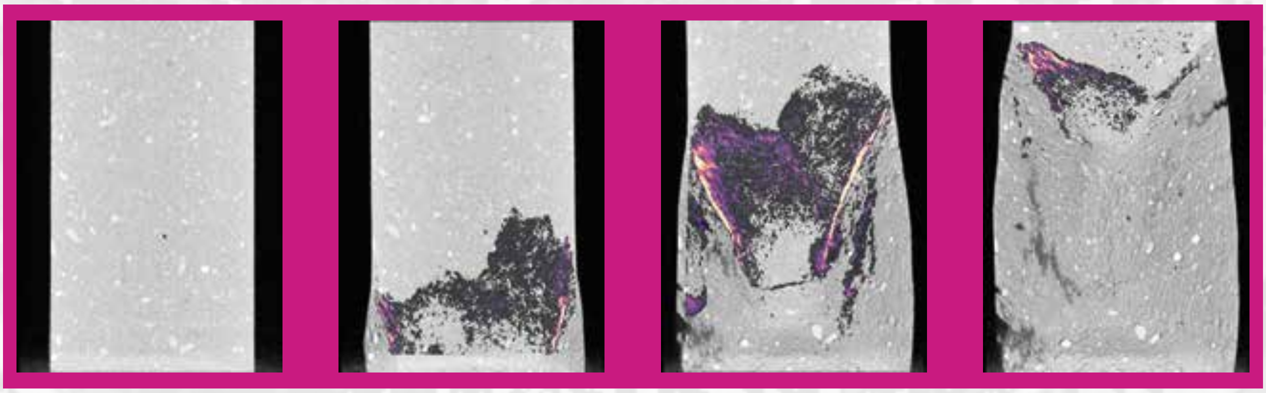
Scientific Highlights 2025



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EDITO

HIGHLIGHTS 2025
Laboratoire 3SR

February 2025
Grenoble, France

The 3SR laboratory is a Joint Research Unit (UMR 5521) between Université Grenoble Alpes, CNRS and Grenoble INP - UGA Institute of Engineering and Management. With a staff of around 110, 3SR conducts cutting-edge research on the mechanics of solids, materials and structures, for a wide range of applications (civil engineering, environment, energy, transport, defense, health). To this end, its researchers develop a multi-scale approach (to investigate phenomena ranging from quasi-static to ultra-fast across scales from nm to decam) and a multi-physics methodology combining experimental mechanics (including materials or structures coupled with 2D/3D imaging, field measurements, etc.) as well as theoretical and numerical modeling (homogenization, constitutive laws, simulations of nano/micro/meso/macro structures using finite elements, finite volumes, discrete elements, molecular dynamics, probabilistic methods, etc.).

2024 was an eventful year for 3SR, with a new management team in place as of January 1, 2024; the appointment of one of its members to the IUF, and the award of two prestigious prizes to the laboratory for its groundbreaking work on in operando scientific imaging using X-rays and neutrons (Cristal collectif CNRS and Prix du logiciel opensource).

The 3SR's lab. management is delighted to present the first in a new series of annual collection of highlights of our research through 8 research initiatives that illustrate some of the laboratory's research activities for the year 2024.

Our warmest thanks to Mehdi BOUZID, the editor of this inaugural issue of our highlights, and we hope you enjoy reading it.

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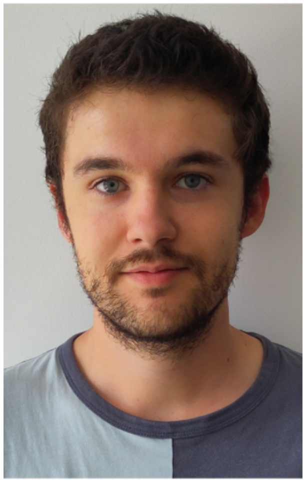
EVENTS

This year, five new staff members have joined the 3SR Laboratory. We are delighted to welcome them!

ELODIE DONVAL: Elodie joined the 3SR laboratory and the RV team in January 2026 as a CNRS research fellow. Her research focuses on the development of numerical multiscale methods, with the aim of better understanding the hydromechanical behavior of raw earth, from the material to the structure scale.

JEAN-BAPTISTE CHARRIÉ :Associate Professor at the PhiTEM department. He joined the RV team, and his research activities focus on the vulnerability analysis of civil engineering structures. The objective is to develop a multi-scale numerical and experimental approach, ranging from high-rate dynamics at the material scale (impact, blast) to the global response of structures under accidental loading (earthquake, loss of load-bearing capacity).

ADRIEN DIDIER :Recruited in 2025 as an Associate Professor at the University Institute of Technology (IUT) in Civil Engineering – Sustainable Construction (GCCD). His experimental research focuses on the relationships between microstructures and mechanical properties, with a particular interest in bio-based materials, notably delignified and densified wood.



AXEL JEHLE: Holder of a Diploma of College Studies (DCS) in Civil Engineering Technology obtained in Québec in 2024 (equivalent to a *BUT* degree in France). This year, he joined the laboratory as a technician within the technical unit.
His two main responsibilities are assisting with experimental work and its implementation, as well as managing a new sample preparation service in collaboration with members of the technical unit.

NICOLAS MARTIN: CNRS Research Engineer. He will join the 3SR laboratory in September 2025 after more than 15 years working in the field of neutron scattering. His work focuses on the installation and commissioning of the multi-scale tomograph developed within the framework of the CDP MuSiTox project. He also collaborates with the Rheology and Processes Laboratory, where he is responsible for operating the future SAXS/WAXS platform. Both facilities are located in the Galilée building and are made available to the scientific community.

Pierre Piault : CNRS Research Engineer. He will join the 3SR laboratory in September 2025 after more than 15 years working in the field of neutron scattering. His work focuses on the installation and commissioning of the multi-scale tomograph developed within the framework of the CDP MuSiTox project. He also collaborates with the Rheology and Processes Laboratory, where he is responsible for operating the future SAXS/WAXS platform. Both facilities are located in the Galilée building and are made available to the scientific community.

Bamboo Fibres in Biomaterial Design: A Promising Path

Natural composites are increasingly valued for their low density, mechanical strength, and sustainability. Bamboo fibres, with their exceptional tensile strength and rapid growth, outperform many traditional plant fibres. Recent research in 3SR-Lab focuses on optimizing bamboo part selection, harvesting techniques, and fibre extraction processes. These innovations aim to unlock bamboo's full potential in designing high-performance, eco-friendly biomaterials for diverse industrial applications.

In recent years, natural composite materials have garnered growing interest for their unique combination of low density, exceptional mechanical properties, and environmental sustainability. Among the diverse range of natural fibres, bamboo fibres stand out due to their remarkable tensile strength and rapid growth—outpacing many traditional woody plants. Through ongoing collaboration between Chiang Mai University in Thaïland, researchers from 3SR-Lab and LGP2 in Grenoble have increasingly focused on optimizing key aspects of bamboo fibre utilization, including the selection of bamboo parts for harvesting, as well as the development of advanced treatments and extraction processes to fully harness their potential,. These efforts aim to enhance the performance and versatility of bamboo fibres in the design of innovative biomaterials.

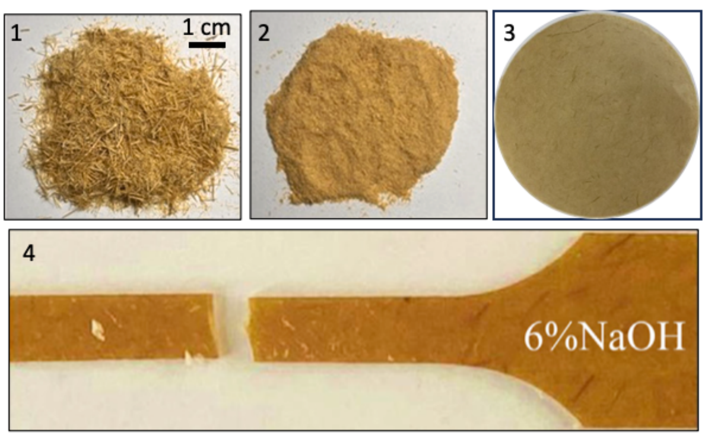


Figure: 1 and 2: Extracted fibres with different level of grinding, 3: Hand sheet of bamboo paper, 4: tensile test on a sample of hand sheet/green epoxy composite.

More specifically, this study focused of Dendrocalamus Sericeus Bamboo from the north of Thailand. It showed that the most mechanically interesting fibres were found in 3-year-old subjects in the middle part of the stem, focusing the analysis on cellulose and lignin content and their influence on the tensile strength of the fibre bundles. In addition, with a view to proposing an optimal method for extracting bamboo fibres, we examined the effect of different alkaline solutions (KOH, NaOH, and ash), their varying concentrations, and immersion time on the tensile strength of bamboo fibre bundles. An optimal immersion time of 48 hours was thus determined for KOH and NaOH solutions at a concentration of 5%.

Once these parameters were determined, the fibres obtained were used to produce various materials: bamboo paper, composites with bamboo paper and green epoxy by a vacuum-injection technique, bulk material obtained by compaction of bundles of fibres (mechanical or ultrasonic compaction). These first attempts to design new biosourced materials demonstrated the feasibility of manufacturing these eco-friendly materials and showed that their properties were comparable to those of traditional reference composites. This research was conducted in particular through two PhD theses by Jerachard Kaima and Panidpim Sawangbunditkun, both funded by the National Research Council of Thailand. New studies are currently underway to further this approach, notably through an ANR project on the manufacture of sanitary napkins (ANR NAPKINS).

Further reading:

Kaima, J. et al. Materials Science Forum, 1067, (2022), 113-118.

Kaima, J. et al. Results in Engineering, 18 (2023) 101186

Sawangbunditkun, P. et al. Results in Engineering, 28 (2025) 107994

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Nils

Cold compaction of powders is a manufacturing process which concerns a wide range of applications from pharmaceutical tablets to high-stength structural parts. One of the most difficult problems can be found in the prediction of compact failure which occur during the forming process. Our work aims at better understanding such failure phenomena through the implementation of a multi-scale analysis based on numerical simulations.

During the densification of cold-compacted ductile powders, interparticle adhesion develops, building up the mechanical strength of the manufactured parts. One of the main challenges of this process is the occasional occurence of failure during densification, which lead to the rejection of manufactured parts. Despite widespread recognition of this problem, few studies in the literature focus on the micro-mechanical understanding of these failure phenomena within this type of material in the case of highly deformable particles. Currently, there is no numerical model capable of predicting the formation of such defects. Only time-consuming trial-and-error procedures efficiently mitigate them, and the role of particle adhesion and deformability in failure phenomena remains poorly understood. Here, this problem is investigated based on a numerical approach in which an idealized granular medium is analysed using a multi-scale numerical simulation approach. Particles are meshed in 3D and their deformations are fully accounted for using the finite-element method and via constitutive laws based on continuum mechanics. The interactions between particle surfaces are handled using finite-element contact formulations. Mesoscopic mechanical properties associated with an equivalent Cauchy volume element are derived from the simulation of a relatively small number of particles, through homogenization techniques and formulation of appropriate boundary conditions. A study analysing the effect of boundary conditions on the simulated mechanical response of a numerical granular sample subjected to quasi-static loading is thus proposed [1]. Such a micro-mechanical approach requires an accurate description of contact interactions since the mechanical strength of powder compacts is to a large part determined by the development of adhesion at the contact level. A multi-scale adhesive contact model including the effect of surface roughness, is proposed and implemented. This contact model predicts, at each node of the finite element mesh, the level of adhesion developed by external mechanical loads [2]. The numerical model is finally used to analyse mesoscopic properties associated with the equivalent Cauchy volume element. This numerical model enables the exploration of highly deviatoric loading paths that are inaccessible experimentally. Its purpose is to support the future development of continuum mechanics-based model for the modeling of a powder volume during compression [3].

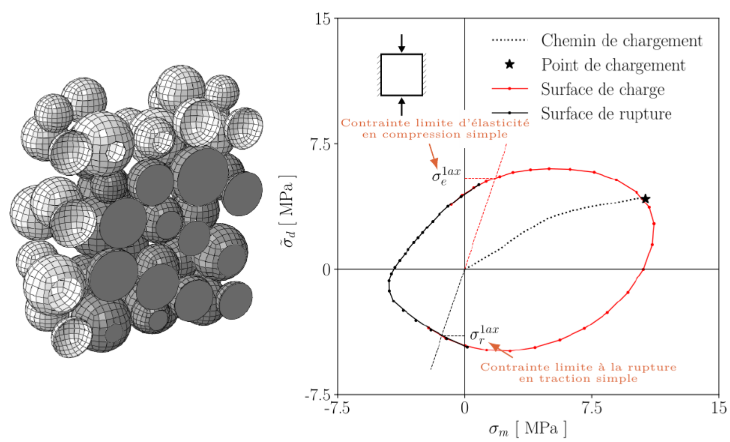

Figure: Schematic representation of the project.

Further reading:
[1] Audry et al. Powder Technology 429 (2023):118871.
[2] Audry et al. International Journal of Solids and Structures 295 (2024): 112826.
[3] Audry et al. Journal of the Mechanics and Physics of Solids 192 (2024): 105807.

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GENIUS: Doctoral Network on Energy Geostructures Integration: Buildings, Infrastructure and Underground Storage

GENIUS, coordinated by the University of Edinburg and funded by the Horizon Europe MSCA, is a doctoral network of 15 PhD thesis among which 2 will be based at the Laboratoire 3SR (UGA) and 3 others will see it involved. The project aims to develop the innovative technology of energy geostructures to drive the shift toward renewable heating and cooling, while training the doctoral candidates to become the leaders in conceptualization, design and implementation of energy geostructure applications.

GENIUS pioneers a comprehensive approach to address the biggest global challenge the energy sector is facing: the transition to renewable-based, energy-efficient heating and cooling systems. Space heating and cooling currently makes up the world's largest energy sector, accounting for approximately 50% of the final energy consumption. This figure is expected to grow rapidly over the coming decades due to economic and population growth, and inevitable increase in urbanisation. At the same time, the world is experiencing one of the most severe global energy crises in history, impacting the fossil fuels' availability and cost. More than ever, there is an urgent need for innovative technologies to harvest renewable energy resources, to decrease our dependence on fossil fuels.

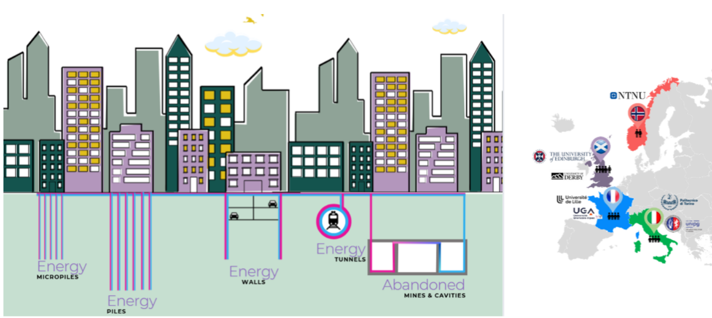

Figure: Schematic of the project)

Energy Geostructures (EGs) represent an effective means to meet the world request of less dependence on unsustainable resources by being designed as dual-purpose elements targeting geothermal heat exchange and structural support for buildings. Yet, their wider use has been hindered by the lack of (i) sustainable expertise pipeline in the field of energy geotechnology, (ii) technical knowledge regarding the integration of energy geostructures to buildings and infrastructure, (iii) scientific knowledge for the integration of energy geostructures with other underground structures. GENIUS will address all three challenges by developing advanced analysis and design tools for energy geostructures (WP-1) and by advancing practical and scientific knowledge for their integration with buildings, infrastructure and other energy resources (WP-2 and WP-3).

Furthermore, the holistic approach of GENIUS will train the 15 Doctoral Candidates to become pioneering experts in conceptualization, design and implementation of energy geostructure applications. Networking with their peers, industry and stakeholders will give them highly attractive skills for transforming their ideas to implementation. An inter-disciplinary, inter-sectoral, and an international consortium of 7 academic beneficiaries and 14 non-academic associate partners is formed to deliver these research objectives. Two PhD candidates among the 15 will be based at the Laboratoire 3SR and will work on the "Use of machine learning tools for estimating EGs performance" and "Energy tunnels to reduce the costs of ventilation in tunnels", under the supervision of Alice Di Donna.
The Laboratoire 3SR will also be involved in 3 other thesis on the soil-geostructure interface, integration of this technology in the district heating systems and use of the technology for road de-icing.

Further reading:
GENIUS website

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SPAM Workshop 2025: Building open-source quantitative imaging community in materials science in Dresden

SPAM workshops are organised each year and aim at bringing support to the software users, while building up a community for open-source tools in quantitative image analysis. The format consists in a four-day event, where participants have the opportunity to bring and analyse their own data with the help of the SPAM core development team. In 2025, the workshop was held in Gohrisch, in the heart of the Saxon Switzerland National Park near Dresden (Germany) supervised by O. Stamati and E. Roubin from 3SR, Edward Andò from EPFL, Gustavo Pinzon from ESRF and Max Wiebicke from the TU of Braunschweig.

The SPAM (Software for Practical Analysis of Materials) project held its third edition of its annual workshops in Dresden, Germany, from November 9th to 13th, 2025 bringing together the SPAM core developers and 20 users from all over Europe. SPAM is now a well-established open-source software for quantitative data analysis of 2D/3D images in mechanics applications featuring a powerful suite of tools for morphological analysis and Digital Volume Correlation (DVC). It recently received further recognition with the 2024 Open Source Software for Research prize from the French Ministry of Higher Education and Research, reflecting its commitment to accessible, well-documented tools useful to the scientific community.

Figure: Picture of the meeting.

What makes SPAM workshops unique is their hands-on, practical approach. A constraint number of participants come with their own research data trying to address specific scientific questions in various research fields. In addition to lectures on generic examples, attendees work directly on their actual datasets whether that involves image registration challenges, specific quantification problems or customised analysis workflows. SPAM developers are there to help troubleshoot and suggest approaches based on real needs. The workshop schedule balances intensive working sessions with outdoor activities. These breaks aren't just for fun—they've proven to be great opportunities for informal discussions about technical challenges and for building connections within the community.

The workshop welcomes participants at all levels, from those just getting started with SPAM to experienced users developing advanced workflows. It's an opportunity to get direct help with users data, learn from others facing similar challenges, and contribute ideas for the software's development. By the end of the four-day event, users have significantly progressed in their specific data analysis problems. This format offers something different from typical academic workshops for attendees who want practical solutions rather than theoretical overviews.

Further reading:
SPAM
Workshop in Dresden

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The Medelia Chair expands: a collective of experts dedicated to the sustainability of hydraulic structures

The Medelia Research Chair is jointly led by Julien Baroth (3SR) and Rafael Estevez (SIMaP – Laboratory of Materials Science and Engineering and Processes), under the auspices of the Grenoble INP Foundation. Initiated by the Artelia Group and its subsidiary SPRETEC in 2023, the Chair expands in 2025 with the support of TEC21 and two new partners, CNR and EDF. Its objective is to extend the service life of hydromechanical structures.

In response to the ageing of the French hydropower asset base and the need to ensure safety while preserving resources, the Medelia Chair now brings together a community of experts, researchers and operators around a shared challenge: improving the understanding of mechanical fatigue in metallic structures in order to better control risks. This expansion was recently celebrated (Business Hydro, 15/10/25, Grenoble). With the arrival of CNR and EDF alongside Artelia, and with the support of the TEC21 Laboratory of Excellence, the Medelia Chair is being strengthened. This joint support makes it possible to extend the research work initiated by the co-holders of the Chair, Julien Baroth (3SR) and Rafael Estevez (SIMaP).

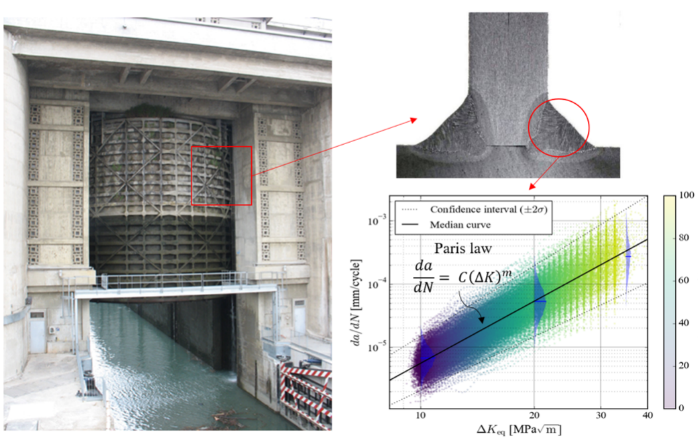

Figure: example of a structure of interest to the Chair (lock gate), a cross-section of a welded joint, and the evolution of the probability density of the crack growth rate as a function of the equivalent stress intensity factor, using Paris' law

The objective is to develop a methodology combining fracture mechanics for the local study of fatigue crack growth with probabilistic modelling, taking into account the variability of material properties and microstructures (via Paris' law, see figure), loading conditions, and manufacturing quality. This research aims to estimate residual service life in order to support asset managers in making informed decisions: monitoring, repair or replacement.

The first PhD project (Kamal Harb, 2023–2026) focuses on the fatigue of welded joints, using numerical and regulatory approaches. The second PhD project (Ghadi Alhanouni, 2025–2028) will additionally include an experimental component, based on fatigue tests to be carried out on materials supplied by operators (EDF and CNR). The ambition is to broaden the range of structures studied and to move toward a reliability-based characterisation, i.e. the estimation of failure probabilities, which is particularly relevant for safety assessment studies.

By combining operational data, field expertise, scientific knowledge and industrial needs, one of the ambitions of the Medelia Chair is to provide a forum for dialogue and co-construction for current and future engineers and asset managers.

Further reading:
Medelia Chair

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