# Master Thesis Proposal

## **Title**: *Finite Element Modelling of Bones loaded by Muscle-Induced Forces with Heterogeneous Material Properties from CT Scans of Fossils*

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**Context**

In evolutionary biology and palaeontology, the study of extinct species often involves reconstructing the biomechanical function of fossilized remains. Researchers aim to understand how forces—especially those generated by muscles—were distributed across the skeletons of extinct animals, such as dinosaurs or sabre-toothed cats, to infer possible behaviours, feeding strategies, or evolutionary adaptations.

A tool used by several research groups worldwide—including in Belgium, Germany, Brazil, and the USA—is the open-source finite element code **fossils**, which allows the simulation of complex bio-inspired structures subjected to mechanical loads derived from muscular forces. Currently, the material properties used in simulations are overly simplified—typically assuming bones to be linear, isotropic, and homogeneous. However, real bones are complex, heterogeneous composite materials, with notable differences between cortical and trabecular bone, or between dentin and cranial bone.

Improving the physical realism of such models is essential for drawing more accurate conclusions from biomechanical simulations.

**Thesis Objective**

The primary goal of this thesis is to enhance the *fossils* code and its surrounding workflow to support finite element models of bones with **spatially varying material properties**, derived from 3D medical images (e.g., CT scans).

The student will:

- Implement or adapt a **multi-region meshing pipeline** that assigns different elastic properties to different anatomical regions (e.g., bone vs. tooth).
- Integrate and process **3D imaging data** (CT scans) using tools such as **3D Slicer**, **VTK**, or **Paraview**, potentially combining segmentation and mesh labelling techniques.
- Contribute to the **C++ codebase** of the *fossils* code (available online), including functionality related to material assignment and preprocessing.
- Optionally, explore the implementation of additional features, such as large deformation mechanics, new boundary conditions, or multi-body interactions (e.g., contact mechanics), depending on the student's interests.

The work will be performed in close collaboration with palaeontologists from the University of Liège and beyond, ensuring real-world applicability and scientific impact.

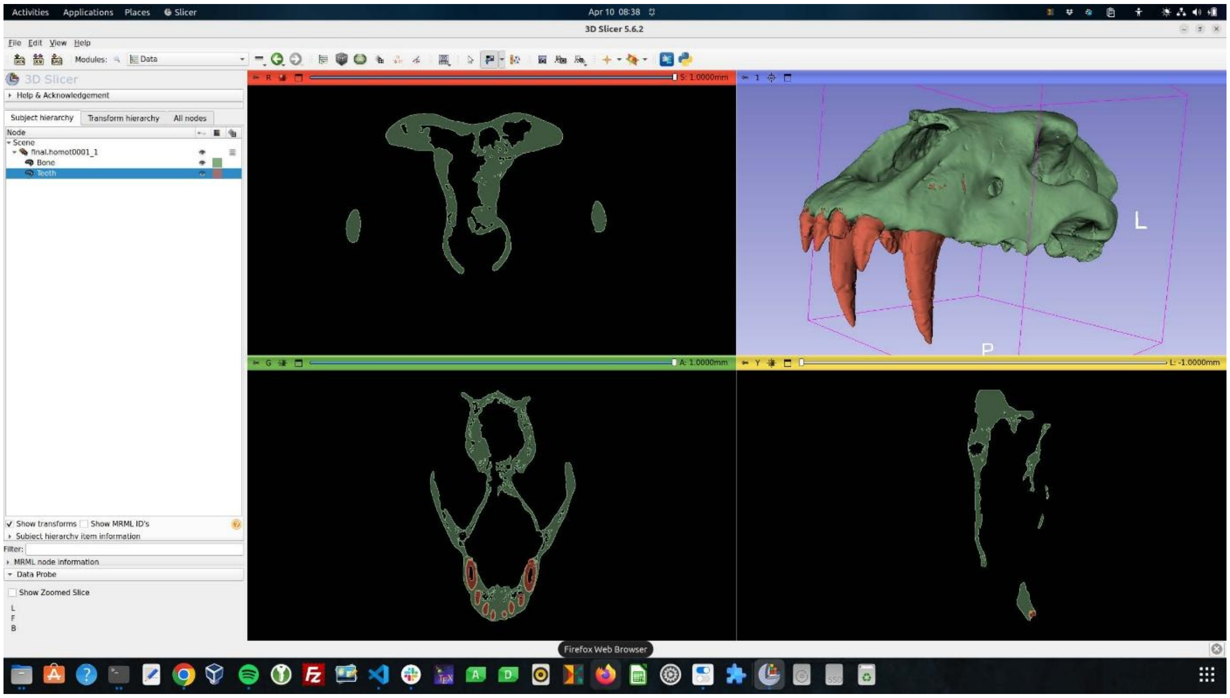


*Figure 1: Segmentation and 3D reconstruction of a fossil specimen using 3D Slicer. Bone (green) and teeth (red) are identified as distinct material regions.*

**Expected Candidate Profile**

This thesis is primarily suited for a student in engineering physics or biomedical engineering with a strong interest in:

- Numerical modelling and simulation (particularly FEM),
- Programming (C++, Python),
- Biomedical or biomechanical applications (even with no prior domain expertise).

Some experience or motivation to work with image processing and mesh generation software (e.g., Blender, Gmsh) will be appreciated.

**Bibliography / Useful Resources**


- R. Boman, *fossils: Free, Fast, and Open-source Biomechanical Modelling*, [Methods Blog, 2023]
- d'Otreppe et al., *Generating smooth surface meshes from multi-region medical images, Int. J. Numer. Meth. Biomed. Engng., 28: 642-660, 2011*. https://doi.org/10.1002/cnm.1471
- GitLab Repository: https://gitlab.uliege.be/rboman/fossils
- 3D Slicer: https://www.slicer.org
- VTK Toolkit: https://vtk.org
- Gmsh: http://gmsh.info
- Valentin Fischer (palaeontology collaboration): ULiège profile