5th Symposium on Acoustic Metamaterials

15-17 April 2026, Leuven, Belgium

Symposium on Acoustic Metamaterials

Leuven 2026

Organised by YRAM (Young Researchers in Acoustic Metamaterials)

Young Researchers in Acoustic Metamaterials

https://yram.org

Web: yram.org
Web: sam-2026.sciencesconf.org/

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General information

Welcoming words

We are delighted to welcome you all to Leuven for the 5th Symposium on Acoustic Metamaterials (SAM 2026). SAM 2026 is dedicated to doctoral students and early career researchers coming from numerous European and overseas countries, reflecting the international nature of research in the field of acoustic metamaterials. It aims at sharing new advances and breakthroughs as well as fostering the community of young researchers.

SAM 2026 will feature six scientific sessions, along with four plenary lectures delivered by senior researchers:

- Felix Langfeldt, Associate Professor, ISVR, University of Southampton (UK)
- Varvara Kouznetsova, Associate Professor, Eindhoven University of Technology (NL)
- Marie Touboul, CNRS Researcher (CR), POEMS, ENSTA (FR)
- Nicolas Noiray, Associate Professor, ETH Zürich (CH)

This is an exciting time to be working in the field of acoustic metamaterials. During the symposium, we will learn a lot about emerging applications and their impact on sound transport, wave absorption, noise control, and much more.

We will also have the opportunity to explore the rich heritage of Belgian beer and chocolate through social and cultural visits to the Stella Artois brewery in Leuven on Thursday afternoon and the Choco Story Museum in Brussels on Saturday.

We warmly welcome you and hope you enjoy the Symposium!

Best wishes from the organisers.

Venue

SAM 2026 will take place at the Maria Theresiacollege of KU Leuven (Sint-Michielsstraat 6, 3000 Leuven, Belgium).

Information

For practical reasons, we have created a WhatsApp community for the symposium. It will be used to share updates, announce any last-minute changes during the event, and help coordinate social gatherings outside the official program.

We strongly encourage you to join the community by scanning the QR code below, so that you can receive the latest information in real time.

Organizing Committee

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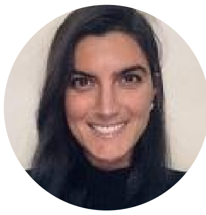

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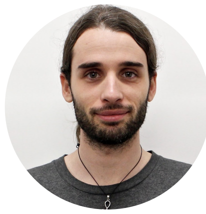

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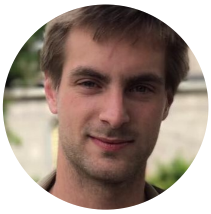

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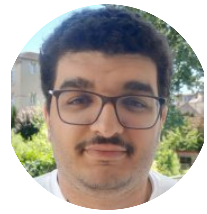

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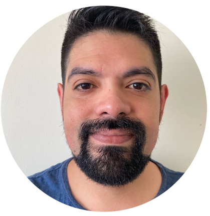

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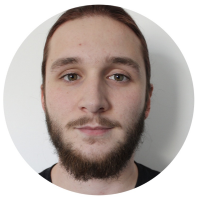

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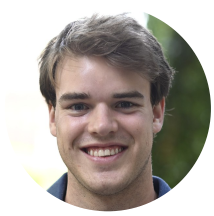

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Abhijeet Singh
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Bertin Many Manda
Tel Aviv University
Israel

Should you have any questions, do not hesitate to come to us!

Breaks & Catering

The coffee breaks in the morning and afternoon will be offered at the conference venue. In particular, the coffee break on Thursday morning is proudly sponsored by the *METAVISION doctoral network*.

The lunches will take place at the restaurants listed below:

Wednesday April 15th:

- Lunch at 12.40: Restaurant “Domus” (Tiensestraat 8)
- Dinner at 18.30: Restaurant “Café Entrepot” (Vaartkom 4)

Thursday April 16th:

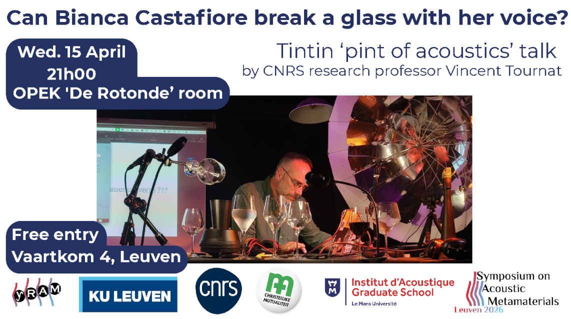
- Lunch at 12.40: Restaurant “Café Sport” (Martelarenplein 13)
- Dinner at 20.00: Restaurant “Brasserie ’t Oud Gasthuys” (Brusselsestraat 63B)

Friday April 17th:

- Lunch at 12.30: Restaurant “Domus” (Tiensestraat 8)
- Dinner at 20.00: Restaurant “Café Sport” (Martelarenplein 13)

Social events

Popularization event on Wednesday Evening



On Wednesday, 15 April in the evening, Vincent Tournat (DR, CNRS) will take the stage at OPEK with one of his most acclaimed public science shows, a captivating performance that brings sound and waves to life.

The event is free and will be held at OPEK (Vaartkom 4, 3000 Leuven) from 21:00 to 23:00.

Cultural visit on Thursday - Tour of the Stella Artois brewery

On Thursday, 16 April at 17:00, SAM participants will visit the Stella Artois brewery, home to one of Belgium's most iconic beer brands. This visit will provide a unique opportunity to discover Leuven's contribution to the rich heritage of Belgian beer brewing. The event is free of charge for conference participants, but registration is required.

Address: Aarschotsesteenweg 20, 3000 Leuven

Photography credited to Stella Artois

Extra Social day in Brussels - A visit of the Choco Story Museum

An optional extra social day is organized on Saturday, 18 April in the city center of Brussels. Registration is required, with a participation fee of 40.00 € per person. This fee includes transportation from Leuven to Brussels, luggage storage, lunch, and a visit to the Choco Story Museum (Rue de l'Étuve 41 Stoofstraat - Bruxelles).

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Acoustical Society of Italy
www.acustica-aia.it

International Commission for Acoustics
www.icacommission.org

Young Acousticians Network
euracoustics.org/yan

KU Leuven: www.kuleuven.be
KU Leuven is one of Europe's oldest and most prestigious universities, with a rich history dating back to 1425. KU Leuven is renowned for its diverse international community and wide range of study and research programs across various disciplines, founded on a long tradition of excellence in science and engineering.

KU Leuven - Structural Mechanics Section: bwk.kuleuven.be
The Structural Mechanics Section of the Department of Civil Engineering at KU Leuven conducts research on the static and dynamic behavior of structures, integrating fundamental research with practical engineering applications. A central theme is vibration and noise in the built environment, with focus on numerical modelling, experimental testing, and the development of innovative mitigation solutions.

Acoustics Laboratory of Le Mans University (LAUM): laum.univ-lemans.fr
The Acoustics Laboratory of Le Mans University (LAUM) is a Joint Research Unit of Le Mans University and the CNRS (UMR 6613). LAUM counts about 160 people. The activities of LAUM are mainly focused on acoustics 'of the audible', but new research topics in the field of vibrations and ultrasounds have been integrated in recent years.

European Acoustics Association
The European Acoustics Association (EAA) is a non-profit organization founded in 1992. It brings together predominantly European societies dedicated to advancing the science and application of acoustics across its many disciplines, technologies, and practical uses. Today, the EAA comprises 33 member societies and represents over 9,000 individual members throughout Europe. The EAA is also an Affiliate Member of the International Commission for Acoustics (ICA) and the Initiative for Science in Europe (ISE). **SAM 2026 is co-organized by the EAA's Technical Committee on Acoustic Materials.**

Institut d'Acoustique - Graduate School
Led by Le Mans University and the CNRS, the "Institut d'Acoustique - Graduate School" university research school was launched in 2018. Inspired by the Anglo-Saxon model of "graduate schools", the Institute aims to become an international reference center for research and training in the field of acoustics.

Acoustic Metamaterials Group
AMG is a smart materials and acoustics company that is changing the way we interact with sound and providing noise control solutions in conditions conventional materials cannot address. Coupling applied physics with intelligent design and manufacturing, AMG is

pioneering a new class of multifunctional materials - called metamaterials.

Arenberg Doctoral School

The Arenberg Doctoral School aims at training doctoral researchers both as future scientists and as scientifically trained professionals. The core of the doctoral training is doing research. In addition to research as an instrument for training and development, doctoral researchers also follow more formal training via seminars, workshops, summer schools, and other course components. In order for doctoral researchers to be employable in a broad range of highly qualified positions, transferable skills are a necessary part of the doctoral training program.

Leuven Mecha(tro)nic System Dynamics

Active since the late sixties, the Noise and Vibration Research Group is still playing an essential role in researching many relevant and advanced industrial applications in the noise and vibration engineering field.

EMPA

EMPA is a Swiss Federal research institute within the ETH domain with 1000 employees including 150 PhD students. As part of the Swiss Federal Institutes of Technology Domain, it is an institution of the Swiss federation. For most of the period since its foundation in 1880, it concentrated on classical materials testing. Since the late 1980s it has developed into a modern research and development institute. According to its vision – Materials and technologies for a sustainable future – Empa aims at developing solutions for current problems facing industry and society in areas such as energy, the environment, mobility, health and safety.

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15 April 2026

Plenary talk - The Return of the Helmholtz-resonator: A Story of Acoustic Metamaterials and Advanced Acoustic Resonators

Felix Langfeldt[1] *†

[1] Institute of Sound and Vibration Research, University of Southampton, United Kingdom

Abstract: First conceptualised in the 19th century by Hermann von Helmholtz, the Helmholtz-resonator (HR) has been a staple in acoustical engineering with various applications, e.g., as tonal sound absorbers in rooms, duct silencers, or in ported loudspeaker enclosures. Owing to their long history and the well understood physical principles, most of the scientific community in acoustics moved on from HR-related research in the late 20th century. However, with the emergence of acoustic metamaterials (AMMs) in 2000 and the discovery that HR-based AMMs can be used to, for example, achieve negative bulk modulus, a whole new chapter was opened in the history of Helmholtz-resonators. This presentation aims at providing an overview covering the most recent innovative developments in HRs, with a focus on advanced sound control using acoustic metamaterials and smart acoustic resonators. First, the basic underlying physical principles of HRs will be introduced, alongside a summary of common misconceptions and pitfalls in the design of HR-based acoustic systems. Then, the presentation will highlight recent developments in acoustic metamaterials using HRs to achieve broadband subwavelength absorption or enhance reduction of sound transmission. The final part of the presentation will focus on advanced acoustic resonator designs, based on the HR principle, which offer enhanced functionality compared to conventional HRs, such as HRs combined with structural resonators, active HR absorbers, and smart self-tuning HRs.

Curriculum vitae: Dr Felix Langfeldt is Associate Professor and Doctoral Programme Director at the Institute of Sound & Vibration Research (ISVR), University of Southampton. Felix did his PhD in Acoustical Engineering (2018) at Technical University Hamburg, with a thesis on "Membrane-type acoustic metamaterials for aircraft noise shields". Since then, his research focuses on innovative technologies for low-frequency sound control, involving lightweight acoustic metamaterials, Helmholtz-resonators, and active control. He joined ISVR in 2021, funded by a Walter Benjamin fellowship from the German Research Foundation, and became an academic in Southampton in 2022. Felix is also the Co-Lead of the Special Interest Group on "Acoustic Metamaterials" in the UK Metamaterials Network (UKMMN+).

*Speaker

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Metamaterials for sound absorption

Multi-Resonant Low-Frequency Sound Absorption Using a Slit-Neck Helmholtz Unit Cell Capped by a Folded Quarter-Wave Resonator

Christopher Barrett *† [1], James Windmill [1]

[1] Centre for Ultrasonic Engineering – Department of Electronic and Electrical Engineering, University of Strathclyde, Royal College Building, 204 George Street, Glasgow G1 1XW, United Kingdom

Persistent low-frequency noise in urban environments disrupts sleep and speech clarity in both residential and commercial rooms. Conventional porous absorbers become prohibitively thick below 500 Hz, while single-mode resonators provide limited bandwidth. We present a compact rectangular slit-neck Helmholtz unit cell capped by a folded quarter wavelength resonator. The capping structure acts as an extended neck that lowers the primary Helmholtz resonance and, with deliberate tuning, introduces an additional quarter-wavelength resonance to create a multi-resonant absorption response. An analytical model based on the transfer-matrix method, including thermoviscous loss effects, predicts a strong Helmholtz absorption peak with an additional tuneable quarter-wavelength resonance. Impedance tube measurements of a four-cell metamaterial array validate the model, demonstrating peak absorption coefficients up to 0.9 within the 200-1000 Hz range (with multiple resonant peaks across the band). Finite element simulations agree with the analytical and experimental data and show that an optional porous layer can be added to smooth the peak-based response, increasing the effective absorption bandwidth. The square unit-cell geometry would enable gap-free tiling on walls or ceilings, providing a lightweight, rigid, and tuneable metamaterial for low-frequency noise mitigation in urban interiors, vehicle cabins, and workplaces.

Keywords: Helmholtz, Resonator, Absorption, Quarter Wavelength, Impedance Tube

*Speaker
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Broadband Sound Absorption Using Weakly Coupled Parallel-Arranged Helmholtz Resonators in Acoustic Metasurfaces: A Numerical Study

Faisal Rafique * [1], Dong Yang [1]

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Broadband, low to mid-frequency sound absorption with thin, compact structures presents a significant challenge in acoustical engineering. This work presents a novel acoustic metasurface based on weakly coupled parallel Helmholtz resonators (HRs). The design begins with an optimized dual-cavity HR unit, where a small inter-cavity perforation bridges two resonance peaks to create a continuous absorption band. By extending this principle to a network of several cavities interconnected via carefully designed perforations, multiple overlapping resonance modes can be created, effectively covering a continuous and wider frequency range. This scaled-up weak-coupling network allows for superior impedance matching across a broader spectrum, maintaining the near-optimal condition where dimensionless reactance approaches zero, and resistance approaches unity over an expanded interval. Based on this mechanism, a nine-HRs acoustic metamaterial unit cell (four perforated pairs and one single resonator), achieving an average absorption coefficient of 0.82 between 750 Hz to 3000 Hz, with individual peaks above 0.9. By coupling five such unit cells, a mixed multi-cavity parallel-arranged HRs based acoustic metasurface is realized, attaining an average absorption of 0.87 from 650 Hz to 3000 Hz with only 57 mm total thickness. The design was optimized via finite element analysis (FEM), fabricated using Low-Force Stereolithography (LFS), and validated experimentally with an impedance tube based on the two-microphone method. Excellent agreement between simulation and measurement confirms the design's accuracy and robustness, demonstrating a compact, high-performance solution for practical noise-control applications.

Keywords: Helmholtz Resonator, Sound Absorption, Broader Bandwidth, Acoustic Metamaterial, Metasurface, 3D Printing, Additive Manufacturing, Low, Force Stereolithography

* Speaker

Wideband Post-Resonance Absorption in Mycelium-Based Helmholtz Resonators

Tomas Gomez * [1,2], Andreas Biront [3], Edoardo Piana [2], Christ Glorieux [1]

[1] KU Leuven, Department of Physics and Astronomy, Laboratory for Acoustics - Soft Matter and Bio-physics – Heverlee, Belgium
[2] University of Brescia, Department of Mechanical and Industrial Engineering – Brescia, Italy
[3] KU Leuven, Department of Architecture – Campus Saint-Lucas, Brussels and Ghent – Ghent, Brussels, Belgium

Helmholtz-type resonators are attractive as subwavelength acoustic metamaterials. This type of resonators, as well as other conventional rigid resonators, typically deliver a sharp absorption maximum at resonance, followed by a rapid drop in absorption at higher frequencies. This behavior motivates hybrid solutions that combine resonant elements with classical porous soundproofing layers to widen the effective bandwidth. In this work, we investigate mycelium-based resonators as a bio-derived metamaterial approach that intrinsically broadens the absorption peak and maintains high absorption at high frequencies without sacrificing peak magnitude. Mycelium was pre-grown under controlled conditions to reach a consistent colonization state and subsequently transferred into dedicated molds to form the resonator components (cavity and front panel/neck). This approach enables repeatable macroscopic geometry while retaining the intrinsically porous microstructure of the bio-composite, which is central to the observed acoustic dissipation. Geometrically comparable resonators were measured in an impedance tube over a 125–3150 Hz one third octave frequency span. Two resonator configurations were evaluated, one as a conventional rigid plastic 3D print as a reference and the other one, a mycelium composite intended to introduce distributed dissipation. Across the tested configurations, the mycelium-neck resonators preserve near-unity peak absorption at resonance comparable to rigid-neck designs. Beyond resonance, mycelium resonators maintain strong high-frequency absorption, whereas rigid resonators show low post-resonance absorption. This broadband widening around resonance, paired with high absorption after the resonance frequency, suggests that the mycelium microstructure provides added loss mechanisms (e.g., viscous and viscoelastic dissipation) that are not present in conventional rigid necks, effectively ”smoothing” the resonant response while preserving its magnitude.

Keywords: Helmholtz Resonators, Mycelium, Sound absorption

*Speaker

Utilizing integrated beam-resonators to characterize manufacturing variability in Selective Laser Sintered metamaterials

Alexander Kryuchkov † [1,2], Michele Pavan [1], Claus Claeys [2,3], Elke Deckers [3,4]

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[2] Department of Mechanical Engineering, KU Leuven – Celestijnenlaan 300, 3001 Heverlee, Belgium
[3] Flanders Make – Gaston Geenslaan 8, 3001 Heverlee, Belgium
[4] Department of Mechanical Engineering, Diepenbeek, KU Leuven – Agoralaan, building B, 3590 Diepenbeek, Belgium

Manufacturing variability in Selective Laser Sintering (SLS), caused by uneven temperature distribution and scanning time dependencies, can influence the performance of locally resonant based metamaterials. This study explores the use of embedded diagnostic beam resonators at key locations close by the functional metamaterial structures as in-situ proxies to understand how local manufacturing conditions influence effective material properties. By mapping frequency shifts across the build volume, these variations in geometry and stiffness can be quantified. These findings provide a framework for identifying optimal printing strategies to improve the reliability and consistency of 3D-printed metamaterials.

Keywords: additive manufacturing, selective laser sintering, metamaterials

† Speaker

Building an Absorber Using Inclined Wiremesh Gratings

Juan Pablo Escudero * [1], Jean-Philippe Groby [1], Vincent Pagneux [1]

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The design of an acoustic absorber necessitates two fundamental elements: impedance matching and a lossy mechanism to attenuate the incident wave. In this work, we present a grating constituted by the periodic arrangement of inclined ultrathin resistive layers. Impedance matching is achieved thanks to the reciprocity property of the grating, when the angle of the incident wave corresponds to the angle of inclination of the ultrathin layers as well as its exact opposite angle. The employed lossy layer mechanism is a wiremesh, defined as an ultrathin woven material exhibiting broadband resistance. We focus our attention on the absorption performance of the rigid-backed architecture. The study is conducted through numerical computations and the structure is analyzed using the effective medium approximation. The proposed metasurface exhibits either large absorption over a broad frequency band or almost omnidirectional large absorption over a subwavelength narrow frequency band depending on the structure parameters. The peculiar acoustic behavior of the wiremesh grating offers novel possibilities for the design of broadband omnidirectional subwavelength sound-absorbing devices. A possible perspective application is the creation of anechoic environments by using the metasurface attached to the walls of a room.

Keywords: absorber, wiremesh, metasurface, grating

*Speaker

Numerical Investigation of Metasurface and its Application in Room Acoustics

Jonas Helboe Jørgensen *† [1], Kirill Shaposhnikov [1], Mads Herring Jensen [1]

[1] COMSOL A/S – Diplomvej 381, 2800 Kongens Lyngby, Denmark

Metasurfaces are widely used for sound absorption and are using several techniques to absorb low frequency sound that have a longer wavelength than the thickness of the metasurface. Two common techniques are Helmholtz resonators and mechanical resonances. In this presentation we will simulate and investigate a metasurface consisting of a porous layer, a Helmholtz resonator, and a mechanical resonance.
We are studying a metasurface consisting of a foam with complex embedded cylindrical structures. The cylindrical structure have both acoustic resonances as a Helmholtz resonator and a mechanical resonance. First, we will model the unit cell of the metasurface and find its effective impedance depending on frequency and incident angle of the acoustic wave. We will investigate the effect of the different resonances in the system and how they help absorb low frequency sound. The setup consists of a vibroacoustcs mutliphysics model including solid structures, poroelastic domains, and air domains. For simulating the unit cell of the metasurface Floquet periodicity is used together with a periodic port condition. The periodic port condition uses modal superposition to treat an incident plane wave as well as specular and higher order diffractions, hence ensures no spurious reflection from waves travelling away from the metasurface. This is a more accurate alternative than to use a perfectly matched layer. The model is set up in COMSOL Multiphysics. Secondly, the effective impedance of the surface is used in a macro room acoustic model in the time domain. To be able to apply a frequency dependent impedance in the time domain the so-called partial fraction expansion method is used to represent the impedance in the time domain. The modeled angle and frequency dependent surface impedance can also be directly used in a classical ray acoustics model for modeling in the high frequency regime.

Keywords: Acoustic metasurface, Multiphysics, Room acoustics, Numerical modeling

*Speaker
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Plenary talk - Multi-scale approach to analysis and design of subwavelength mechanical and acoustic metamaterials on finite size domains

Varvara Kouznetsova[1] *†

[1] Eindhoven University of Technology, Netherlands

Abstract: This talk will present the recent advancements in the computational homogenization techniques for modelling elastic and acoustic wave propagation in locally resonant metamaterials on finite size domains in both frequency and time domains, including transient regimes. I will start by describing the main idea of the transient computational homogenization approach that allows the direct simulations of wave propagation and attenuation on finite size domains. The general approach is suited for arbitrarily complex unit cell geometries and material behaviour, including material and geometrical non-linearities. As an example illustrating the emergent behaviour due to non-linearities, energy transfer by an auto-parametric resonance from propagative to evanescent wave will be shown. Next, extensions and applications of the approach will be presented for visco-elastic (lossy) metamaterials, porous materials including fluid-solid interaction and acoustic labyrinthine metamaterials.

Curriculum vitae: Varvara Kouznetsova is an Associate Professor of Multi-scale Solid Mechanics at the Department of Mechanical Engineering of Eindhoven University of Technology. She holds a degree in Applied Mathematics from Perm State Technical University, Russia, and a PhD in Mechanical Engineering from Eindhoven University of technology. Her research focus is on the development of multi-scale techniques applicable to various materials, ranging from high-strength steels to metamaterials, and related physical phenomena, emerging from non-trivial interactions across different space and time scales.

*Speaker

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Elastic metasurfaces

Efficient modelling and design of multimodal seismic metasurfaces for broadband ground vibration mitigation

David Carneiro *† [1], Daniele Giannini [1], Stijn François [1], Geert Lombaert [1], Geert Degrande [1]

[1] KU Leuven – Department of Civil Engineering, Structural Mechanics Section, Kasteelpark Arenberg 40, B-3001 Leuven, Belgium

Inspired by promising results obtained with seismic metamaterials to protect civil structures, we investigate how seismic metamaterials can mitigate railway induced vibration (1 - 80 Hz). This is a very challenging problem, as the wide spectrum of railway induced vibration requires broadband mitigation. Moreover, a complex vibration pattern is created during a train passage due to the omnidirectional wave radiation from each axle of the train exciting a large volume of soil, as well as multiple wave reflections and refractions at the layer interfaces of a stratified soil.

A 3D finite element - boundary element (FE-BE) formulation can be used for modelling the soil-metasurface interaction. Evaluating detailed interaction between a large number of resonators involves substantial computational time and memory, limiting the applicability of the method. An efficient relaxed approach is therefore proposed under the assumption that the wavelengths of interest are much longer than the dimensions of the soil-resonator interface. Transfer functions from a single rigid foundation to single points at the surface representing resonator positions can therefore be used. The proposed method is verified considering different wavelength-footprint ratios. An excellent accuracy and a significant (roughly 2800 times) reduction in computational time is obtained, offering an accurate and efficient solution to problems involving a large number of resonators.

The effectiveness of resonator arrays composed of mass-spring systems is widely studied. They have limited effectiveness as only their vertical motion affects surface waves. In this work, multi-modal metasurfaces are proposed. A resonator consisting of plates connected by ligaments with opposite chirality is employed. This design induces coupled torsional-vertical modes, enhancing performance. The effectiveness of chiral resonators on a homogeneous soil is investigated. Mitigation between 20 and 80 Hz is obtained using a graded configuration. The results stimulate using this new concept to protect civil structures from ground vibration.

Keywords: Seismic metasurfaces, Railway induced vibration, Dynamic soil, structure interaction, Finite element, boundary element

*Speaker

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Analytical and numerical study of Scholte-Stoneley wave control through elastic metasurfaces

Farhad Zeighami *† [1], Said Quqa [1], Jacopo Maria De Ponti [2], Nadeen Ayyash [1], Alessandro Marzani [1], Antonio Palermo [1]

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This study investigates the control of Scholte-Stoneley Waves (SSWs), which propagate along solid-fluid interfaces, by means of elastic metasurfaces. The solid medium is modeled as an elastic, isotropic half-space under plane-strain condition, while the fluid layer is treated as an inviscid acoustic medium. The metasurface is composed of a periodic array of discrete mechanical resonators attached to the interface, whose spacing and characteristic dimensions are assumed to be subwavelength, allowing geometrical scattering effects to be neglected. The collective response of the resonator array is represented through an effective boundary condition that introduces a uniform, frequency-dependent vertical traction on the solid surface.

Within this framework, dispersion relations are derived in the long-wavelength regime, providing an analytical description of the interaction between SSWs and the elastic metasurfaces. The analysis shows that the phase velocity and spatial confinement of the fundamental SSW mode can be tuned through appropriate design of the metasurfaces. Analytical predictions are then validated via numerical simulations based on a wave finite element approach, complemented by harmonic response analyses to illustrate the wave control mechanisms. In addition, metasurfaces formed by graded mass-spring resonators with smoothly varying resonant frequencies along the interface are examined. These graded configurations enable two distinct effects: progressive wave trapping induced by a gradual decrease in the local resonant frequency, and controlled conversion of SSWs into leaky modes radiating into the fluid medium, achieved through a smooth increase in the resonant frequency along the array [1]. The results demonstrate the efficiency of elastic metasurfaces for manipulating solid-fluid interface waves and suggest potential applications in fluid-structure interaction problems, including wave-based microfluidics, surface acoustic wave devices, and energy harvesting systems.

REFERENCES

[1] F. Zeighami, S. Quqa, J. M. De Ponti, N. Ayyash, A. Marzani, A. Palermo, Philos. Trans. R. Soc. A-Math. Phys. Eng. Sci. 382 (2278) (2024) 20230365.

Keywords: Elastic metasurfaces, Scholte waves, Solid fluid interaction, Dispersion analysis, Graded metasurfaces

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Phononic crystals

Influence of the Unit Cell Choice on the Effectiveness of Band-Gap Metamaterials

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In recent years, mechanical metamaterials have gathered significant attention for their ability to manipulate mechanical waves in ways that surpass the capabilities of classical materials. The focus of this work is on mechanical metamaterials capable of generating band-gaps, which can be exploited for shielding and passive vibration control. Band-gaps can appear in the dispersion diagrams of a metamaterial with a rationally designed periodic architecture, when a standard Bloch-Floquet analysis is performed on its representative unit cell. As this analysis employs Bloch-periodic boundary conditions, which imply an infinitely extended metamaterial, this representative unit cell choice is non unique. In fact, for truncated periodic systems, this choice dictates the boundary of the domain and consequently the boundary effects that can manifest (3). If such effects take place in the band-gap, they can reduce the effectiveness of the metamaterial (1, 2). The goal of this contribution is to firstly address this unit cell choice in a systematic manner and secondly to show, through a series of finite element simulations of finite-sized metamaterials, what influence this choice has on the boundary effects and effectiveness of mechanical metamaterials. The effectiveness is quantified via the Transmissibility in the band-gap. The results demonstrate that boundary effects induced by the unit cell choice play a crucial role in the effective band-gap behavior and may significantly alter the predicted attenuation performance when compared to idealised infinite models. These findings suggest that a general procedure is needed for selecting appropriate unit cells for realistic engineering applications involving finite domains.

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Keywords: band, gap, finite sized metamaterials, unit cell choice, boundary effects

*Speaker

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Symmetry-Breaking in Twisted Kelvin Cell Lattices for Elastic Wace Control

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This study investigates the control of elastic wave propagation in one-dimensional periodic waveguides through twist-based geometric variations of the Kelvin cell. By imposing controlled twists, the original lattice topology is preserved while mirror symmetries are selectively broken through a single geometric parameter. This approach allows for the adjustment of dispersion characteristics without requiring embedded resonators or substantial mass augmentation. Using a complex-valued Bloch-Floquet framework, we demonstrate that these twist-induced modifications activate two distinct attenuation regimes: traditional Bragg scattering and polarization-dependent band gaps resulting from longitudinal-torsional mode coupling. To validate these computational predictions, transmission spectra are benchmarked against experimental data from SLA-printed lattice specimens. We show that capturing the precise transmission characteristics requires a material model that incorporates viscoelastic effects. To provide a deeper mechanical interpretation of these phenomena, an analytical mass-spring model with coupled translational and rotational degrees of freedom is presented as a minimal model for symmetry-induced mode coupling. This framework enables the tracing of numerically obtained dispersion relations and the identification of avoided crossings accompanied by the formation of complex-conjugate eigenvector pairs. As an outlook, potential metrics inspired by modal similarity measures are discussed to quantify the strength of these modal interactions, offering preliminary insights into the systematic design of wave-interaction mechanisms in architected Kelvin cell lattices.

Keywords: Kelvin cell

*Speaker

Analysing Wave Dynamics in Additively Manufactured Viscoelastic Metamaterials

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Elastic metamaterials offer significant potential for advanced control of elastic and acoustic waves, enabling functionalities such as vibration attenuation, waveguiding, filtering, and energy localization. However, their predictive design remains challenging when polymers are used as constituent materials, primarily due to the frequency-dependent viscoelastic behavior that is often oversimplified or neglected in conventional modeling approaches. As a result, discrepancies between numerical predictions and experimental observations persist, limiting the reliable translation of material properties into functional wave-control performance. In this study, we present an experimentally validated framework to characterize and model the viscoelastic behavior of additively manufactured polymers under dynamic conditions. Quasi-one-dimensional phononic metamaterial structures fabricated from acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are employed as representative systems to systematically investigate the role of material dissipation on wave propagation. The proposed methodology integrates frequency-dependent material characterization with numerical and experimental analysis. Dynamic mechanical analysis (DMA) is used to obtain storage and loss moduli over a broad frequency range, complemented by tensile testing to establish baseline elastic properties. These experimentally measured viscoelastic properties are directly incorporated into finite-element models using linear viscoelastic constitutive formulations, enabling realistic simulation of wave transmission and band-gap behavior. To validate the predictive capability of the framework, ultrasonic transmission experiments are performed on the additively manufactured metamaterial specimens, allowing direct comparison between simulated and measured transmission spectra. The results demonstrate that accurate incorporation of frequency-dependent viscoelasticity is essential for capturing both the location and attenuation depth of band gaps, particularly in polymer-based systems where damping plays a dominant role. Neglecting material losses or relying on simplified elastic approximations leads to significant errors in predicted wave behavior, even in relatively simple lattice geometries. By contrast, the proposed framework yields good agreement between numerical predictions and experimental measurements across different polymers and structural configurations. Overall, this work provides a robust and transferable approach for predicting wave dynamics in additively manufactured polymer metamaterials, establishing material dissipation as a key design parameter rather than a secondary correction. The framework supports the rational development of functional elastic metamaterials for applications including waveguiding, vibration isolation, energy harvesting, and other dynamically driven systems.

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Keywords: Polymer phononic materials, viscoelastic, wave dynamics, additive manufacturing

Tunable Matryoshka Local Resonance Sonic Crystal acoustic barrier for optimised low frequency noise control.

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Continuous development in construction, transportation and industrial technology has raised low-frequency noise in densely populated developing countries. Matryoshka Sonic Crystal (MSC) offers a promising solution for low-frequency noise control, as it has the ability to mitigate environmental noise with multiple band gaps, a broader bandwidth, and a compact structure without affecting air flow. This study investigates the tunability of the first complete band gap due to local resonance (LR) of MSC. The proposed design of the MSC consists of three concentric C-shaped resonant scatterers, where the central frequency and the bandwidth of the MSC are tuned by varying the orientation angles of the slits of the scatterers. A multi-objective particle swarm optimisation (MO-PSO) algorithm is developed with multivariate regression for achieving a broadened bandwidth at the targeted frequency. An increase in scatterers' disorientation shifts the band gap (BG) to lower frequencies with increased bandwidth and vice versa. The optimisation algorithm is numerically validated with a mean error of 3.1% for the central frequency and 3.02% for the bandwidth of the first complete band gap. This paper proposes a key approach for tuning the mid to lower frequency and bandwidth of sound attenuation without changing the dimensions of the structure.

Keywords: Sonic Crystal, Noise Control, Particle Swarm Optimisation, Band Gaps.

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16 April 2026

Plenary talk - Wave propagation across time-varying interfaces

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Abstract: The metamaterial field has strongly expanded recently with the introduction of the time variation of the mechanical properties referred to as Space-Time metamaterials and which offers new possibilities for waves control. While research has largely focused on modulated materials with bulk properties dependent on both space and time, we rather focus in this work on time-modulated interfaces. More precisely, we consider wave propagation in a 1D medium containing interfaces whose jump conditions are modulated in time. In the case of a single interface, properties of the scattered waves are investigated theoretically and numerically: energy balance, generation of harmonics, impedance matching and non-reciprocity. In the case of a periodic network, low-frequency homogenization is performed for different regimes of the frequency of modulation. When the frequency of modulation is low or moderate, standard homogenization is applied and ends up with a reciprocal effective model with time-dependent effective coefficients. For time-periodic modulations, the occurrence of gaps in wavenumber is illustrated. In the regime of high-frequency modulation, homogenization with a fast-time scale leads to an effective model with constant effective parameters but with a Willis coupling term breaking reciprocity. Comparisons with time-domain simulations illustrate the findings.

Curriculum vitae: Marie Touboul is a CNRS researcher at the POEMS Laboratory (CNRS–Inria–ENSTA Paris, Institut Polytechnique de Paris). Her work focuses on the mathematical modeling and analysis of wave propagation in complex and structured media. She develops and studies models that describe how waves interact with materials and interfaces, with particular attention to time-domain simulations and multiscale effects. Her recent projects involve high-frequency homogenization, time-modulated systems, and sensitivity analysis in acoustic and elastic settings.

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Non-linear, non-hermitian and topological acoustic/elastic systems

Turning Walls into Sound Routers: A Reconfigurable and Active Time-Reversal Metasurface

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Sound control in noisy or reverberant spaces is crucial for applications ranging from communication to immersive audio, yet existing methods often struggle to deliver sound selectively to specific listeners without interference. We introduce an active acoustic metasurface composed of programmable elements, each functioning as an individual sensing, processing, and emitting unit, that enables precise and adaptive targeting of audio in complex environments. Each unit cell operates as a real-time convolution filter, using prerecorded Green's functions between the emitter, the metasurface, and the receiver to compute temporal filters based on reciprocity and time-reversal symmetry in wave propagation. To evaluate the performance of this reconfigurable metasurface, we conduct experiments with airborne audible sound inside a reverberant room. The active cells, each integrating a microphone, a speaker, and a microcontroller, implement the predesigned filters in real time to shape the acoustic field dynamically. Our results show that this approach can create clear, individualized sound channels while suppressing unwanted noise, even in highly reflective and cluttered environments. This work expands the possibilities for adaptive sound delivery in crowded or dynamic settings, with potential applications in conferencing, entertainment, and assistive listening technologies.

*Speaker

Acoustics with time modulating ultrathin resistive sheet

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This work studies the effect of a time-modulated ultrathin resistive sheet (wiremesh) on the acoustic pressure field. We first examine how the modulation modifies the eigenmodes of a 1D rigid–rigid cavity with a wire mesh at its centre. We then investigate the reflection problem of a wiremesh backed by a rigid wall and show how time modulation can enhance, or diminish, the energy absorbed from an incident wave packet. Finally, we discuss specific configurations that lead to perfect absorption.

Keywords: Time modulation, time crystals, scattering, wiremesh

*Speaker

Time-Domain Robustness of Classical and Detuned Resonator Chains Under Nonlinear Impulsive Excitation

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Waveguides loaded with coupled subwavelength resonators are commonly designed using frequency-domain metrics under linear and steady-state assumptions. However, their behavior under impulsive and high-amplitude excitation-where transient dynamics, waveform distortion, and resonator interactions become significant-remains insufficiently understood, particularly in the time domain. This contribution presents a stepwise modeling study of compact resonator chains subjected to impulsive excitation, bridging classical frequency-domain design concepts and time-domain analysis. Uniform and detuned Helmholtz-type resonator chains are first assessed using conventional transmission-based criteria. The investigation is then extended to time-domain simulations, where impulsive signals are applied to examine pressure evolution, spectral changes, and resonator state dynamics across increasing excitation levels. By progressively enriching the modeling framework, the study identifies which aspects of resonator-chain performance are preserved from frequency-domain expectations and which are sensitive to impulsive loading and nonlinear effects. Particular attention is given to the comparative robustness of detuned configurations and to the modeling assumptions that limit predictive capability in the time domain. The results provide guidance for the analysis and design of resonator-based structures operating in high-intensity and transient acoustic environments, with relevance to emerging metamaterial concepts for military applications.

Keywords: nonlinear acoustics, impulsive excitation, acoustic metamaterials

*Speaker

Scattering properties of rotating metamaterials with effective properties

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In our previous work, (https://doi.org/10.1016/j.jsv.2025.119562), we successfully modelled the impact of rotation on a transformation acoustics invisibility cloak. In this work, we derived a generalised differential equation which can be used to model a rotating, anisotropic, graded, acoustic cylinder. We are now exploring the application of this equation to other kinds of metamaterials with porous and anisotropic properties. Our study takes advantage of the Orbital Angular Momentum (OAM) effects introduced in our equation and boundary conditions. We have derived analytical solutions which show promising effects such as superradiance and superscattering. We are currently in the process of validating these results. Possible applications include stealth and noise reduction by means of tuneable absorption and non-reciprocal propagation.

Keywords: metamaterials, rotation, transformation acoustics, superradiance, time varying

*Speaker

Long-Time Dynamics of Nonlinear Topological Mechanical Lattices

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Our understanding of topological systems has significantly advanced in recent decades (1), but much less is known about their behavior in the nonlinear regime (2-4), from the definition of robust nonlinear topological markers to the understanding of their stability and long-time dynamics. In this study, we consider a nonlinear topological Klein–Gordon lattice, consisting of a one-dimensional chain of nonlinear classical oscillators coupled through alternating springs. This model provides a simple mass-spring description of a broad class of topological systems, including mechanical, LC, and acoustic metamaterials.
We investigate the long-time dynamics of random initial wave excitations in the aforementioned model. By performing extensive numerical simulations and computing dynamical and chaos-related observables associated with the energy distribution, like the entropy and the maximum Lyapunov exponent (5-7), we show that nonlinear dynamics in topological mechanical lattices lead to energy equipartition, characterized by the saturation of these observables at long times. We also demonstrate how topology affects the statistical properties of the equipartition states: in particular, the presence of the band gap and edge modes induces multiple equipartition time scales and a large probability of occurrence of metastable coherent states. Lastly, we show that the nonlinear dispersion of the equipartition states retains symmetries inherited from the topological nature of the lattice. These findings open new perspectives for the control of nonlinear topological metamaterials and the identification of robust nonlinear topological markers.
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Keywords: Topological lattices, nonlinear lattices, energy equipartition, chaos & nonlinear dynamics

*Speaker

Auxetic Higher-Order Topological Insulator with a Tunable Band Gap

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We present a mechanical higher order topological insulator (HOTI) made of four solid squares connected by thin beams, whose behavior is described by a highly general analytical set of equations of motion. The system exhibits quasistatic properties such as tunable auxeticity, as well as a dynamic phononic topological band gap characterized by a nontrivial 2D Zak phase. Analytical predictions, supported by finite-element simulations and experimental measurements, demonstrate robust edge and corner states in a system analogous to the 2D Su-Schrieffer-Hegger model, and the analytical model generalizes to other classes of HOTIs.

Keywords: Mechanical Topological Insulator, Phononic Band Gap, SSH, Auxetic, Tunable

*Speaker

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Amplitude-Dependent Wave Attenuation in Nonlinear Locally Resonant Metamaterials

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Locally resonant linear elastic metamaterials offer powerful capabilities for vibration attenuation, but their performance is often limited by narrow and fixed bandgaps, which are frequency bands where wave propagation is prohibited. A promising avenue to overcome this limitation is the introduction of nonlinear metamaterials. Exploiting nonlinear effects in local resonators can enable amplitude-dependency to achieve bandgap broadening. However, the resulting dynamics are challenging to analyze due to the loss of the superposition principle and cross-coupling between frequencies. In this work, wave propagation in a one-dimensional monoatomic chain equipped with Duffing-type cubic stiffeners is investigated. A multi-harmonic balance formulation is used to compute amplitude-dependent dispersion relations. Unlike traditional linearized or single-harmonic approaches, energy exchange between fundamental and higher-order harmonics is investigated in a non-perturbative manner. The results indicate that dispersion curves exhibit a dependency on wave amplitude. These preliminary findings highlight the potential for periodic metamaterials for amplitude-dependent vibration isolation, where operating frequency ranges are influenced by input energy rather than geometry alone.

Keywords: Nonlinear Metamaterials, Locally Resonant Lattices, Tunable Bandgaps, Wave Propagation, Amplitude Dependence

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Metamaterials for sound insulation

A holistic design framework for Acoustic Metawindows: from simple metamaterial units to sustainable full-scale building integration

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The conflict between acoustic insulation and natural ventilation remains a primary challenge in facade engineering. This research presents the systematic development and multi-domain evaluation of a full-scale Acoustic Metawindow (AMW), designed to provide passive noise control while maintaining high airflow rates. The work establishes a comprehensive framework that spans historical review, unit design, full-scale experimental validation, and environmental impact assessment.
The initial stage of the study involved a structured review of acoustic metamaterials (AMMs) in ventilation ducts from 1928 to 2024. By analysing 54 studies, we identified the physical mechanisms (such as resonant cavities, Fano-interference, and subwavelength membranes) most effective at mitigating low-to-medium-frequency noise. Utilising these insights, a modular AMW unit was developed into a full-scale prototype. The transition from a laboratory prototype to a functional building element was evaluated by assembling a full-scale metawindow and testing it in a laboratory and in situ environment in accordance with international standards. The experimental characterisation followed a multi-disciplinary approach:

- **Acoustic Performance:** The sound reduction index (R) was measured in accordance with ISO 10140. Results indicate that the AMW achieves significant noise reduction, with R values ranging from 13 to 34 dB across the 100–3150 Hz range. To further analyse the system's performance, phased microphone arrays and beamforming techniques were utilised to map sound transmission paths and identify potential leakages.
- **Aerodynamic Performance:** Air permeability and ventilation efficiency were assessed in accordance with ISO 9972. Across a pressure range of 10-80 Pa, the results confirmed that the integrated metamaterial filters do not introduce significant pressure drops, ensuring that the ventilation requirements of residential and commercial spaces are met.
- **Sustainability Assessment:** A cradle-to-gate Life Cycle Assessment (LCA) was conducted in accordance with ISO 14040/44. By analysing the environmental impacts of the materials (PLA and PMMA) and the digital manufacturing processes, we quantified the Global Warming Potential (GWP) and energy demand associated with the AMW's production.

*Speaker

This research demonstrates that integrating metamaterials into building facades is not only technically feasible but also scientifically verifiable across the acoustic, aerodynamic, and environmental domains. The findings provide a rigorous methodological basis for implementing AMM-based solutions in the next generation of sustainable building envelopes, moving the field from theoretical exploration toward industrial application.

Keywords: Acoustic Metawindow, Natural Ventilation, Building Facades, Multidomain Characterisation, Life Cycle Assessment

Study of the wave propagation inside an open phase gradient metamaterial

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In recent years, phase gradient metamaterials have been studied extensively for their ability to steer waves in specific directions. This behavior is governed by the generalized Snell's law, which links these angles to the gradient of the phase of the reflection coefficient along the surface. By following a linear profile for that gradient, the material is able to convert the reflections into surface waves, which leads to their total suppression, hence the potential of the metamaterial to create excellent absorbers. In practice, a phase gradient metamaterial is typically made of a periodic repetition of a number of discrete cells, which contain specific structures to realize the required phase at that point in the period. Recently, some studies were conducted to combine high absorption and high sound transmission loss, which requires phase gradients on both transmission and reflection coefficients. For such structures, the interactions between the cells and the effect of the combination of phase gradients are very complex and not well understood. The purpose of the presentation is to study the physical phenomena happening in this kind of phase gradient metamaterials, focussing in particular on the interactions between neighbouring cells and between the phase gradients on the different transmission and reflection coefficients. These physical insights will provide a better understanding of how phase gradients can be exploited to create materials with both high absorption and high sound transmission loss.

Keywords: phase gradient metamaterial, sound absorption, sound insulation

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Exploring the influence of chirality in the band gap formation of 3D metamaterials

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Mechanical metamaterials derive their unusual static and dynamic properties from carefully designed periodic microstructures rather than from their base material alone. Among these, chiral metamaterials - structures with only orientation-preserving symmetry operations - exhibit unique deformation and wave propagation characteristics such as stretch–twist coupling, polarization effects, and symmetry-induced band gaps. In this work, we investigate how chirality can be exploited to manipulate band-gap formation in mechanical metamaterials. Building on concepts from crystallographic symmetry and chiral space groups, we analyze the role of the unit-cell by obtaining the dispersion diagrams of several chiral geometries. In particular, a 3D unit cell composed of disks and beams is utilized as the instrument to obtain meta-atoms with well defined space groups and a parametrized geometry. By systematically altering the structure, we can deduce to what degree the underlying geometry and unit cell symmetry play a role. The results highlight how controlling symmetry at the microstructural level can guide the design of new geometries for wave manipulation and tunable band gaps, offering new pathways for vibration isolation, energy localization, and advanced mechanical wave control in next-generation metamaterials.

Keywords: Chiral, metamaterial, band gap

*Speaker

Vibration reduction on an automotive power electronic unit using a locally resonant metamaterial solution: predictive methodology and validation

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In recent years, Locally Resonant Metamaterials (LRMs) have gained significant attention due to their ability to reduce vibrational loads on structures within specific frequency ranges known as stop bands. This reduction is achieved by adding appropriately tuned resonators to the host structure, resulting in enhanced Noise, Vibration, and Harshness (NVH) attenuation. LRM solutions offer high design freedom, allowing the use of various materials and manufacturing technologies, making them attractive for implementation in diverse industrial contexts. LRMs are often modeled as infinite, periodic systems using a unit cell (UC) approach. This technique, combined with finite element (FE) modeling, enables robust prediction of LRM solutions when a sufficiently dense grid of resonators is applied. However, in many industrial applications, this is not feasible. Constraints such as limited mass addition restrict the number of usable resonators, and design limitations reduce the number of exploitable locations, resulting in a non-dense grid of resonators. Additionally, accurate dynamic models of the host component are often unavailable, necessitating the integration of experimental data into simulations. This research presents an alternative modeling technique to predict the behavior of LRMs when a non-dense grid of resonators is used. The study focuses on an automotive power electronic unit (PEU) treated with LRM, aiming to reduce the vibrational load on the printed circuit board (PCB) where many sensors are soldered. An excessive vibrational load can break sensor connections, leading to functional failure and loss of PEU functionality. Due to design constraints, direct implementation of the LRM solution on the PCB is unfeasible. Instead, the spider frame, an aluminum cast component to which the PCB is fixed, is used. The frame's geometry does not allow for a dense grid of resonators. Therefore, a modeling technique is proposed that combines experimental transfer functions from the PEU with the numerical model of resonators, using frequency-based substructuring to predict the effect of the LRM solution on the component. The LRM solution is fabricated, and the predictive methodology is validated through modal testing on the PEU first resonance mode. Further experimental validation is conducted using a shaker to mimic operating conditions, applying multiple LRM configurations specifically tuned to PEU resonances. The results demonstrate that the predictive methodology leads to robust predictions and that the LRM solutions can effectively reduce vibrational loads in such applications.

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Keywords: Locally Resonant Metamaterials, Tuned Vibration Absorbers, Reliability, Printed Circuit Board, E, mobility

17 April 2026

Plenary talk - Loss-compensated non-reciprocal wave scattering with synchronized self-oscillators

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Abstract: Non-reciprocal wave transmission through linear resonant cavities exhibiting broken time-reversal symmetry is usually impeded by losses. To avoid the attenuation of the transmitted waves, and even to amplify them, one can equip the resonant cavities with saturable gain. This nonlinear gain turns them into self-oscillators, which can be synchronized by the incident waves. When the conditions for synchronization are met, the interferences between the scattered field and the synchronized radiation from the self-oscillating cavities can result in non-reciprocal wave scattering without net power losses. This nondispersive concept does not require actuators and active sensing of the incident field. It is simply based on the adjustment of the cavity gain. A nonlinear extension of the temporal coupled-mode theory is derived to model this synchronization-based concept of loss-compensated non-reciprocal scattering, and it is experimentally validated with acoustic diodes and circulators.

Curriculum vitae: Nicolas Noiray is Associate Professor at ETH Zürich, where he established the laboratory of Combustion, Acoustics & Flow Physics (CAPS) in 2014. He obtained his Ph.D. from the Ecole Centrale Paris in 2007, and then worked in the Gas Turbine Research Division of Alstom until his appointment at ETH. His theoretical, experimental and computational research activities in the fields of Combustion, Acoustics and Fluid Mechanics address fundamental and applied problems. He was awarded a Consolidator Grant and a Synergy Grant by the European Research Council. A key theme of the research performed by his group is the modeling and control of instabilities at various time and length scales.

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Metamaterials for sound insulation

Multi-material 3-d printing of customizable membrane-type acoustic metamaterials

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Achieving sound attenuation through lightweight structures challenges the conventional mass–frequency law due to advancements in acoustic metamaterials. Among these, membrane-type acoustic materials have attracted significant interest owing to their simple construction and ultra-thin design. The sound manipulation performance of membrane-type unit cells is realized through the incorporation of an attached mass-specifically by adjusting its magnitude and distribution on the membrane, as well as by modifying the membrane's pre-stress. Altering one or both parameters enables shifting of the frequencies at which maximum and minimum sound transmission occur. However, the widespread application of membrane-type acoustic metamaterials is limited by uncertainties arising from their fabrication processes. This limitation primarily stems from the high sensitivity of the structure's vibro-acoustic response to the positioning of the attached mass and to the magnitude of the membrane pre-stress. These issues can be addressed through the implementation of a consistent manufacturing process and a controlled method for applying membrane pre-stress. Utilizing the broad material selection offered by the fused deposition modeling (FDM) method, membranes can be fabricated from flexible materials, while the attached masses and frame components can be produced from relatively rigid materials-all within a single-step multi-material 3D printing process. In this study, as a first step, various unit cell designs are analyzed using finite element analysis to demonstrate configurability through modifications in the geometry of the attached mass-while maintaining its magnitude constant-and through systematic variations in membrane pre-stress. Subsequently, the metamaterial unit cell samples are fabricated using multi-material 3D printing. Sound transmission loss measurements are performed on the fabricated unit cells using an impedance tube, and the results are compared with numerical simulations. The resulting effects on the vibrational characteristic to the acoustic performance i.e. resonance and anti-resonance modal behaviors to the sound attenuation performance, of the unit cells are then analyzed and presented. Furthermore, impedance-tube-scale multi-celled arrays are designed such that each unit cell contains the same attached mass, while the membranes are subjected to different pre-stress magnitudes. The metamaterial arrays are then fabricated and analyzed using the same approaches. This configuration is used to explore sound manipulation performance through pre-stress adjustment, targeting multi-tonal noise attenuation. Finally, the effectiveness achieved through modifications in mass geometry and membrane pre-stress is discussed for both single unit cells and multi-celled arrays.

Keywords: Acoustic Metamaterials, 3D Printing, Sound Attenuation

*Speaker

Auralisation of sound transmission through a vibro-acoustic metamaterial

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Acoustic metamaterials offer highly tuneable sound insulation that can greatly exceed the performance of conventional treatments. Vibro-acoustic metamaterials (VAMMs) are a type of acoustic metamaterial that can enhance low-frequency sound attenuation using mechanical resonators distributed on a host plate structure. Due to their resonant behaviour, VAMMs may introduce audible characteristics which are not fully described by traditional objective measures. Auralisation therefore presents a valuable tool for exploring these effects and for supporting the practical design of VAMM-based noise control technologies. However, generating auralisations for metamaterials presents challenges. Analytical models such as the Effective Medium Method may provide efficient approximations but can be inaccurate for more complex noise treatment structures. Frequency-domain numerical methods like the Finite Element Method can address this limitation, but introduce computational expense and potential numerical artifacts. This paper compares both approaches, using inverse Fourier transforms to obtain impulse responses from complex pressure data for a range of VAMM designs, and subsequently convolving these responses with representative source signals. The results show that analytical and numerical models can be applied to the auralisation of VAMMs under specific scenarios. Auralised examples using broadband and multi-tonal signals are presented to illustrate the differences between the methods.

Keywords: Vibro, acoustic metamaterial, VAMM, FEM, Finite Element, effective medium method, EMM, analytical method, auralisation, inverse fourier transform, convolution, audible, subjective, objective, perception, sound

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Resonant acoustic metamaterials for broadband sound transmission loss enhancement and cavity depth minimization in double walls

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Resonant acoustic metamaterials (AMM) employ subwavelength Helmholtz resonators (HRs) to achieve stopbands, i.e. frequency bands in which the propagation of free traveling acoustic waves is suppressed. Thanks to these properties, AMMs are a promising solution to enhance sound transmission loss (STL) in acoustic partitions, such as double walls, in particular frequency bands. Conventional double walls typically require relatively deep intermediate cavities to perform well and suffer from detrimental mass-spring-mass resonance effects at low frequencies. Previous studies have demonstrated that these resonances can be suppressed by HRs embedded in the intermediate cavity and adequately tuned. However, the STL peak introduced by HRs is typically followed by a decrease in performance at higher frequencies, leading to important trade-off effects between suppressing mass-spring-mass resonances, pushing the STL decrease towards frequencies where performance is already sufficiently high, and minimizing the cavity depth. For this reason, the design of AMMs for practically relevant cases, where the overall STL in a wide spectrum is important, is not straightforward. In this work, these challenges are tackled by developing an efficient framework to model and optimize the broadband STL of double walls with embedded HRs. Sound transmission through the double wall is predicted using a transfer matrix model (TMM), in which the cavity embedding HRs is modelled through effective homogenized properties. The HR design task is then addressed by formulating an optimization problem that minimizes cavity depth while enforcing a minimum required broadband STL, quantified through a standardized single-number rating (SNR). The methodology is applied to the case study of a double wall made of two gypsum boards separated by an air cavity, showing that embedding HRs enables reducing the cavity depth significantly while satisfying practical SNR requirements. The obtained design is validated through detailed numerical analysis. The results of the work open the way towards the experimental realization of compact and well-insulating double walls embedding HRs, for practically relevant cases.

Keywords: Double walls, Helmholtz resonators, Broadband sound insulation, Cavity depth minimization

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A study on the low-frequency vibroacoustic behavior of membranes with added strip masses using a finite element model

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Low-frequency noise adversely affects the physiological and psychological health of humans. Controlling low-frequency noise is challenging as it can travel large distances through walls and structures without significant attenuation. Noise control strategies use physical barriers in the sound transmission path. Such barriers obey the mass law. The mass law is a prediction scheme for noise control that inversely relates sound transmission through a barrier to the barrier mass and the incident frequency. This implies that the same barrier is less effective at lower frequencies and must be very thick to achieve significant attenuation of low-frequency sound. Such barriers are impractical for most real-world applications. In contrast, membranes with added mass are thin, lightweight, pretensioned elastic structures that can defy the mass law. Discrete masses added to the membrane surface can modify the membrane's dynamic response and provide greater passive sound insulation across broader low-frequency bands. Current research efforts aim to further broaden the attenuation bandwidth and optimize the frequency ranges over which it occurs. The geometry of the added masses affects the membrane's dynamic response. Strip masses exhibit significantly higher mass moment of inertia in one direction, making them more resistant to rotational motion about that axis, and can suppress certain vibrational modes while enhancing others. The present work develops a fully coupled finite element model of a membrane with various configurations of added strip masses to analyze its vibroacoustic behavior under normal incidence. The finite element model is developed using COMSOL Multiphysics 6.4, incorporating both the acoustics and structural mechanics modules. The acoustic domain boundaries are made sound-hard, and the area downstream of the specimen is terminated with a perfectly matched layer to simulate a non-reflecting end condition. Plane-wave radiation generates an incident plane wave upstream of the specimen. The sound transmission loss is computed for different configurations of strip masses comprising one, two, three, or all four arms of a cross, with the arm width varied for each configuration to maintain a constant total mass. The asymmetric arrangement of the strip masses introduces additional anti-resonance bands compared to the geometrically symmetric arrangement. The arrangement of the strip masses alters the membrane stiffness and is an additional design parameter to optimize the sound attenuation bands as per the requirements.

Keywords: Membrane type acoustic metamaterial, acoustic metamaterial, sound insulation, locally resonant material

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Suppression of vibration transmission across junctions between thin plates using metamaterial strips

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Many engineering structures encountered in the construction, automotive, aerospace, and industrial machinery sectors consist of assemblies of plates that meet at a junction. Suppressing vibration transmission across such junctions is challenging, especially when the plates meet at an oblique angle, because conversion occurs between bending, shear, and longitudinal wave types. Conventional approaches to reduce vibration transmission in these systems include structural decoupling or the addition of localized mass or damping. However, these solutions often increase structural complexity, cost, and material use, and are furthermore little effective at low frequencies. In this work, a compact, lightweight solution for the suppression of wave transmission across junctions is explored using resonant metamaterials, by means of a narrow strip of sub-wavelength resonators introduced along the junction line. To investigate this concept, we first develop a wave-based analytical model, which describes the connection between semi-infinite thin plates through equilibrium and continuity conditions, and incorporates the metamaterial treatment as a strip with homogenized effective properties. This framework enables evaluating all transmission and reflection coefficients between incoming and outgoing wave types, which are then used in an energy-based model to evaluate the exchange of energy between the different wave types in finite-sized systems. To validate the predicted level of attenuation introduced by the metamaterial strip, vibration transmission experiments are conducted on an assembly of two aluminum plates, considering different widths of the strip and different angles between the two plates. The results show good agreement between model and experiment, demonstrating that a significant reduction in wave transmission is introduced around the local resonance frequency.

Keywords: wave based analysis, locally resonant metamaterials, effective medium theory, vibration transmission

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Sonic Crystal Noise Barrier Design and Validation

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Rapid urban growth has increased the demand for new transportation projects, leading to higher noise levels in cities. Noise barriers are the most common treatment for mitigating this problem, but conventional designs are often unsuitable for urban environments due to their size and aesthetic limitations. Acoustic metamaterials offer a romising alternative. This study proposes a novel design of a sonic crystal unit cell that integrates multiple mechanisms to achieve broadband frequency attenuation. The design was numerically modeled to evaluate both the absorbing material used for the scatterers and the embedded Helmholtz resonators. Following the initial predictions, the concept was experimentally validated using a custom- built test tube inspired by the EN 1793-6 standard. Results show a marked improvement in insertion loss compared with an equivalent rigid configuration, with enhanced performance before and after the band gap.

Keywords: Sound insulation

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Numerical methods

Numerical Modeling of Nonlinear Sound Propagation in Bubbly Viscoelastic Acoustic Metamaterials

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A small amount of gas bubbles induces significant frequency-dependent variations in sound speed, nonlinear effects, and attenuation. This property allows the manipulation of acoustic signals through bubble populations, which can be introduced into a medium via gas injection or contrast agent microbubbles. The ability to control sound with oscillating bubbles underlies the concept of bubbly-liquid-based acoustic metamaterials (BLAMMs). One of the main challenges is achieving uniform bubble size and stability, which can be addressed by using viscoelastic media instead of liquids. In this work, a two-dimensional numerical model is developed to evaluate the nonlinear interaction of monodisperse bubble populations confined in restricted regions, coupling the acoustic wave equation with a modified Rayleigh–Plesset equation for bubble dynamics formulated in terms of volume variation and incorporating a linear Kelvin–Voigt viscoelastic model. The governing equations are solved using finite-difference methods in time and finite-volume techniques in space, with potential future extensions to finite element methods. Numerical experiments explore acoustic shielding and resonance effects induced by bubble layers, analyzing the influence of bubble density, size, layer position, and interlayer spacing on nonlinear wave propagation. The role of viscoelasticity is also investigated. The results demonstrate the potential of bubbles to manipulate sound in targeted frequency ranges, providing a versatile tool for designing nonlinear acoustic systems and guiding the development of bubbly elastic structures as practical acoustic metamaterials for industrial, and biomedical applications.

Keywords: Nonlinear acoustics, Ultrasonic waves, Bubbly layers, Numerical simulations, Viscoelastic media

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Deep learning-based inverse design of tolopogical interface and corner states in two-dimensional phononic crystals

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Topological phononic crystals exhibit remarkable capabilities for manipulating elastic and acoustic waves through band gaps and topological states. In higher-order topological phononic crystals, topological interface and corner states enable robust wave localization and propagation that are largely immune to defects and disorder. However, owing to the high-dimensional design space and the complexity of the topological properties in two-dimensional phononic crystals, the direct prediction and inverse design of their band gap boundaries and topological state frequencies remain extremely challenging. In this work, deep learning approaches are used for the design of two-dimensional phononic crystals with high design freedoms. The considered two-dimensional phononic crystals are composed of unit cells made of 32 × 32 pixels in which either an acoustically rigid material or air paying the role of background medium are placed. First, the variational autoencoder is applied to reduce the dimensionality of unit cell images, allowing accurate reconstruction of images with different spatial distribution of rigid material. Subsequently, the multilayer perceptron and the tandem neural network are used to realize the property prediction and customized design of two-dimensional phononic crystals, respectively. The correlation coefficients for the property prediction and inverse design are more than 97%. The unit cell images of two-dimensional phononic crystals with specific band gap properties could be successfully and instantaneously designed. Furthermore, phononic crystals with prescribed topological interface state and corner state frequencies are realized. Importantly, a "one-to-many" design strategy is achieved for the inverse design of all target properties. This study demonstrates the broad application prospects of deep learning approaches in the field of phononic crystal design and provides new ideas and methods for the intelligent design of artificially functional materials.

Keywords: Phononic crystal, Topological states, Deep learning, Inverse design

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WFEM-based assessment of the robustness of finite metamaterial vibration isolation under varying, realistic load cases

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Dispersion analysis is commonly employed to study wave propagation in periodic media. Frequency ranges of improved vibration attenuation can then be identified by observing so-called bandgaps. However, this method assumes a structure of infinite extent, thus neglecting the effect of boundary conditions and loading on the practical vibration isolation efficiency. Moreover, in elastic metamaterials the bandgaps are often partial, meaning that they are only present for one particular wave type. A structure could effectively block longitudinal waves but guide flexural waves, and vice versa. Modelling the finite size structure is therefore required to assess the vibration efficiency of the metamaterial solution in a realistic setting. This can be computationally expensive due to the size and the geometrical complexity of the full system. In this work, unit cell analysis using the Wave Finite Element Method is performed to compute both the dispersion and the forced response of finite size metamaterial solutions under different load cases. After computing the dispersion relations, the wave amplitudes, and thus the contribution of each wave type to the forced response, are studied. Therefore, this method enables us to investigate the dependence of various wave contributions on the loading conditions of the finite structure. The robustness of vibration attenuation within partial bandgaps, is studied by evaluating the forced response of the finite structure, especially in excitation cases where wave mode conversion is observed. Two examples are presented, showing the practical use of the method for one-dimensional wave propagation. First, the robustness of partial bandgaps is discussed in the simple case of off-axial excitations for a beam with periodically varying thickness. Secondly, the identification of attenuation ranges in complex, multi-wave dispersion curves is detailed using the example of a kirigami-inspired metamaterial.

Keywords: WFEM, unit cell analysis, forced response, mode contribution

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Mechanical Metamaterials for Modulating Turbulent Flow Dynamics

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Flow-induced vibrations (FIV) pose significant challenges in the high-tech industry, particularly in semiconductor manufacturing and electron microscopy. Conventional mitigation methods are often characterized by narrow-bandedness, high technical complexity, or weak efficacy. While recent work has shown that subsurface mechanical metamaterials can delay the laminar-to-turbulent transition via interference with Tollmien-Schlichting waves, their efficacy in fully developed or complex flows remains unexplored. In this work, we investigate the coupling between localized subsurface metamaterials and coherent turbulent structures in non-canonical flows. Through coupled fluid-structure interaction simulations, we analyze how subsurface properties modify the dynamics of the bulk flow. Our results characterize the interaction between the mechanical metamaterial and turbulent flow structures, identifying the conditions under which passive subsurface modulation can influence flow-induced vibrations.

Keywords: Mechanical metamaterials, flow induced vibrations, fluid structure interaction, passive flow control

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Characterizing and Quantifying the Impact of Production Uncertainties on the Dynamic Response of a series of Metamaterial beams

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Metamaterials have attracted increasing industrial interest in recent years thanks to their strong, tunable vibration control capabilities. Although promising results have already been obtained in literature, the challenge of manufacturing uncertainties and their impact on the dynamics of metamaterials remains to be addressed. In this presentation, a novel framework is proposed for the evaluation of the vibration attenuation performance of metamaterial structures under the influence of manufacturing uncertainties. A dedicated parametric Model-Order Reduction (pMOR) scheme is developed to measure the impact of material and geometric uncertainties on the ensemble of response of the series. To validate this procedure, a small series of 3d printed metamaterial beams is produced. The geometric and mechanical properties of the structures are directly measured to evaluate the input parameter distributions for numerical simulations. Then, the dynamic response statistics of the series of beams is evaluated experimentally and compared to the numerical simulations.

Keywords: Vibro, Acoustic Metamaterials, Uncertainty Quantification, Reduced, order Modeling

*Speaker

Monolithic inertial metamaterial for vibration absorption

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The implementation of compact, high-power density solutions for simultaneous attenuation of elastic waves and energy harvesting of low-frequency elastic waves remains a central challenge. The use of locally resonant metamaterials has furthered progress, and non-local coupling schemes have become increasingly adopted for broadband frequency response. Cantilever-based resonators with tip masses have been shown to generate low frequency bandgaps through cantilever bending modes; however, such designs often require a large primary host structure and exhibit directional sensitivity to in-plane and out-of-plane waves. This work proposes a monolithic cantilever-based plate metamaterial with plane symmetry that combines the dynamic response of a large primary plate and cantilever. The irreducible Brillouin zone is studied numerically using the Floquet-Bloch theorem. Then, the way the monolithic design promotes hybridisation of Bragg scattering in the periodic array and local resonance of the cantilevers is discussed, leading to the formation of degenerate bands where multiple modes merge and veer away into zero velocity groups, ideal for piezoelectric energy harvesting. Tuned for a bandgap in the tens to hundreds of Hz, the proposed design is also desirable for low-frequency vibration energy trapping. The merits of the monolithic design are characterised by its suitability for mass manufacturing and reduction in assembly steps; these are compared to other metamaterial solutions for simultaneous vibration attenuation and energy harvesting.

Keywords: Vibration absorption, Finite element modelling, Locally resonant, Piezoelectric energy harvesting

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