metallic plates

Blast loading is a critical extreme condition that can trigger complex failure modes in structural plates. Due to the difficulty of capturing detailed experimental data during such events, numerical modelling plays a key role in understanding and predicting structural response. This thesis will focus on developing advanced numerical tools to simulate failure mechanisms using experimental data for calibration/validation.

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Rapid prediction of fluid-structure interaction in blast-loaded plates

Accurate estimation of fluid-structure interaction (FSI) effects is crucial for predicting the response of lightweight metallic plates subjected to air blasts. Despite numerous studies, understanding and predicting these coupling phenomena remains a challenge. Developing simplified yet reliable predictive tools enables both efficient high-fidelity simulations and the design of blast-mitigation solutions.

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Experimental characterization and multiscale modelling on composite materials under impact loading

Composite materials are believed to have outstanding mechanical properties, especially for impact resistance. However, as development of composites, different technologies have been applied for advanced composites, leading to some critical challenges:

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Mechanical and thermal characterization of polymer materials

Polymer materials, such as polycarbonate, are widely applied. During deformation, their mechanical behaviours are always coupled with heating to release extra work, especially with high-speed loading. So, understanding the phenomenon is of great importance for modelling.

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Modelling of curved composite structures and optimization for impact resistance

As the composites developed, they have been widely applied into structures considering their mechanical properties, such as composite pressure vessels, which are always facing the impact loading. The critical mechanism of curved structure is the elastic deformation from structural level, while the damage introduced by impact may cause a nonlinear recover after impact, influencing the overall performance.

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02

Digital Twins for Health & Usage Monitoring and SHM

Programme head: Prof. Claudio Sbarufatti | 20 topics

Population-Based SHM for Fatigue Damage Identification

This thesis focuses on the experimental validation of Population-Based Structural Health Monitoring (PBSHM) through fatigue crack propagation tests on a fleet of instrumented aluminum plates. The activity is designed from a fleet perspective, where multiple nominally identical specimens are tested under controlled conditions, with thickness as the only varying parameter to induce a structured domain shift. Each plate is equipped with a distributed network of strain sensors to monitor crack growth under cyclic loading. The objective is to develop and validate data-driven models capable of detecting damage, estimating structural health, and transferring knowledge across structurally related domains. Particular emphasis is placed on uncertainty quantification and cross-domain generalization. The work provides a controlled benchmark for assessing PBSHM capabilities before extending the methodology to more complex and realistic systems.

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Vibration-Based Fleet Monitoring under Structural and Environmental Variability

This thesis investigates vibration-based Population-Based Structural Health Monitoring (PBSHM) on a fleet of simplified aircraft-like structures. The systems share a common layout but differ in material, scale, or topology, introducing controlled heterogeneity. Each structure is instrumented with a limited number of accelerometers to reflect realistic sensing constraints. The experimental campaign includes dynamic testing, progressive damage introduction (mass addition, joint loosening), and systematic environmental variability (temperature and wind). The objective is to develop methods capable of distinguishing damage from operational and environmental effects, while enabling knowledge transfer across heterogeneous structures. The work provides a realistic intermediate validation step toward full-scale UAV applications.

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Telemetry-Enhanced Fleet Monitoring for UAV Structural Health

This thesis investigates Population-Based Structural Health Monitoring (PBSHM) on a fleet of real quadrotor UAVs by combining onboard telemetry with additional sensors (e.g. accelerometers) integrated within payload constraints. The monitoring strategy leverages flight data together with selectively deployed sensing to enhance sensitivity to structural changes.

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Population-Based Monitoring for Wind Turbine Structural Health

This thesis investigates Population-Based Structural Health Monitoring (PBSHM) applied to wind turbines using publicly available datasets from the literature. The activity focuses on fleets of turbines operating under varying environmental and operational conditions, exploiting signals such as vibration, SCADA, or load measurements.

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Population-Based SHM for Engine Fleet applications

Based on industrial data provided by the company on engine states and operations, the project aims to develop a Population-Based Structural Health Monitoring (PBSHM) system that leverages data from multiple similar engines to enhance monitoring, diagnostics, and maintenance efficiency. By sharing information across the engine population, the system will overcome data scarcity-enabling early fault detection even for engines with limited or no labeled data. In fact, some units provide rich datasets while others do not, yet all require consistent, reliable monitoring

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Domain Adaptation for transferring knowledge between Battery fleets

In a fleet of batteries, instead of treating each battery in isolation, PB-SHM exploits the shared behavior across a population of cells or modules. This enables learning from similarities and differences between batteries to improve diagnostic accuracy; by this way, PB-SHM allows knowledge gained from well-characterized batteries to be transferred to new or partially monitored batteries, using Domain Adaptation (DA) techniques like Transfer Component Analysis (TCA) or Joint Domain Adaptation (JDA). The same can be performed on multiple separated fleets of batteries (for example with different technologies), whether homogeneous or heterogeneous

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Reinforcement Learning for Fleet O&M Optimization in UAV Systems

This thesis investigates the application of Reinforcement Learning (RL) to Operation and Maintenance (O&M) optimization in UAV fleets within a parametric simulation environment. The activity focuses on developing adaptive decision-making policies that optimise fleet-level performance under varying mission requirements and operational constraints. A flexible simulation framework is used to model different fleet configurations, enabling the training and evaluation of RL agents across multiple scenarios. An interactive interface allows direct comparison between RL-based decisions and user-driven strategies. The objective is to assess the capability of RL to improve key performance indicators such as fleet availability, mission efficiency, and robustness to changing conditions. Particular emphasis is placed on scalability, interpretability, and generalisation across configurations.

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Reinforcement Learning for Battery-Aware Fleet Management in UAV Systems

This thesis investigates the application of Reinforcement Learning (RL) to the operational management of battery usage in UAV fleets. The activity focuses on learning decision policies that optimise fleet availability and mission continuity by managing the state-of-charge of individual UAVs.

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Development of an engine digital-twin

Optimising maintenance policies is a complex task pushing towards a shift from programmed maintenance to condition-based maintenance. An engine digital twin is thus suitable to monitor and keep track of the health condition throughout the lifespan of the engine, enabling the prediction of engine health state by implementing diagnostic and prognostic algorithms enabling conditions-based maintenance policies.

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Engine fleet logistic digital twin for life cycle management optimisation

Optimising maintenance policies is a complex task pushing towards a shift from programmed maintenance to condition-based maintenance. This task is fundamental when dealing with aircraft fleets, developing a Discrete Event Simulator (DES) to simulate numerous fleet lifecycles and implement Reinforcement Learning algorithms for automatic decision making.

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Reinforcement Learning for O&M Optimization in Wind Turbine Fleets

This thesis investigates the application of Reinforcement Learning (RL) to Operation and Maintenance (O&M) optimization in wind turbine fleets using publicly available datasets from the literature. The activity focuses on learning decision policies that optimise turbine availability and energy production under varying environmental and operational conditions.

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Displacement Field Reconstruction Using the nonlinear iFEM Methodology under extreme loading conditions

Most structures operate in the linear-elastic range under normal service loads, where small-deformation assumptions hold. Under extreme loading (e.g., air-blast events), the response can become nonlinear (geometric and/or material), requiring methods that remain reliable beyond linear models. Building on strain data, this research aims to develop nonlinear iFEM techniques to reconstruct full-field displacements and identify damage under extreme loading conditions and geometric nonlinear cases.

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Displacement Field Reconstruction under Torsional Loading Using iFEM-Based Sensor Networks

Torsional loading can occur in many engineering structures such as shafts, naval components, aerospace structures, and mechanical systems. Compared with bending, torsion produces complex strain distributions that are not easy to capture using conventional sparse sensing approaches. This thesis aims to investigate the design of efficient sensor networks for iFEM-based displacement field reconstruction under torsional and combined loading conditions (torsion + bending).

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Displacement Field Reconstruction of beam structures using iFEM considering degrading Boundary Conditions

In real structures, boundary conditions may degrade over time due to damage or deterioration, significantly affecting the structural response. This thesis focuses on the development of an iFEM-based framework for reconstructing the displacement field of beam structures considering degrading boundary conditions and support stiffness variations.

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Displacement Field Reconstruction Using the iFEM Methodology on a Rotating Shaft for Imbalance Detection

Building on strain data, this research aims to develop advanced iFEM methods for damage and imbalance identification by integrating physics-based models with machine learning techniques. The study will also incorporate pre-extrapolation methods to enhance prediction accuracy. Furthermore, adaptive strategies will be designed to accommodate varying shaft boundary conditions, ensuring robust and reliable full-field displacement reconstruction under realistic operational scenarios.

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iFEM-Based Battle Damage Identification in Naval Structures

This thesis investigates the application of the inverse Finite Element Method (iFEM) for real-time damage identification in naval structures using experimental strain data. The activity is based on measurements acquired from a scaled structural model tested in a controlled wave tank under different sea states and damage scenarios. The objective is to reconstruct the structural response from strain measurements and detect damage conditions through deviations in the estimated displacement and stress fields. Different levels of structural damage and environmental loading are considered. Particular emphasis is placed on robustness to operational variability, sensitivity to damage, and the integration of iFEM within data-driven monitoring frameworks.

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Data-based monitoring for impact/corrosion damage identification in helicopters

In the framework of SAMAS 2, flight tests with real helicopters are performed to evaluate the health status through a specifically designed Structural Health Monitoring and Prognosis system. The data from the flight tests are used to develop diagnostic algorithms capable of identifying damage and the degradation level of the structure.

SAMAS 2 | claudio.sbarufatti@polimi.it | emanuele.petriconi@polimi.it | marco.giglio@polimi.it

Self-Sensing Composite Structures for Impact Damage Detection Using CNT Buckypapers

This thesis investigates impact damage detection, localisation, and characterisation in heterogeneous composite structures through the integration of self-sensing layers. A composite specimen is designed and manufactured using multiple material phases (e.g. CFRP and ceramic-like layers), embedding CNT buckypapers at different depths within the laminate.

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Development of quantum algorithms for Engineering (FEM)

Quantum computing is a novel, promising technology that may have a great impact also in the Engineering field. Nowadays, it is in its first development stages, while the potential and applicability of such technology still have to be determined. This thesis project aims to study the latest innovations in terms of quantum computing and reproduce common traditional algorithms with quantum ones. The goal is to reproduce an FEM algorithm in a simple scenario and evaluate possible extensions to more complex ones, considering the actual technological limitations.

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Development of quantum machine learning (QML) for diagnostics

Quantum computing is a novel, promising technology that may have a great impact also in the Engineering field. Nowadays, it is in its first development stages, while the potential and applicability of such technology still have to be determined. This thesis project aims to study the latest innovations in terms of quantum computing and reproduce common traditional algorithms with quantum ones. The goal is to develop a Quantum Machine Learning (QML) algorithm to perform damage detection on dataset already available in our lab.

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AI Applications for Structural Integrity & PHM

Programme head: Prof. Francesco Cadini | 11 topics

Graph neural networks for damage diagnosis

SHM systems aim to detect and diagnose damage in real time. Conventional methods, such as numerical analysis, can be computationally expensive and less efficient for large-scale or complex structures. Graph Neural Networks (GNNs) offer a promising solution by leveraging sensor networks as graphs, where nodes represent sensors and edges capture physical interactions. The objective of this thesis is to validate and enhance the use of GNNs for diagnosing damage within SHM systems.

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Graph neural network-based surrogate modeling for dynamic structural simulation

Simulating the dynamic behavior of structures using traditional methods such as the Finite Element Method (FEM) can be computationally intensive, especially for large-scale or complex systems. Graph Neural Networks (GNNs) present a powerful alternative by representing physical systems as graphs, enabling efficient learning of local patterns with strong generalization capabilities. The objective of this thesis are:

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Dataset and algorithms for damage diagnosis in real-world scenarios

Structural Health Monitoring (SHM) systems aim to detect and diagnose damage in real time. Traditional acquisition systems for SHM are highly accurate but exhibit significant limitations in terms of weight, size, cost, portability, and power consumption. Therefore, the development of systems capable of overcoming these constraints is increasingly crucial to enhance their applicability. Moreover, in the context of SHM, the use of Machine Learning (ML) plays a central role, making it essential to integrate ML even into computationally constrained systems through appropriate optimizations and customizations. In this context, our research project is built up as follows:

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Damage Localization using Autoencoders for Varying Temperatures and Frequencies

Damage localization through the analysis of ultrasonic guided waves can be influenced by an array of confounding factors e.g., temperature and humidity. Besides, the choice of excitation frequency affects not only the sensitivity of the waves but also the size of damage that can be detected. In this context, properly trained convolutional autoencoders that leverage the temperature and frequency information as points in their latent space might be able to overcome such drawbacks and provide a more robust damage localization framework.

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Development of artificial intelligence-based HUMS for UAVs HPS to support optimization of operations and maintenance

In recent years, there has been growing interest in using electric propulsion for aeronautical applications due to its benefits of reduced emissions, vibrations and noise, as well as improved efficiency and performance. Specifically, HPS which integrate batteries, solar panels and fuel cells, have been proposed as a promising solutions for powering High Altitude and Long Endurance (HALE) drones. These drones can operate in extreme environmental conditions for long duration, making the development of advanced HUMS crucial for ensuring their safety and efficiency.

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Offering an achievable and advanced health monitoring strategy for structural batteries

With the higher demands of performances in the automotive and aeronautical fields, more battery cells are required for the higher power and energy of the pack. The trade-off between the power and weight is an open research problem. Structural battery (SB) packs potentially offer a compromise whose multifunctional materials serve both for energy storage and load bearing. However, for SB on aeronautic applications, the maintenance and replacement are complex, which might rely more on an efficient PHM system.

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Towards a Structural Battery Coupon: Development and Experimental Validation under Electrical, Mechanical, and Thermal Loads

With the higher demands of performances in the automotive and aeronautical fields, more battery cells are required for the higher power and energy of the pack. The trade-off between the power and weight is an open research problem. Structural battery (SB) packs potentially offer a compromise whose multifunctional materials serve both for energy storage and load bearing.

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Lithium-ion batteries PHM by exploiting electrochemical models and machine learning

To ensure safe and efficient operation, the power batteries of EVs should be controlled on a suitable operative environment, which includes temperature and pressure as well. Therefore, an accurate battery management system (BMS) which mainly rely on the estimation of battery health states including SOC, SOH, RUL and ISC early occurrence is highly required which means, an efficient prognostics and health management (PHM) system.

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Electrochemical-Thermal Modeling and Learning-Based Control of Li-ion Battery Packs

Battery packs operate under coupled electrical and thermal constraints; conservative control ensures safety but sacrifices usable power/efficiency and accelerates degradation under suboptimal thermal gradients. Physics-based models enable interpretability and extrapolation, while RL can learn control policies for complex multi-objective operation-provided the sim-to-real gap is addressed.

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Early-Stage Internal Short Circuit Detection and Proactive Thermal Runaway Prevention in Li-ion Battery Packs via High-Fidelity Digital Twins

Battery packs face a critical trade-off between performance and safety, specifically regarding latent Internal Short Circuits (ISC) that trigger thermal runaway. This research develops a physics-informed Digital Twin to identify micro-ISCs during the "slow drop" phase, preventing progression to the "unstoppable" terminal stage. By integrating model-based algorithm with surrogate/lumped-modeling, we enable proactive, detection algorithms that bridges the sim-to-real gap and ensures safety-critical operation without sacrificing efficiency.

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Time series anomaly detection (TSAD) algorithms for satellite telemetry data

The complexity and multidimensionality of telemetry data, encompassing both sensor measurements and commands, present significant challenges in analysis, underscoring the continued necessity for experts to check system integrity. To tackle these challenges, the implementation of intelligent prognostics and health management (PHM) algorithms for telemetry data processing, incorporating both machine learning and standard statistical methods, advances a predictive approach aimed at evaluating the health states of space systems.

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04

Metamaterials & Energy Absorption

Programme head: Dr. Luca Lomazzi | 11 topics

All thesis topics can incorporate machine learning and data-driven methods, including surrogate modeling, optimization, generative and inverse design, and physics-informed learning, depending on the student's interests and background.

Fractal-inspired structures for enhanced Structural Health Monitoring (SHM)

Fractals are geometrical structures characterized by repeating patterns across multiple scales and distinctive properties such as self-similarity and scale invariance. These features have motivated their use in several fields, including materials science, acoustics, and energy systems, to design efficient multiscale systems. In Structural Health Monitoring (SHM) the dynamic behavior of fractal-inspired structures can be exploited to enhance the performance of diagnostic systems.

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Programmable metamaterials for adaptive mechanical behavior

Programmable metamaterials are engineered materials whose mechanical properties can be dynamically altered through embedded actuation and control mechanisms. A defining feature is closed-loop adaptivity: the material senses its state (e.g., load, strain) and tunes its properties (e.g. stiffness, damping) accordingly, enabling adaptive behavior under changing conditions. Thanks to this, it is possible to realize structures that autonomously adapt their mechanical response to improve performance, robustness, and safety.

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Design and application of metamaterials computational capabilities for damage diagnosis

Mechanical metamaterials are structural components engineered and designed to exhibit properties that go beyond the intrinsic characteristics of the base material itself. Given the vast design space offered by the numerous geometries and solutions that can be employed to achieve a wide range of different properties, these metamaterials can be used to perform actual computations. Thanks to this, it is possible to exploit the computing capabilities of mechanical metamaterials to highlight and facilitate the detection of specific structural damages.

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Generative Design of Disordered Mechanical Metamaterials for Tailored Dynamic Response

Use machine learning and inverse design to generate disordered architectures with prescribed mechanical behavior under dynamic loading.

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Mechanical Neural Networks: Topology Optimization of Computational Unit Cells

Design optimized mechanical unit cells that process mechanical inputs and realize targeted computational or logic-like responses.

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Rainbow Effects and Wave Control in Spatially Graded Mechanical Metamaterials

Investigate how spatial grading can localize, steer, and filter elastic waves, producing tunable rainbow effects.

In collaboration with the Wave Lab, University of Colorado Boulder

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Magnetorheological Elastomer Metamaterials for Tunable Mechanical Response

Develop architected elastomeric materials whose stiffness and deformation response can be controlled through an external magnetic field.

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Active Wave Control and Rainbow Effects in Magnetorheological Fluid-Based Phononic Crystals

Design phononic crystals with magnetorheological-fluid inclusions to magnetically tune wave propagation, band gaps, and rainbow localization.

In collaboration with the Wave Lab, University of Colorado Boulder

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Wave Dynamics in Twisted TPMS Metamaterials under Irreversible Deformation

Study how permanent deformation and twist modify elastic-wave propagation in triply periodic minimal-surface metamaterials.

In collaboration with Università Politecnica delle Marche

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Fractal Mechanical Metamaterials for Elastic Wave Control and Structural Health Monitoring

Explore fractal architectures for wave filtering and localization, and exploit their wave response for damage detection.

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Non-Hermitian Exceptional Points for Enhanced Structural Health Monitoring

Investigate exceptional-point phenomena in mechanical systems to enhance sensitivity to small structural changes and damage.

In collaboration with the Wave Lab, University of Colorado Boulder

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