Two PhD Positions – ANR Project Exo2GeCo
LMGC-Montpellier University & Mines Alès.

From **Exo**tic grain shapes to smart meta-granular structures:
the road **to Ge**ometric **Co**hesion origins

Classical granular materials, such as soils or concrete, derive their cohesion from adhesive forces that bind grains together, transforming the contact network into a system of tensile and compressive stresses. While effective, this mechanism relies on energy-consuming and irreversible adhesion. A new and fascinating paradigm has recently emerged: **geometric cohesion**, the spontaneous emergence of macroscopic cohesion in assemblies of *non-convex grains* —entangled and interlocked— without any adhesive interactions (Fig. 1)

Figure 1: *3D designed star shapes exhibiting "**Geometric Cohesion**" from preliminary works done by the team.*

These *metagranular materials* can form self-supported, load-bearing structures that display tensile resistance, compliance, and shape-induced stability. The ANR project **Exo2GeCo** aims to explore the origins of geometric cohesion and identify the fundamental geometric and mechanical conditions that give rise to it. To achieve this, the project combines **numerical simulations** and **experimental investigations** to establish a unified framework linking grain-scale geometry, force networks, and macroscopic strength.

Two complementary PhD projects are now open within this program.

PhD 1 – Numerical Investigation of Geometric Cohesion in 3D Star-Shaped Grain Assemblies:

The first PhD, hosted at LMGC (Laboratoire de Mécanique et Génie Civil - Université de Montpellier), will focus on the numerical modeling of dense assemblies made of rigid, star-shaped meta-grains using the Discrete Element Method (DEM) ; Fig.2. The candidate will work with 3D periodic simulations to investigate how shape parameters—such as the number, length, and orientation of arms—influence the emergence of macroscopic cohesion under quasistatic shear. After an initial phase dedicated to bibliographic review and training on DEM simulation tools, the doctoral candidate will design and shear various assemblies of non-convex grains. Using existing numerical frameworks developed at LMGC, the candidate will extend post-processing routines to compute mechanical observables such as stress, strain, and contact network properties. The main objective of this first part of the PhD is to measure the effective cohesion (c) and friction angle (ϕ) derived from Mohr–Coulomb envelopes, and to analyze their dependence on particle geometry, contact friction, and system size. This study will produce a database of 3D metagrain shapes and configurations that induce measurable geometric cohesion. In addition, the PhD candidate will conduct a **complementary experimental validation** on a selected subset of metagrains (identified through DEM). These simple proof-of-concept experiments—performed in collaboration with PhD2—will serve to test the robustness of the numerical predictions regarding the onset of geometric cohesion. This cross-disciplinary approach will provide the candidate with a broader understanding of both modeling and experimental methodologies within granular physics.

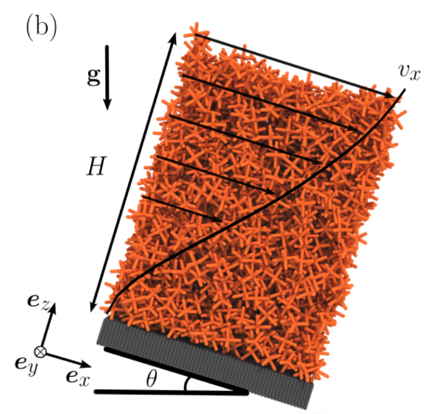

Figure 2: *3D DEM of the flow of 6-branch polypodes on an inclined plane (code LMGC90).*

PhD 2 – Experimental Investigation of Geometric Cohesion in 3D Printed Metagranular Materials: The second PhD, hosted at IMT Mines Alès, will experimentally explore the same physical mechanisms using 3D-printed or molded metagrains and custom-designed shear and compression apparatus. Building on the shapes and configurations identified in PhD 1, the candidate will design and perform experiments aimed at measuring the macroscopic cohesion and friction angle of dense metagranular packings. The PhD will start with a bibliographic and training period focusing on experimental methods, image correlation, and granular physics. The candidate will then design and assemble a versatile testing apparatus—based on Couette or compression geometries—that allows controlled deformation of metagrain assemblies while measuring the resulting stresses. The setup will be compatible with in-situ X-ray tomography, enabling full 3D observation of the internal structure during deformation. In parallel, the candidate will fabricate meta-grains via Selective Laser Sintering (SLS) or molding, testing different geometric configurations derived from the numerical database. Advanced image processing techniques will be developed using GPU-accelerated Digital Volume Correlation (DVC) to extract displacement fields and contact kinematics within the bulk of the samples. The final experimental campaign will aim to measure the same macroscopic quantities (c, ϕ) as in PhD 1 and to validate, by direct comparison, the numerical predictions. This experimental database will thus provide a crucial validation of geometric cohesion mechanisms in real materials. In addition to the experimental work, the candidate will perform a **complementary numerical study** using simplified DEM simulations (performed in collaboration with PhD1) to compare the measured stress–strain responses with numerical predictions. This cross-validation will help identify the key geometrical and mechanical factors that govern geometric cohesion and provide a stronger connection between the two PhD projects

Candidate Profile: Applicants should hold a master's degree in **mechanical engineering, physics, materials science, or Civil Engineering**. For **PhD 1**, strong skills in numerical modeling (DEM, Python/C++) and an interest in computational mechanics are expected. For **PhD 2**, experience in experimental mechanics, 3D printing, and image-based measurements (DIC/DVC, tomography) will be appreciated. Both candidates should be curious, autonomous, and motivated by interdisciplinary research combining **granular physics, materials science, physics and civil engineering**. Proficiency in English is required; knowledge of French is an asset.

Practical information:

- **Duration:** 3 years
- **Starting date:** 2026 (flexible)
- **Funding:** Fully funded by the French National Research Agency (ANR) under project *Exo2GeCo*
- **Locations:** Montpellier (LMGC)/Alès (IMT Mines Alès),
- **Research Axis and Hosting Team:** the project will be conducted within the *Milieux Divisés* research axis of the *Laboratoire de Mécanique et Génie Civil (LMGC)*. The supervising and collaborating team includes: Emilien Azéma (PR), Mathieu Renouf (CR), Jonathan Barés (IR), and Rémy Mozul (IR) at LMGC/Université de Montpellier & Arnaud Regazzi (Ass.Pr), Patrick Ienny (Pr), and Sylvain Buonomo (IR) at LMGC/IMT Mines Alès.
- **International collaboration**: the project will be conducted in collaboration with *Universidad de los Andes* (Bogotá, Colombia), Department of Civil and Environmental Engineering, with Prof. Nicolas Estrada (Short research stays at *Los Andes University* will be possible during the course of the PhDs).

Application Procedure:

Applicants should send a **single PDF file** including:

- A detailed **CV**
- A **motivation letter** indicating the preferred PhD position (or both)
- **Academic transcripts**
- **Contact details of two referees**

Applications and inquiries should be addressed to:

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