Soundboard Bracing Techniques and Modal Behavior, a Numerical Study

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Overview

I. Introduction

II. Method

III. Results

IV. Conclusions and perspectives

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Introduction

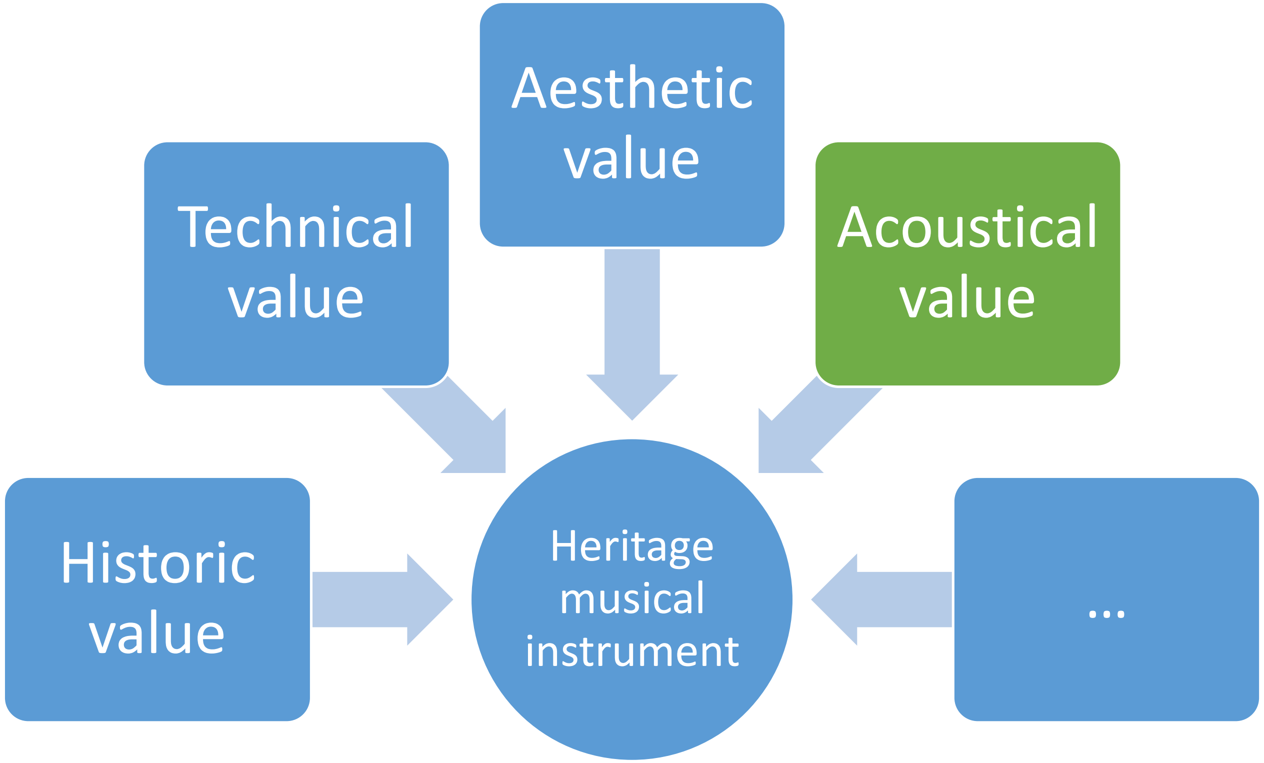
Museum problematics

Music museum of Paris

- Describe the story of music through its instruments
- Conserve and restore heritage musical instruments
- Assess the playability of heritage musical instruments

Introduction

Assessing playability in museum context



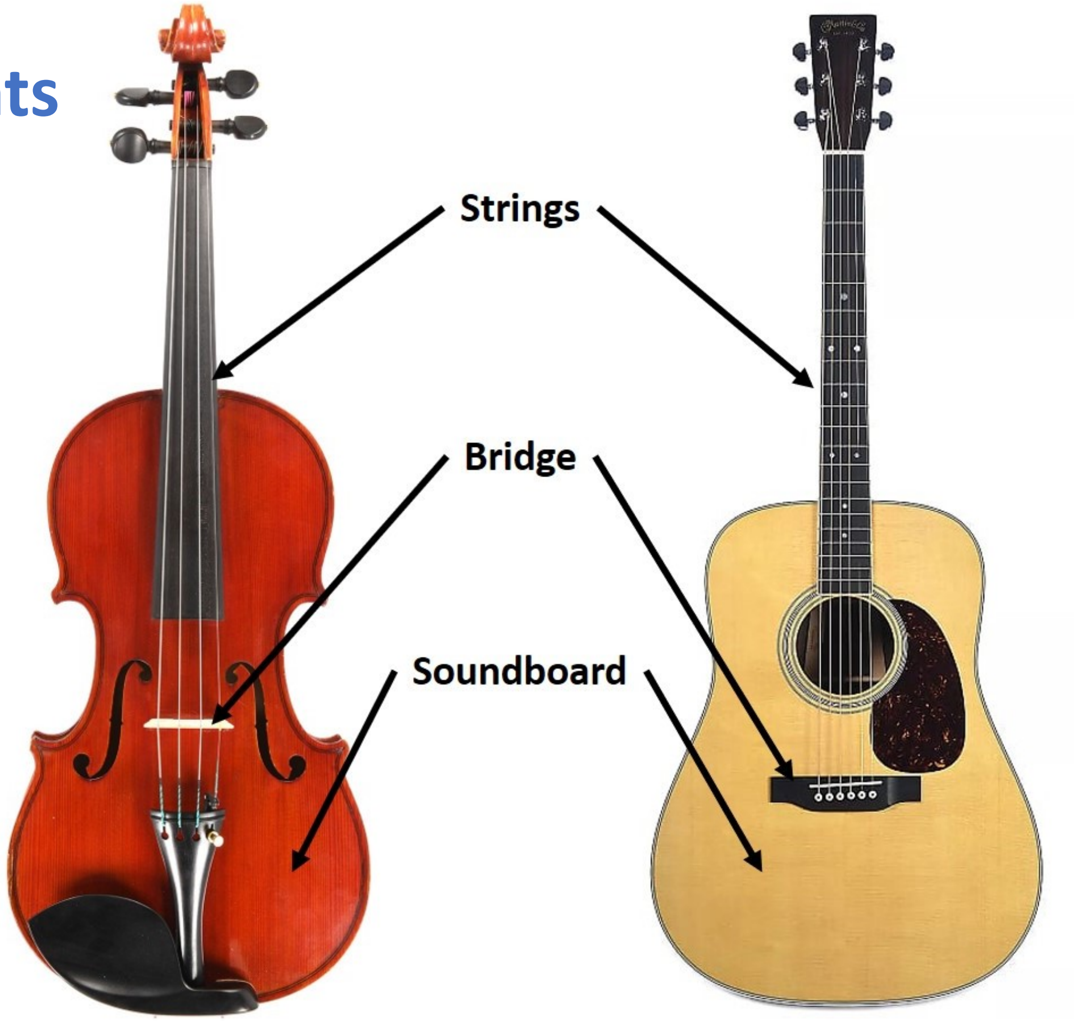
- Music museum of Paris → collection of 7000 instruments but only 5% in playable state
- Heritage musical instruments present many cultural values
- These cultural values are subjectively compared and hierarchized

→ Provide an objective response to assessing playability of heritage musical instruments

Introduction

Focus on wooden stringed musical instruments

- Assess the playability of heritage **stringed** musical instruments
- A string instrument is a musical instrument in which the sound is produced by the vibration of strings
- The vibration of the string is coupled to the soundboard by the bridge
- Soundboards are traditionally made of **wood** though other materials are used, such as skin or plastic on instruments in the banjo family



Stringed musical instrument nomenclature

Introduction

Assessing playability

Assessing playability of heritage stringed musical instruments raises many questions

- Does playing the musical instrument damage the heritage object ?
- Form an acoustic point of view, is it historically relevant to play an instrument that has lived ?
- …

→ Develop a methodology to study the mechanical state of heritage musical instruments

The mechanical state includes

- The strings tension
- **The soundboard fabrication technique**

Cracks on 1924 Grapelli violin soundboard due to strings tension

Introduction

Soundboard fabrication techniques

- Soundboard is very thin structure reinforced by braces glued to the back of the table
- Bracing techniques differ according to the instrument family
- Bracing techniques can be grouped according to common mechanical criteria:
  i. Techniques using external forces
  ii. Techniques using the hygroexpansion behavior of wood

→ Structural dynamics models can be used to study the impact of bracing techniques on the dynamical behavior of soundboards

Different bracing techniques

Introduction

Mechanical study of prestressed structure

The dynamical behavior of prestressed structures has been widely studied in the literature *(K. K. Raju & al. 1986, A. Dall'Asta & al. 1999, D. Addessi & al. 2005, …)*

The interpretation of the observations strongly depends on the structure and prestressed type

→ The transfer of these observations to wooden soundboards is not easy

Few studies exist on the behavior of prestressed soundboard:

- Adrien Mamou-Mani studied this problem in his doctoral work *(A. Mamou-Mani 2007)*
- Julien Colmars studied this problem at the Music Museum of Paris laboratory focusing on the fabrication prestresses in wooden soundboards *(J. Colmars 2012)*

Study of a braced piano soundboard
(J. Colmars 2012)

Introduction

Objective

Develop a model-based methodology

- To study the mechanical state of heritage musical instruments
- Induced by the soundboard fabrication technique
- Usable in museum framework
- Complex numerical model (behavior laws, geometry, loading)

Christoph Koch Archlute (1654) E.546

Overview

Method

Traditional bracing techniques

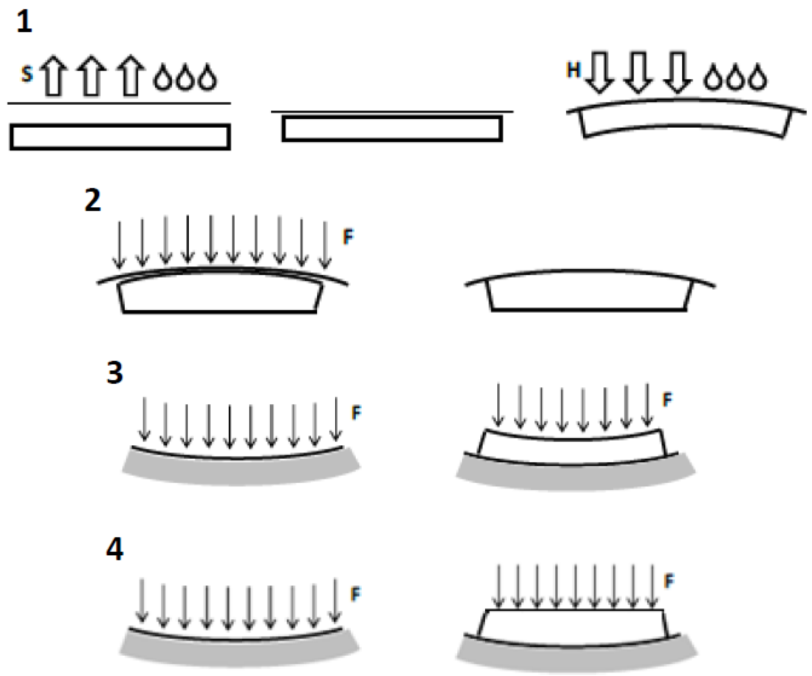
Preliminary study on the impact of traditional soundboard bracing techniques on the dynamical behavior of a simplified assembly

Four techniques

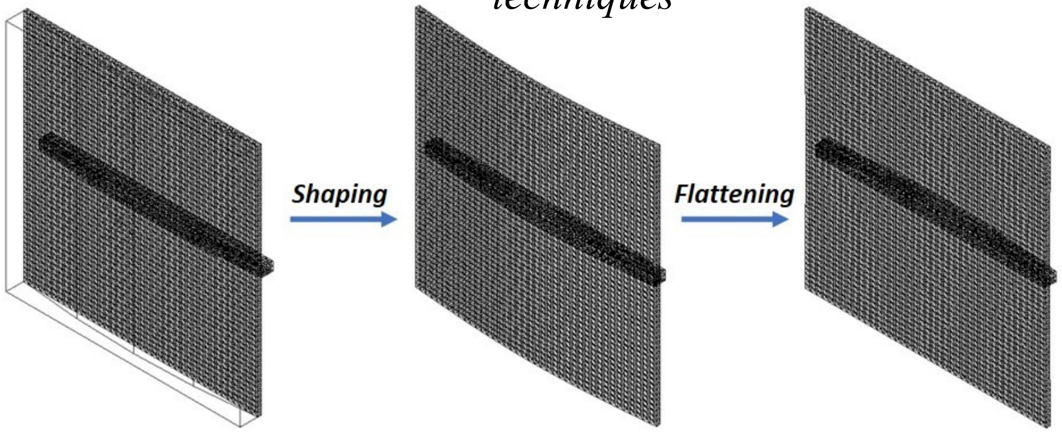
1. Glue flat braces to a previously dried plate on a flat worktable. Return to normal humidity produces a slight bulge
2. Glue curved braces to the plate on a flat worktable
3. Glue flat braces to the plate on a curved mold
4. Glue curved braces to the plate on a curved mold with the same curvature as the braces

Two fabrication steps

1. The soundboard is shaped with the braces (shaping step)
2. The braced soundboard is flattened on the body of the instrument (flattening step)



Traditional soundboard bracing techniques



Studied fabrication steps illustration

Method

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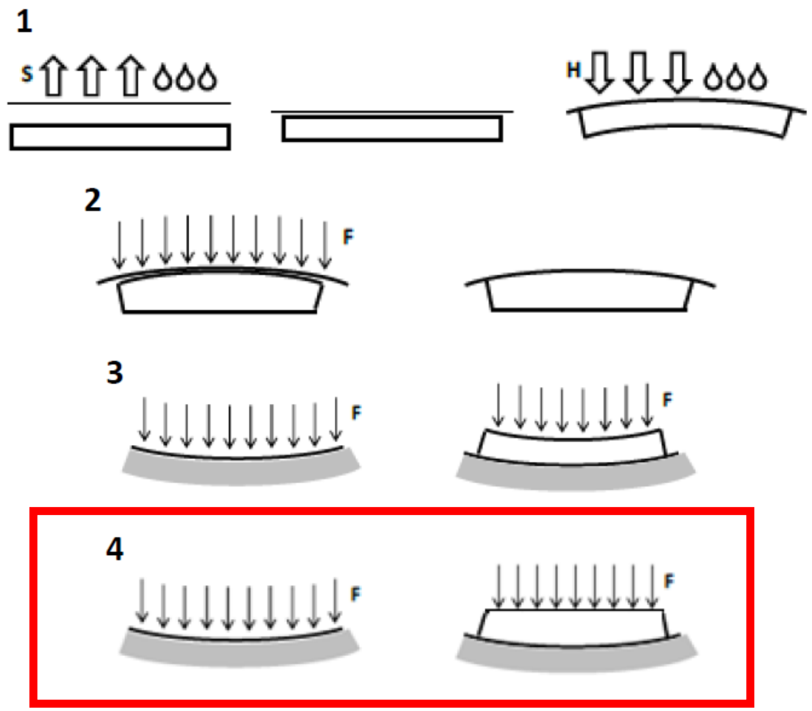
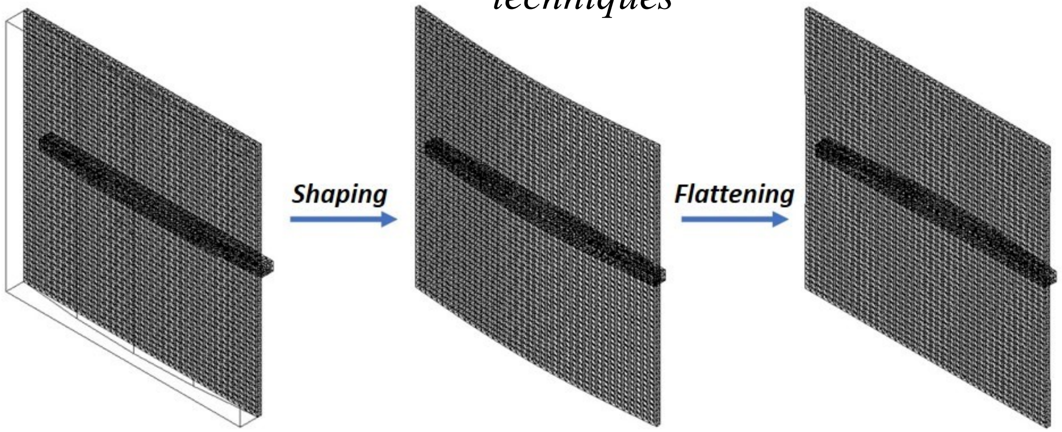


Traditional soundboard bracing techniques



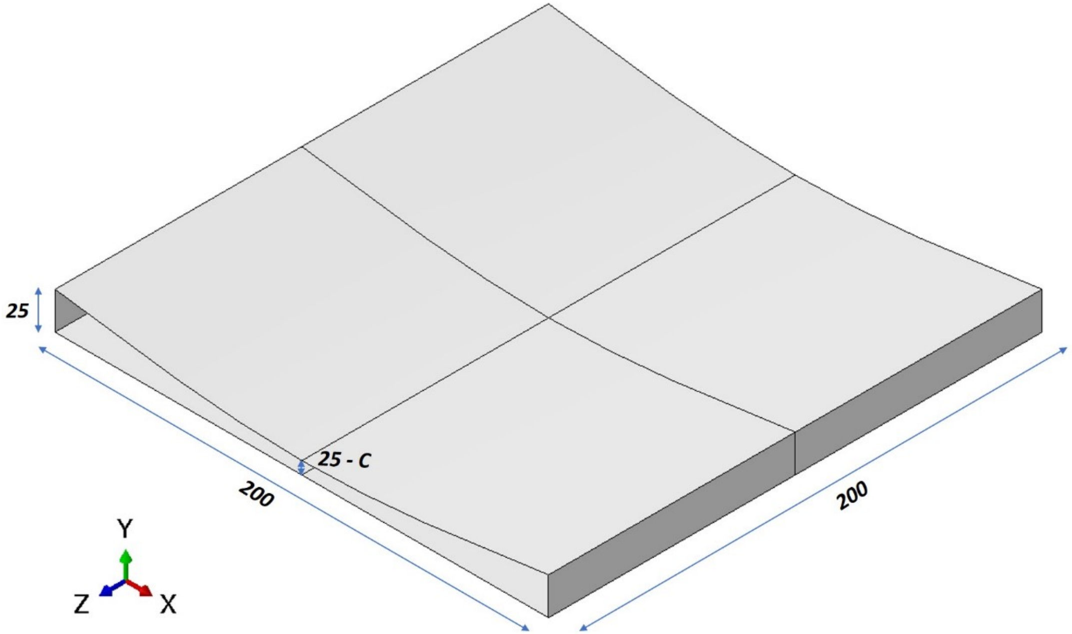
Studied fabrication steps illustration

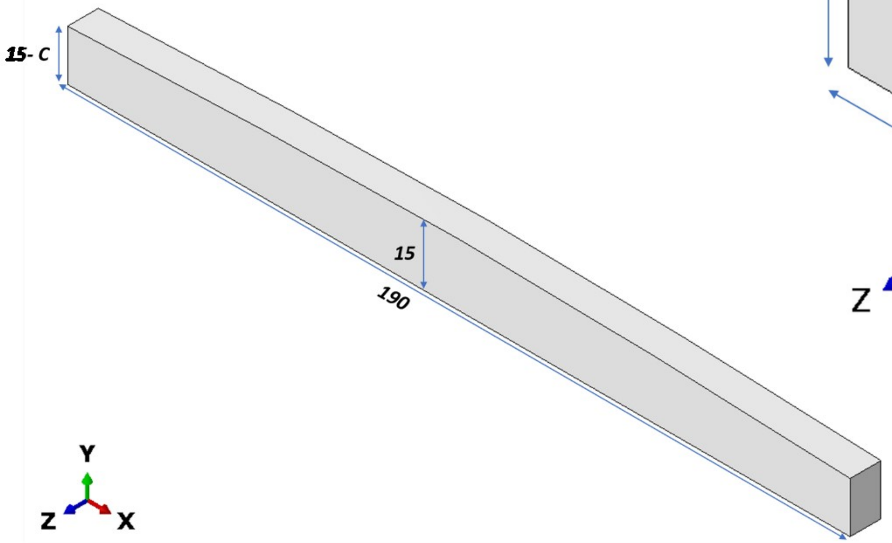
Method

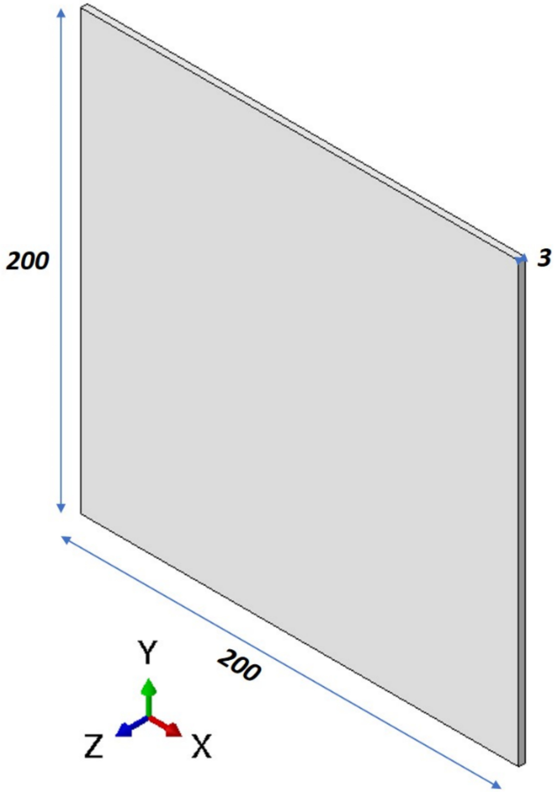
Geometric model

Three different parts

- Two deformable parts (plate and bar)
- A rigid part (mold)







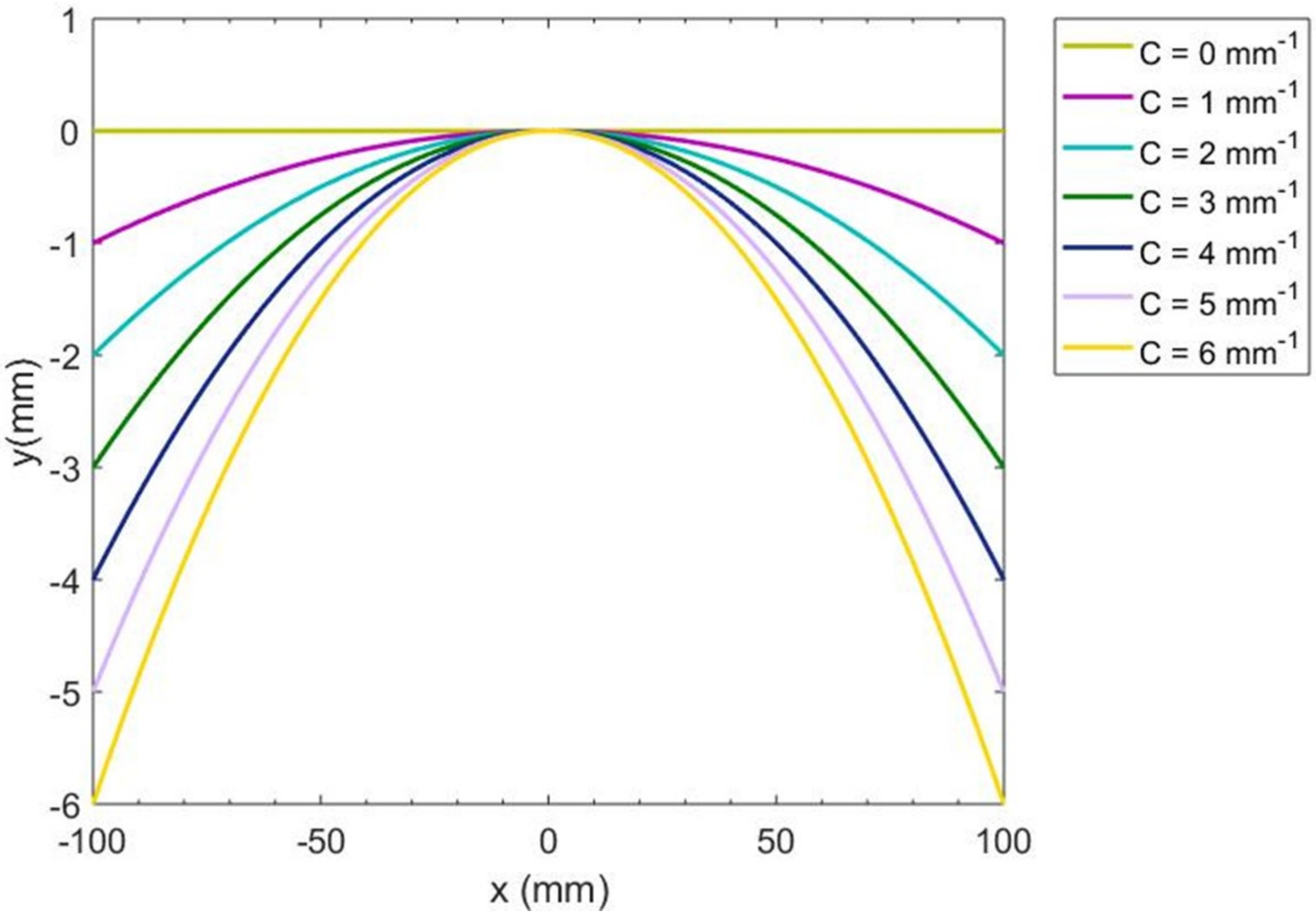
Method

Geometric model

The curvatures of the bar and the mold are in the form of the following two-order polynom:

$$y(x) = -10^{-4}Cx^2$$

- C represents the gap between the plate and the bar
- C is between 0 and 6 mm^{-1}

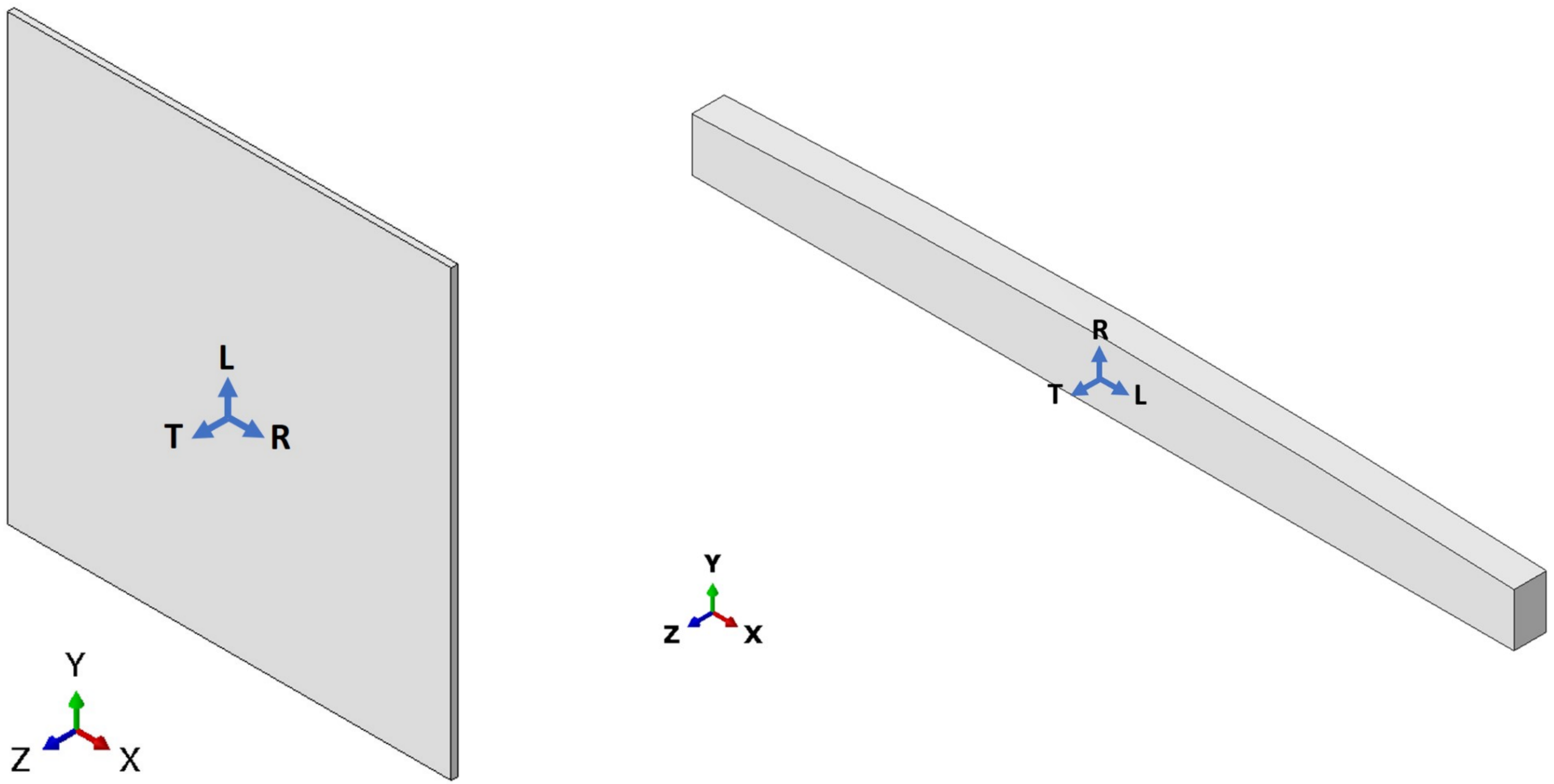


Method

Behavior model and parameters

Hypothesis: Wood is modeled with linear orthotropic elastic behavior

Constants	Spruce
E_L (MPa)	10200
E_R (MPa)	850
E_T (MPa)	500
ν_{LR}	0,39
ν_{LT}	0,43
ν_{RT}	0,5
G_{LR} (MPa)	750
G_{LT} (MPa)	675
G_{RT} (MPa)	75

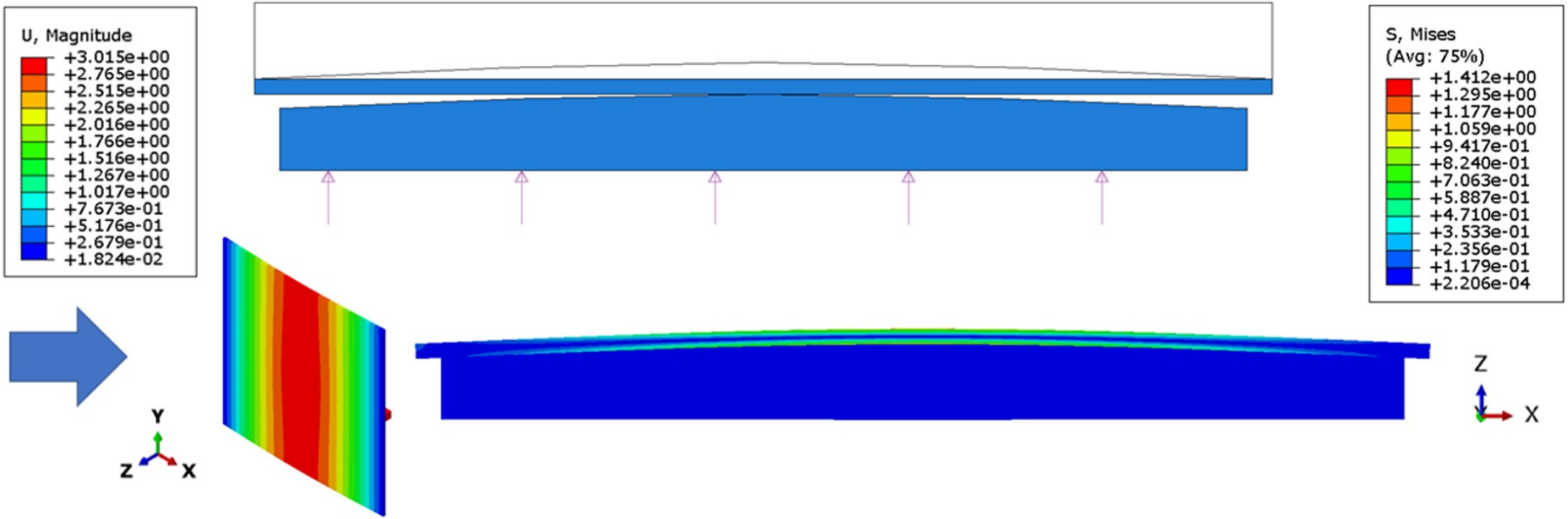


Method

Shaping step

Loads and boundary conditions

- The mold is clamped
- A load is imposed on the lower surface of the bar

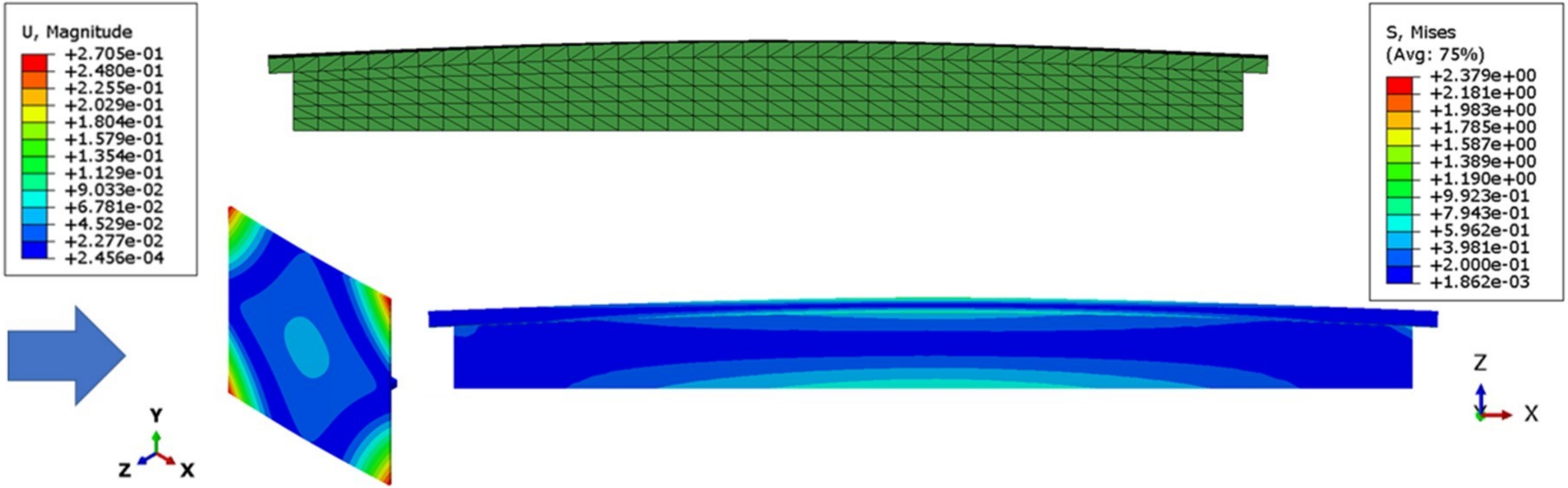


Method

Shaping step

Loads and boundary conditions

- The nodes of the bar and the plate are linked
- No loading is applied in order to obtain an elastic return

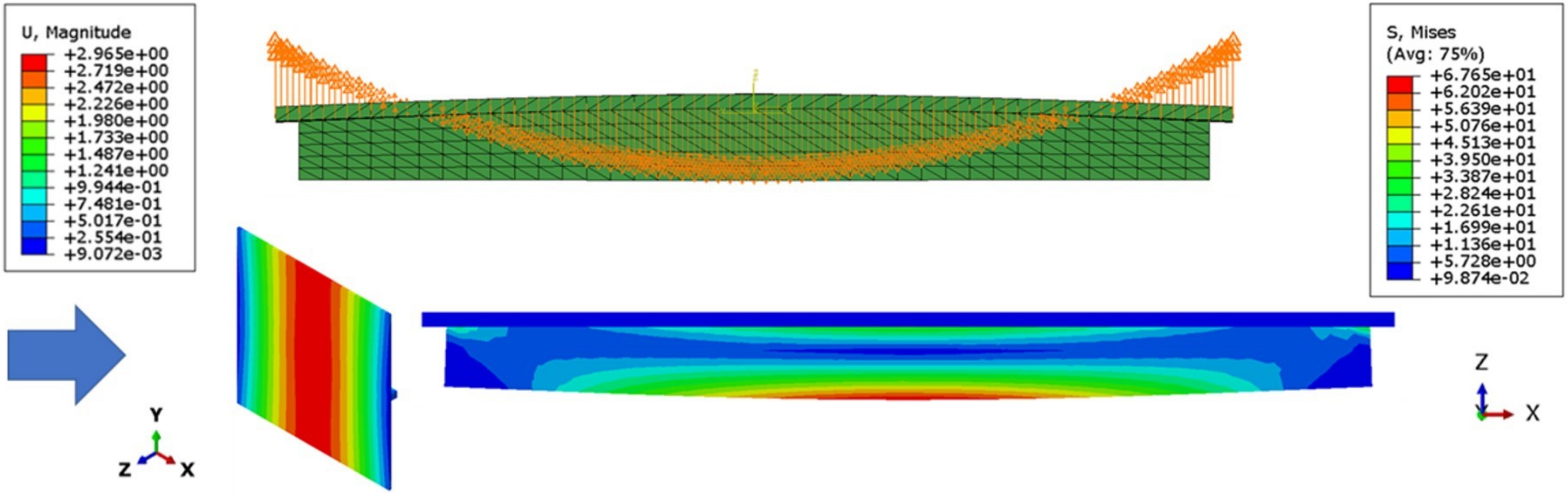


Method

Flattening step

Loads and boundary conditions

- A displacement is imposed on all the nodes of the plate to put it back flat

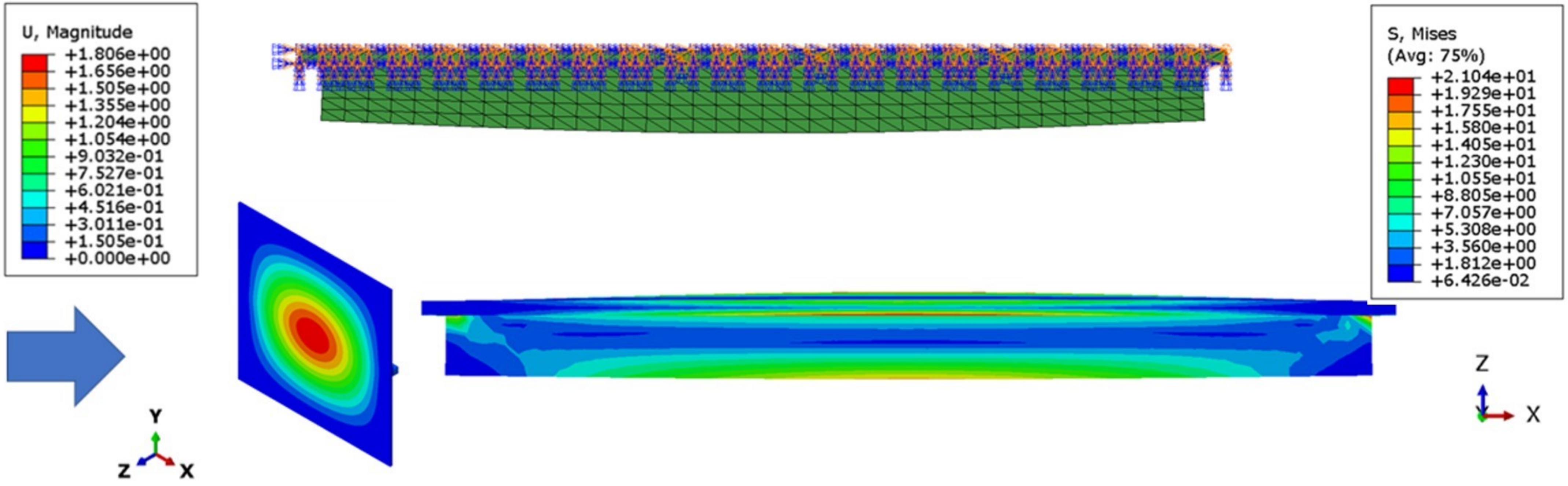


Method

Flattening step

Loads and boundary conditions

- The sides of the plate are clamped
- No loading is applied in order to obtain an elastic return



Method

Modal analyses

- Modal analyses are performed in order to obtain the dynamical response of the braced plate **clamped** on its sides

- Three configurations have been studied in order to **separate** the impact of the resulting geometry and stress state:

  1. The plate presents the **resulting geometry and stress state**
  2. The plate presents the **resulting geometry** only
  3. The plate is **flat** and presents the **resulting stress state** only

- Each of these configurations has been compared to an initial configuration, a **flat plate with a zero stress state** (configuration 0)

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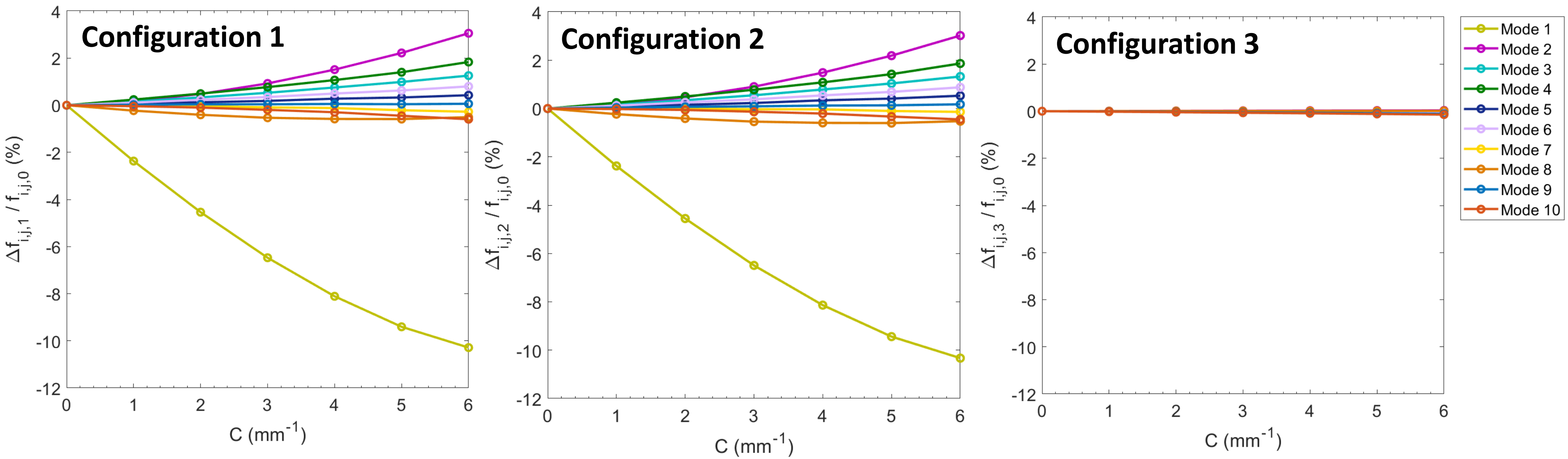
Results

Shaping step

$$\frac{\Delta f_{i,j,k}}{f_{i,j,0}} = \frac{f_{i,j,k} - f_{i,j,0}}{f_{i,j,0}} \times 100$$

$$where\ f_{i,j,k}\ the\ eigenfrequency\ of\ the\ eigeinmode\ i\ for\ C = j\ in\ configuration\ k$$



Observations

- The variations are very small for configuration 3
- The results in configuration 1 and 2 are very close

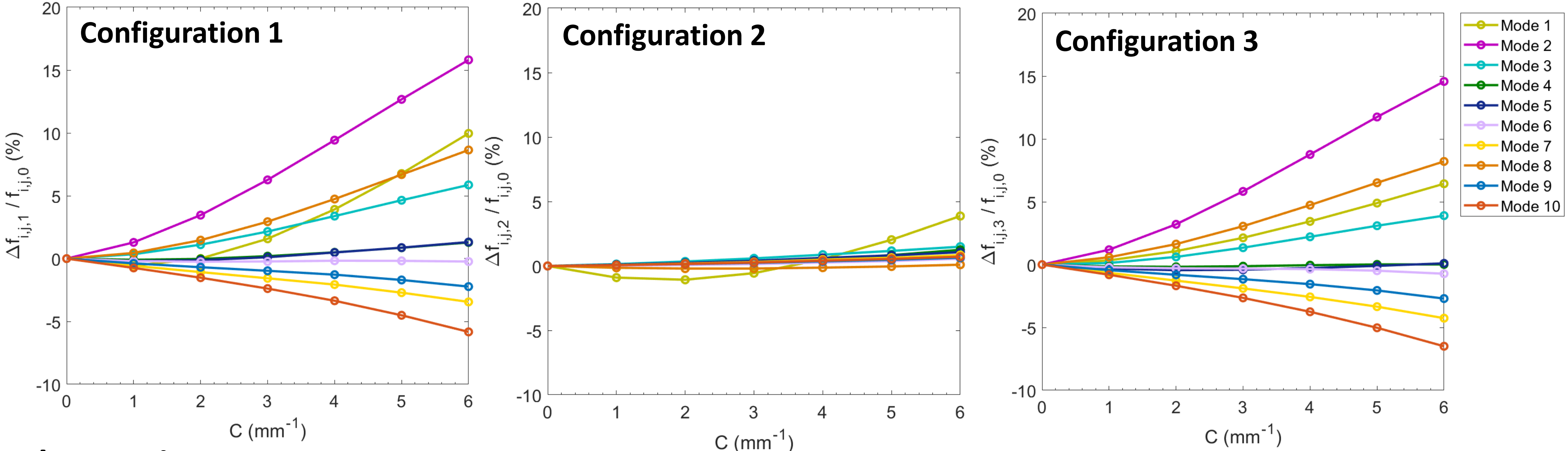
→ The variations seem to be mainly due to the resulting geometry

Results

Flattening step

$$\frac{\Delta f_{i,j,k}}{f_{i,j,0}} = \frac{f_{i,j,k} - f_{i,j,0}}{f_{i,j,0}} \times 100$$

$$\textit{where } f_{i,j,k} \textit{ the eigenfrequency of the eigeinmode } i \textit{ for } C = j \textit{ in configuration } k$$



Observations

- The variations are bigger than before
- Variations are small for configuration 2
- The results in configuration 1 and 3 are very close

→ The variations seem to be mainly due to the resulting stress state

Results

Other techniques and conclusion

The results obtained with technique 2 are the same than those presented before

Shaping step

Variations for techniques 1 and 3

- Seem to be driven by both the resulting geometry and stress state
- Show similar trends and amplitudes

Flattening step

For all techniques the variations are:

- More important than after the shaping step
- Mainly due to the resulting stress state

Variations show different trends and amplitudes

→ The impact of bracing techniques differs from one technique to another, in terms of trend, amplitude, but also of dominant factor (resulting geometry/stress state)

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Conclusions and perspectives

Conclusions

- Present the assessing playability problematics for heritage musical instrument
- Propose a model-based methodology to study the mechanical state induced by soundboard fabrication techniques
- Preliminary study on traditional soundboard bracing techniques

Perspectives

- Apply the model-based methodology to a real instrument of the collection
- Reproduce a precise soundboard fabrication technique
- Study and position the impact of the different fabrication steps on the dynamical response of braced soundboard

Facsimile of the Christoph Koch Archlute soundboard

Christoph Koch Archlute (1654) E.546

Thank you for your attention !