Bio-inspired materials: learning from nature and applying the lesson

Principal Investigator: Davide Ruffoni

PhD student: Laura Zorzetto

Department of Aerospace and Mechanical Engineering, University of Liege, Liege, Belgium

AIM OF THE RESEARCH GROUP

We investigate **mechanical properties** of biological and bio-inspired materials. The main biological tissue considered is **bone** and **its interface with ligaments and tendons**, which is a rather unexplored topic yet of paramount importance in the clinical context. We combine **experimental tools** with **computer simulations** to quantify and predicts tissue changes during **aging**, **diseases** and **treatments** as well as to establish new standards for the **regeneration of soft tissue-to-bone interfaces**. We also prototype novel bio-inspired material designs based on the mechanical construction principles identified in biological materials with the final mission of developing **high-performance and multifunctional composite materials** at the centimeter length scale**.**

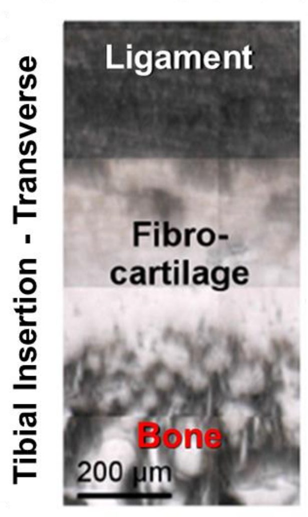
Biological materials: the lesson

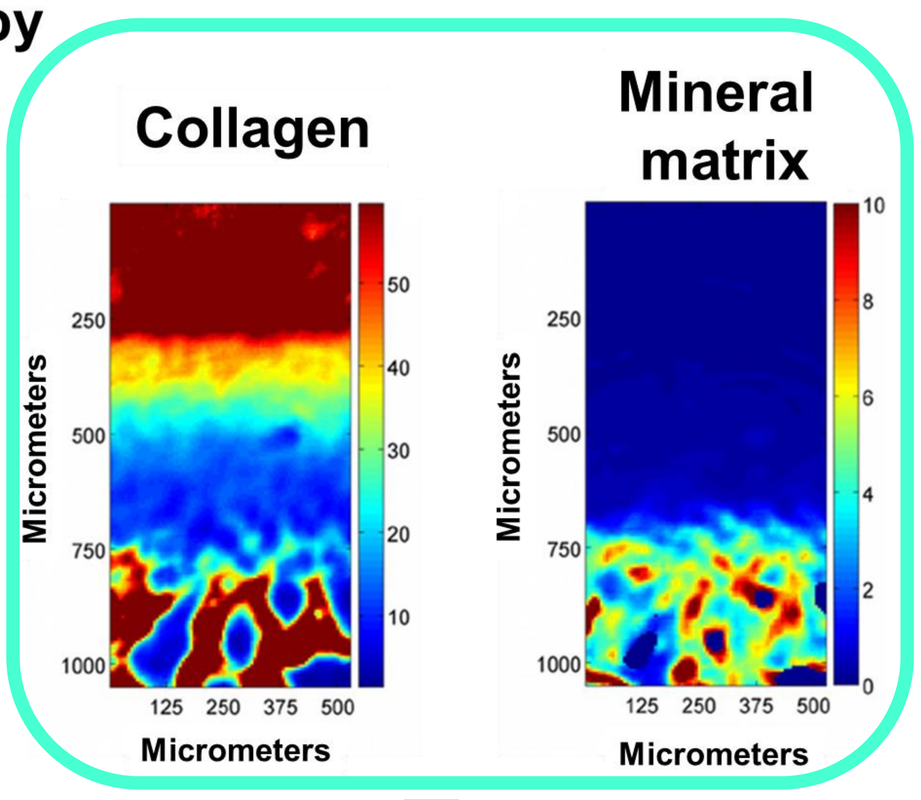
Strategy: image-guided nanoindentation and nano-dynamic mechanical analysis to characterize the nanoscale mechanical properties of the **bone/ligament interface** in heathy and diseased scenarios with the final aim to establish new standards for interface regeneration**.**

State of the art: across the bone/ligament interface tissue composition and spatial organization are highly complex (see figure below) → the corresponding local variations in mechanical properties are, to date, poorly characterized.

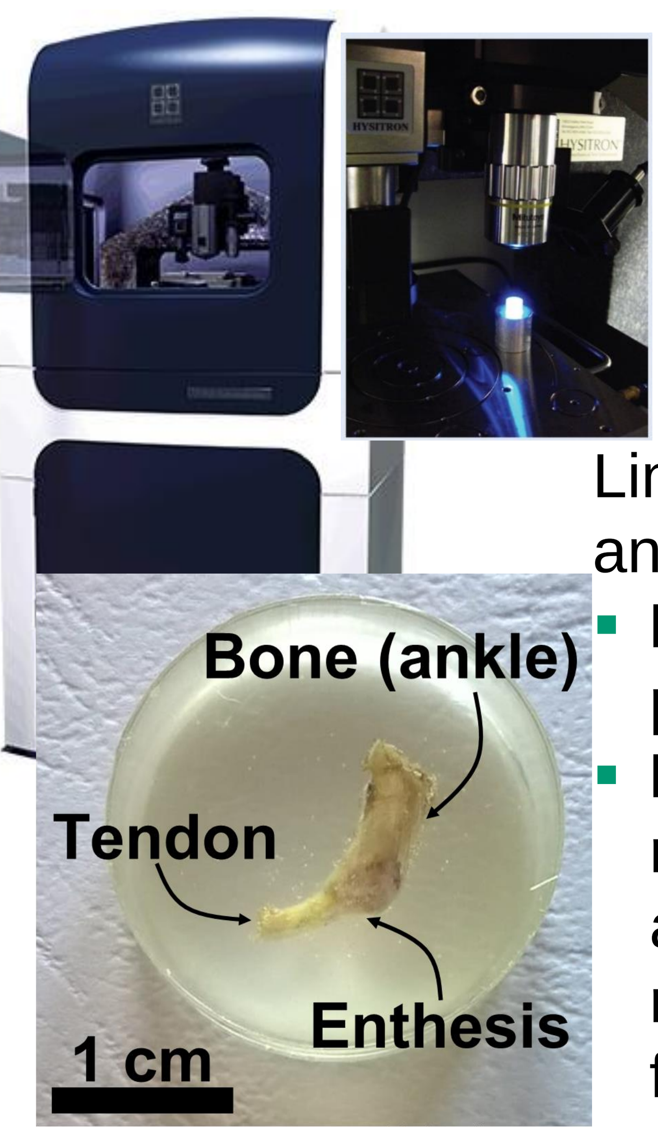
Knee joint: Anterior cruciate Ligament (ACL) Insertion

Light microscopy picture of ACL insertion





Adapted from Spalazzi et al., PlosOne, 2013



TI 950 TriboIndenter (Hysitron Inc., Minneapolis, USA)

Mechanical properties

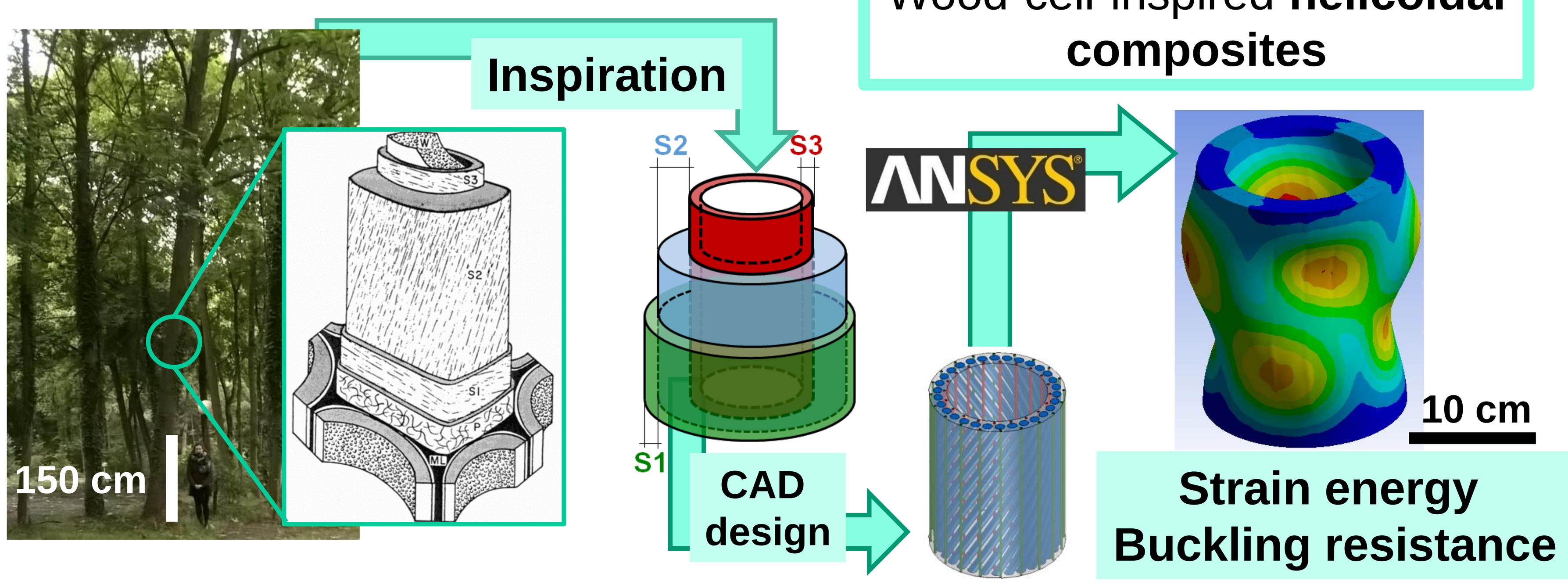
Link between mechanical properties and tissue composition/organization :

- **NanoDMA:** elastic and viscoelastic properties nanoscale properties
- **Fluorescence image guided nano-indentation**: mechanical assessment of highly specific regions only visible under fluorescence imaging

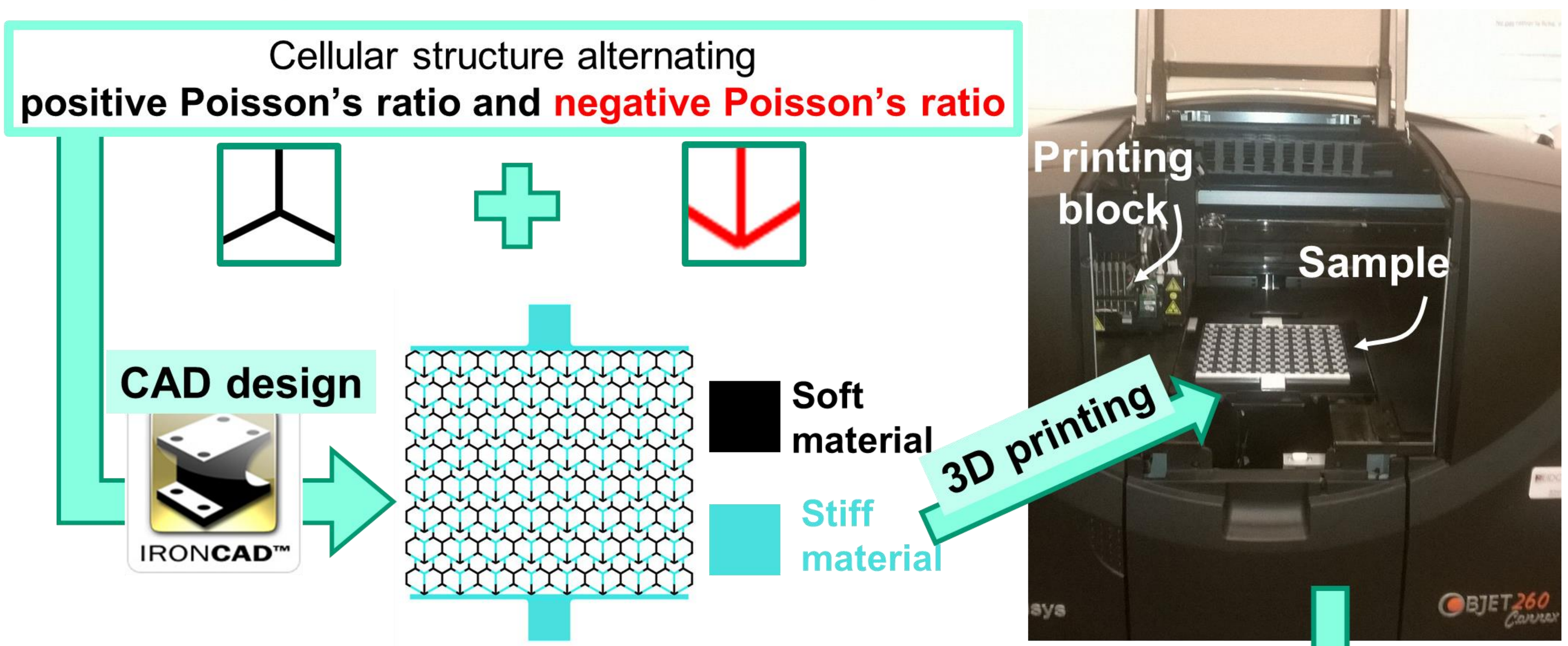
Bio-inspired materials: the application

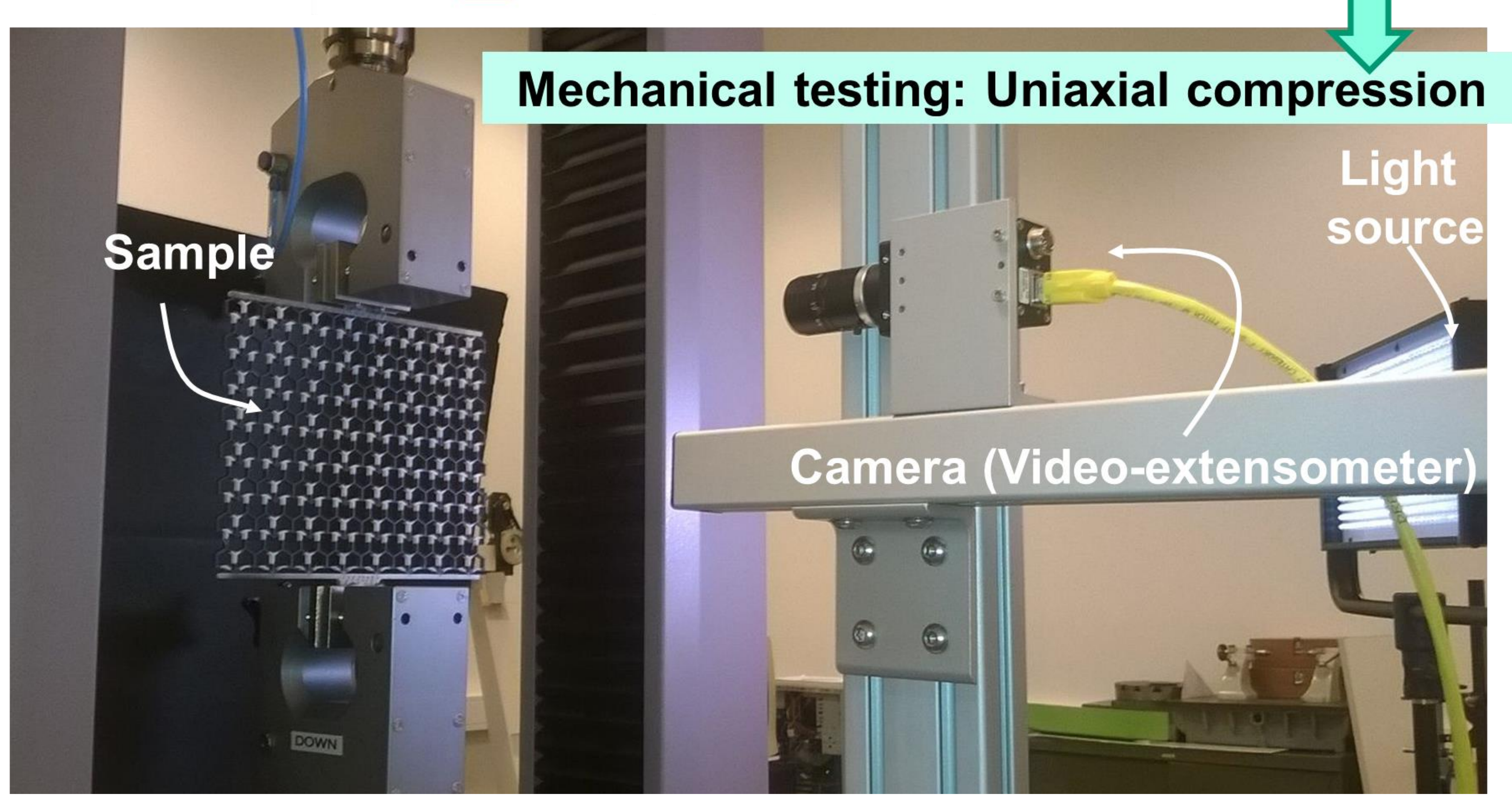
Strategy: replicate into synthetic materials building principles observed in biological structures such as embedding **stiff fiber-like elements into a soft matrix**, **hierarchical structuring** and **cellular architectures**.

- ***In silico* characterization**:



- **Prototyping by multimaterial 3-dimensional polymer printing & mechanical testing**





Adapted from Zorzetto and Ruffoni, Composite Structures, 2017

COLLABORATIONS

Ralph Müller, Zihui Li
ETH Zurich, Institute for Biomechanics

Luca Andena, Francesco Briatico Vangosa
Politecnico di Milano, Chemical Engineering

Richard Weinkamer
MPI, Dep. of Biomaterials, Potsdam

Thierry Marchal and Thomas Dalberto
Ansys Benelux, Wavre (Belgium)