# Identification of the constitutive properties of complex shaped composite structure parts using a mixed method based on 3D velocity field measurement and FEMU : An application to a violin soundboard

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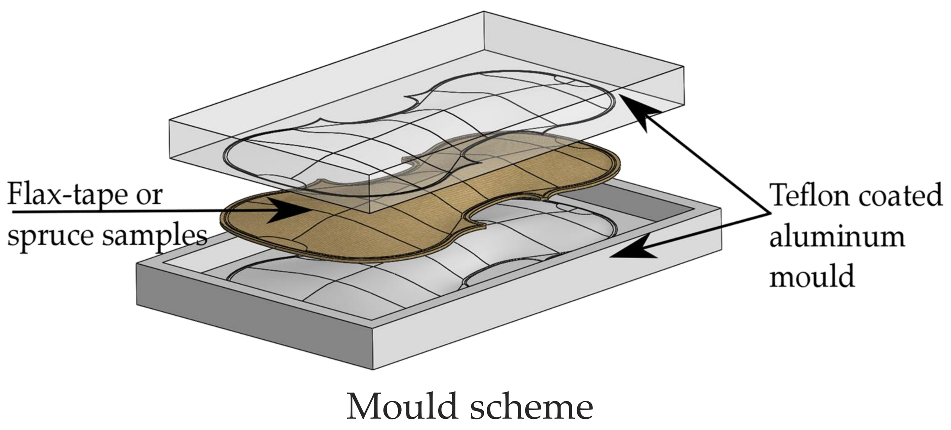
## Context and motivations

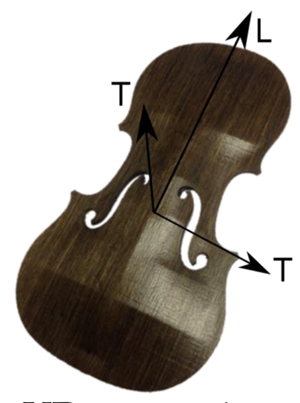
- Growing need for non-destructive tests in composite technologies.
- Indirect methods have proven useful for simple geometries.
- Finite element model updating (FEMU) is a powerful tool to determine several parameters at once in a non destructive way.
- The objective is to apply this method to complex shaped structure parts made of anisotropic material.

## Studied structure :

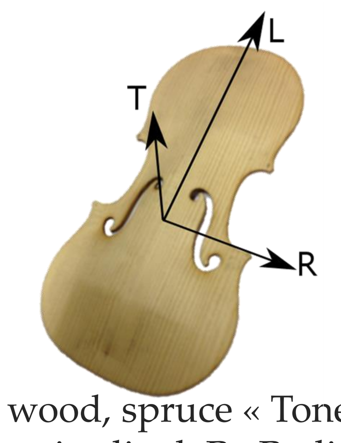
- Violin soundboard
- Cut by laser ($CO_2$)
- Different materials and manufacturing techniques
- LINEO® Flaxtape 110g/m², hot embossing (130°c, 3 Bars), 16 layers, $V_f$=55%
- Spruce wood, bending (90°c, 2 bars)
- Specific gravity :
  - 1,28 (biocomp)
  - 0,474 (spruce)



Mould scheme



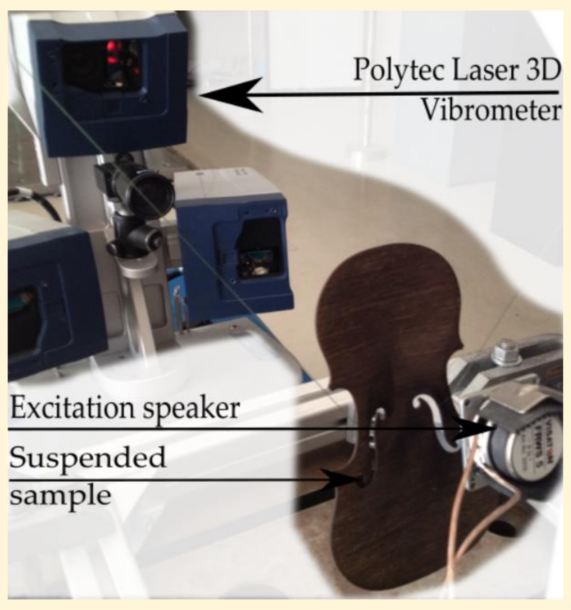
UD composite
L : longitudinal
T : Transverse



Bended wood, spruce « Tonewood »
L : Longitudinal, R : Radial, T : Tangential

## Measurement

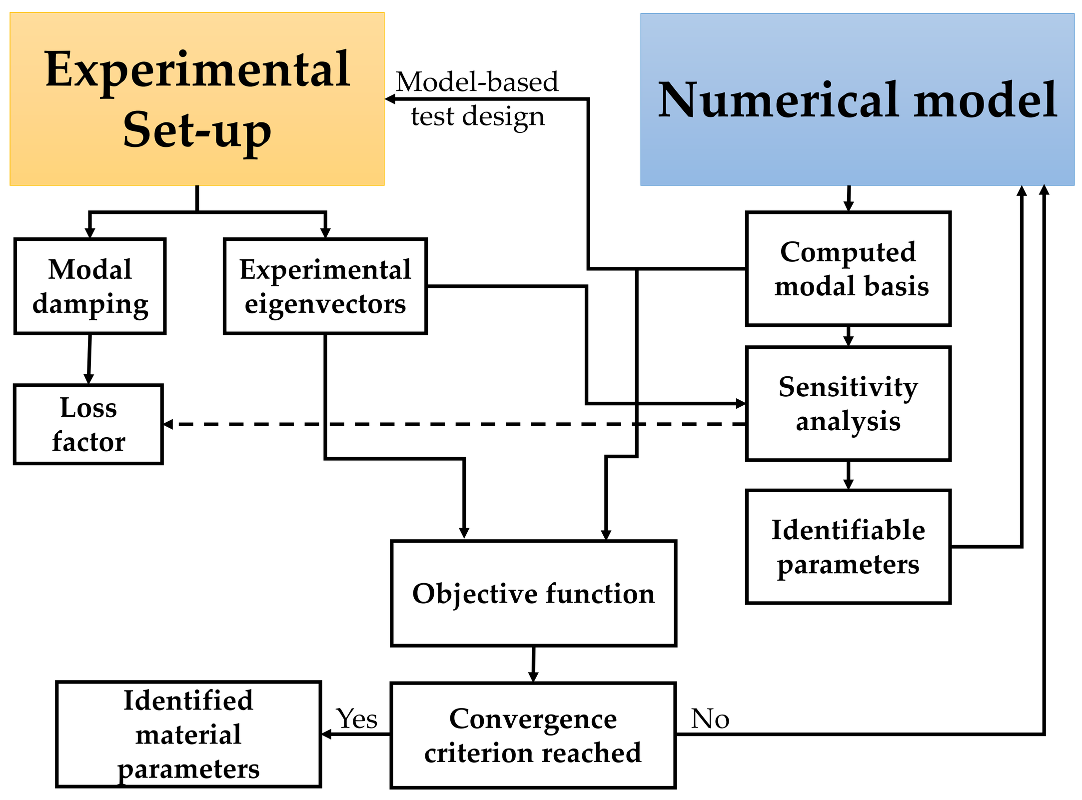
- Field velocity measured using 3D laser vibrometer.
- Suspended sample to approach free boundary conditions.
- Excitation using acoustic speaker.
- Sweep sinus 0 and 3000 Hz.
- 100 nε and 100 nrad strain level.
- Out of plane velocity field used for modal identification (800 points).



Measurement scheme

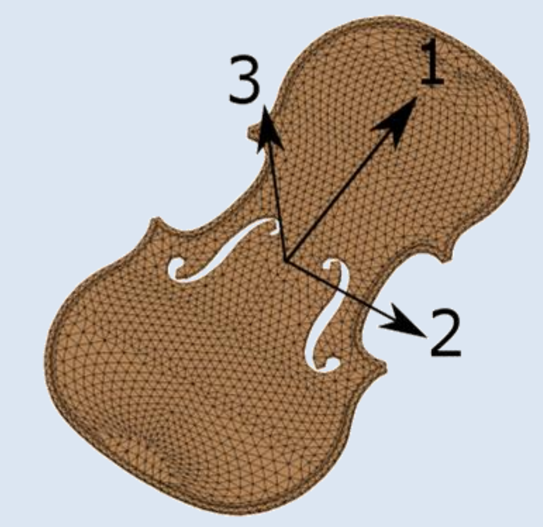
## Method principle

- Minimization of the discrepancy between measured and computed modal basis.
- Finite element model updating.
- First order sensitivity algorithm used for minimization.




## Numerical model

- Quadratic tetrahedral solid elements.
- 20000 elements and 120000 DoFs.
- Free boundary conditions.
- Computation of 20 modes.
- Linear elastic behaviour's law.



Numerical model of sample and local orientation
Biocomp :1=L, 2=3=T
Wood : 1=L, 2=R, 3=T

$$\underline{\sigma} = \underline{\underline{S}}^{-1} : \underline{\varepsilon}$$

$$[S] = \begin{bmatrix} \frac{1}{E_1} & \frac{-\nu_{12}}{E_1} & \frac{-\nu_{13}}{E_1} & & & \\ \frac{-\nu_{21}}{E_2} & \frac{1}{E_2} & \frac{-\nu_{23}}{E_2} & & 0 & \\ \frac{-\nu_{31}}{E_3} & \frac{-\nu_{32}}{E_3} & \frac{1}{E_3} & & & \\ & & & \frac{1}{G_{23}} & & \\ & 0 & & & \frac{1}{G_{31}} & \\ & & & & & \frac{1}{G_{12}} \end{bmatrix}$$

Behaviour's law implemented

## Application to biocomposite :

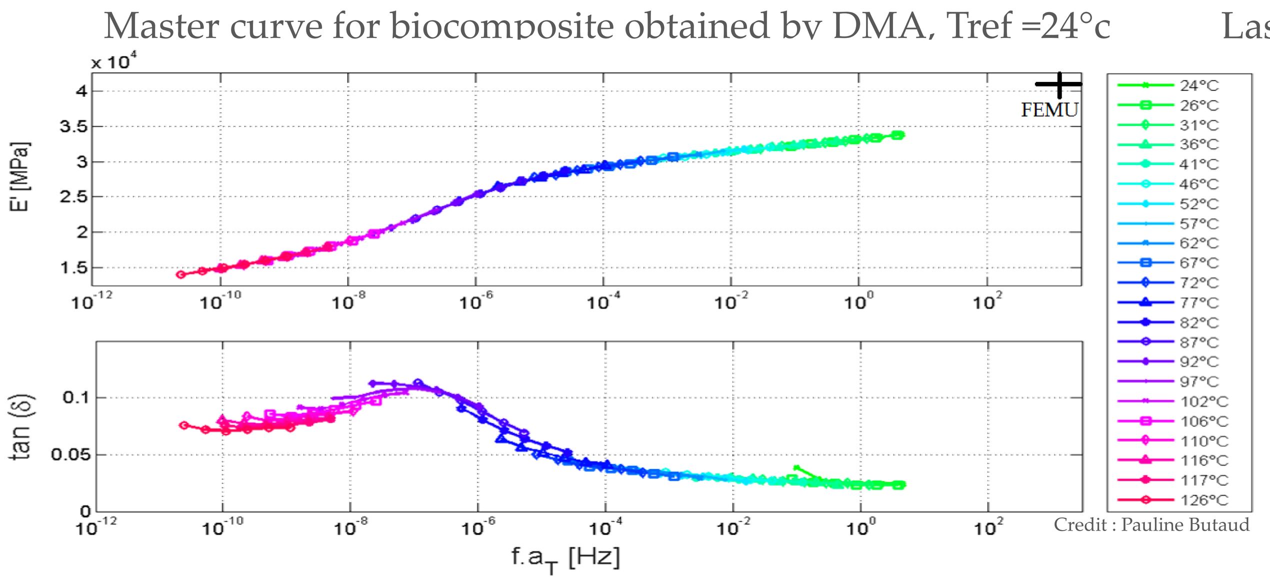
- Comparison between FEMU method and 3-points bending quasi-static tests and Dynamical Mechanical Analysis (DMA).

Identified values using direct and indirect methods :

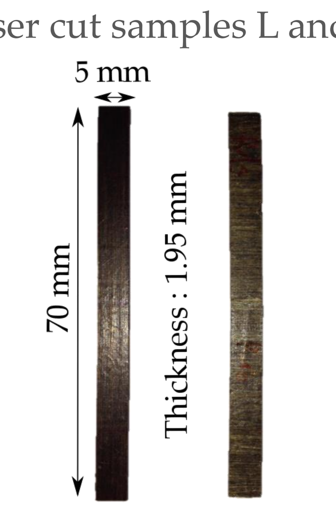
| | FEMU | Quasi-static tests | DMA |
|---|---|---|---|
| $E_L$ (GPa) | 42.5 | 40.5 | 39 |
| $E_T$ (GPa) | 4.2 | 3.8 | - |
| $G_{LT}$ (Gpa) | 2.3 | - | - |
| $\eta_L$ (%) | 2 | - | 2 |
| $\eta_T$ (%) | 2.2 | - | - |
| $\eta L_T$ (%) | 2.4 | - | - |

| | MAC (800 DoF) (%) | Matched eigenfrequency error average (%) |
|---|---|---|
| Before calibration | 87.3 | 5.9 |
| After calibration | 93.9 | 1.1 |

Master curve for biocomposite obtained by DMA, Tref =24°c




Laser cut samples L and T

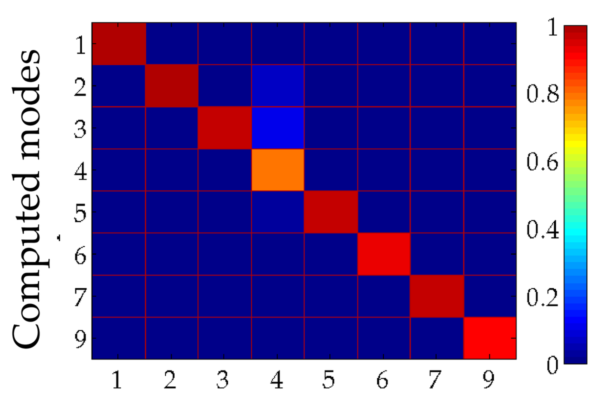



- Simultaneous identification of 6 parameters whose values are in accordance with those measured by quasi-static tests and DMA master curves.

## Application to bended wood :

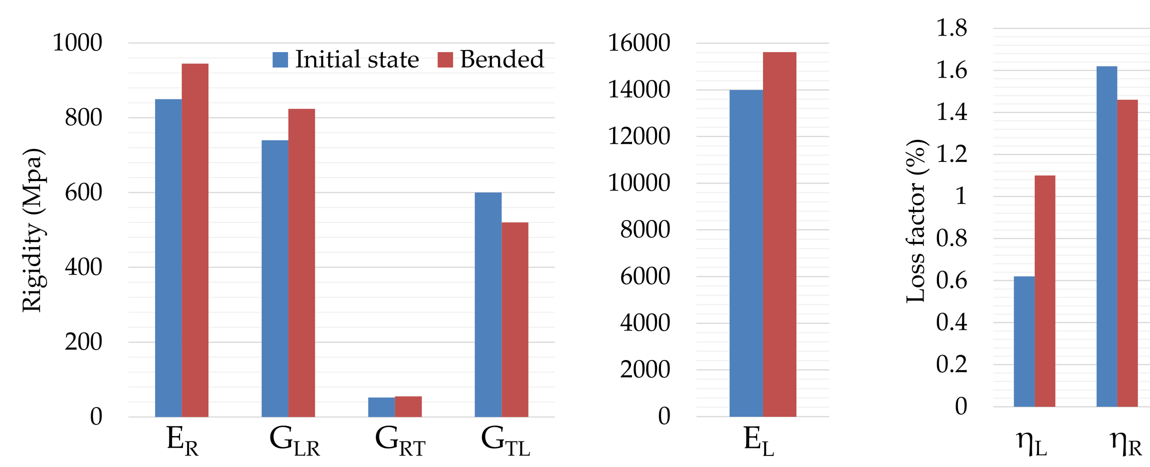
- Effects of the bending are investigated in this section.

MAC Matrix after calibration

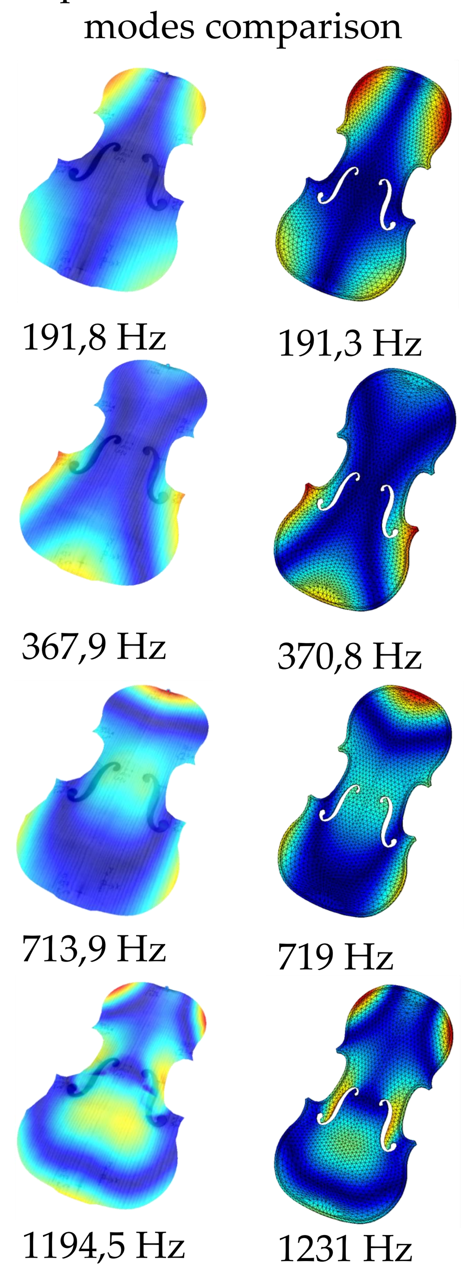



| | MAC (800 DoF) (%) | Matched eigenfrequency error average (%) |
|---|---|---|
| Before calibration | 87.3 | 5.9 |
| After calibration | 93.9 | 1.1 |

Identified values for two states : initial and bended wood




Experimental – Numerical modes comparison




- Bending process has a slight effect on both the rigidity and loss factors.
- Bending globally increases rigidities.

## Strengths

- Non-destructive method to determine numerous material properties simultaneously at different frequencies and small strain levels for complex shape and anisotropic material structure parts.
- Dynamical properties are more representative of a global behaviour of the material than static properties that are generally driven by local phneomena.
- The diversity and the combination of the sollicitation modes of the specimen activate in one experiment different material properties
- Fast, easy to set-up and requires a reduced preparation of the samples

## Weaknesses

- High sensitivity to specific gravity and specimen dimensions,
- Uniqueness of solution has to be assessed by heurisitc methods that are computationally time consuming.
- Compensation effects prevent the application to complex assemblies and strong heterogeneities.

## Perspectives

- Evaluation of the spatial and temporal evolution of the material properties.
- Implementation and improvement of more complex behaviour's laws (visco-elasticity).
- Study of the thermo-hygroscopicity of the material through climatic chamber.

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