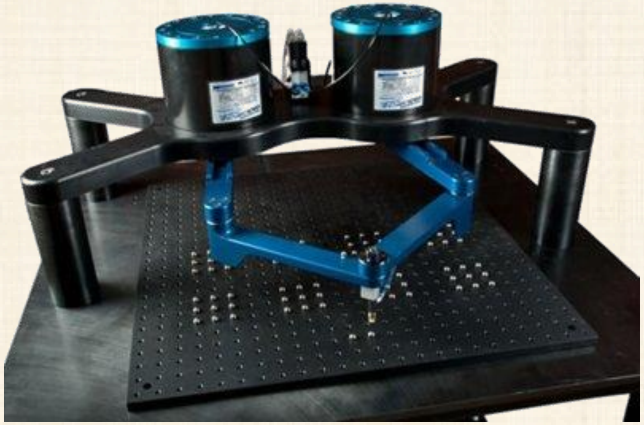
Journée des Jeunes Chercheurs en Robotique
JJCR'17

November 07, 2017



Design and Control of an Industrial Wooden Robot

RobEcolo

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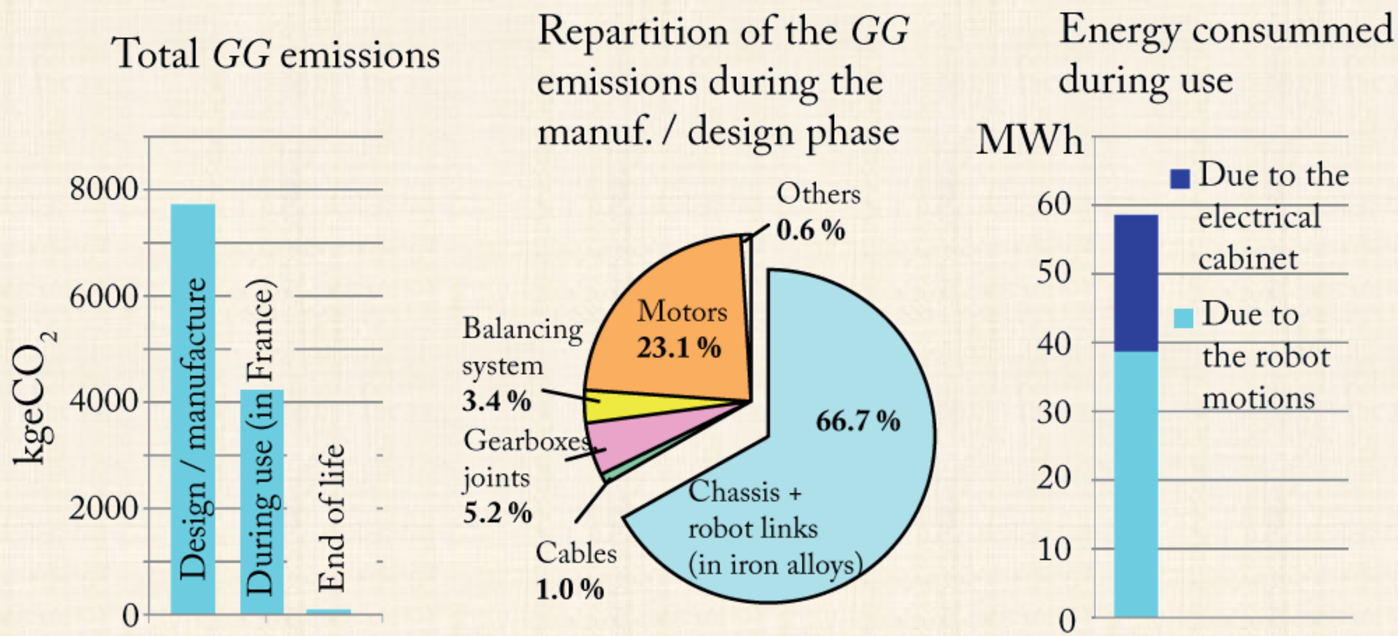
RobEcolo Project



The CO_2 release during use in other coutries is much bigger as most of the energy production in France is due to nuclear power plants (releasing much less CO_2 than other types of plants)

Fig. 1. Environmental impact of a Kuka KR 270 robot during its total life cycle (manufacturing + use during 12 years) / Energy consummed during the use phase (data from)

Fizians Environnement "Eco-design of two types of robots: KUKA 270 and IRSbot-2", 2014.

RobEcolo Project

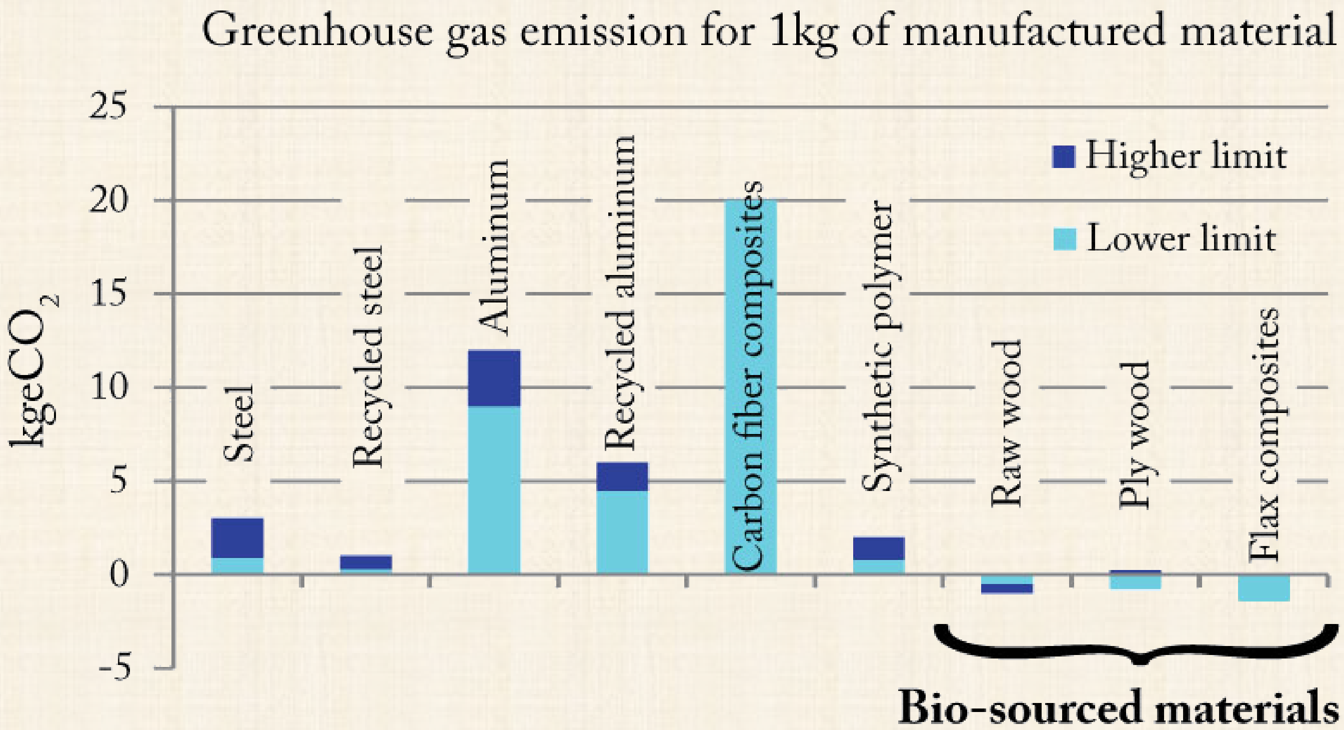
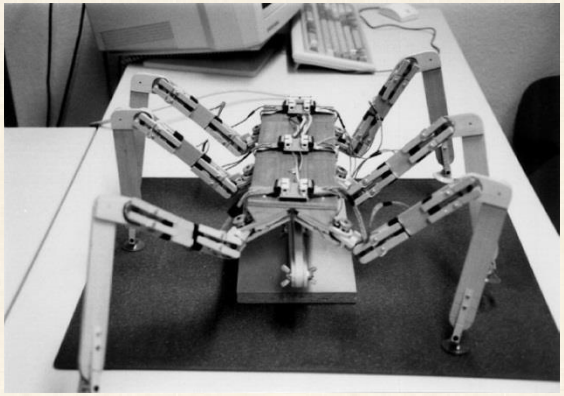
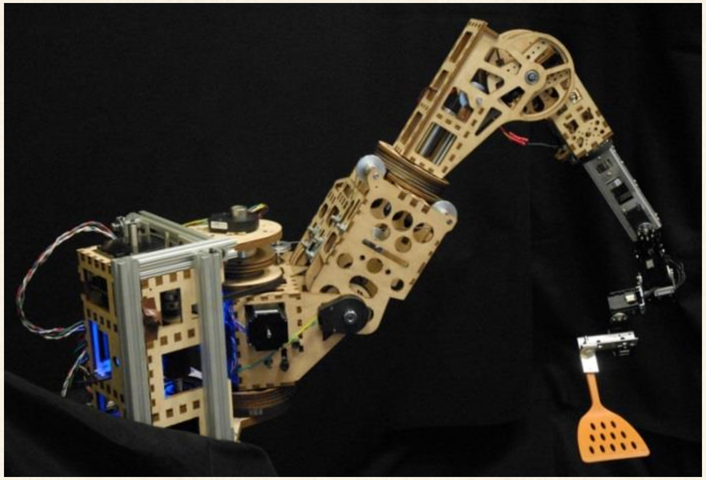


Fig. 2. Greenhouse gas emitted for the production of several materials (equivalence measured in kg of CO2 – data taken in)

T. Laurent et al., "Eco-conception: Vers un Robot en Bois" , Technologie, 168, 2010.

Some examples of wooden robots

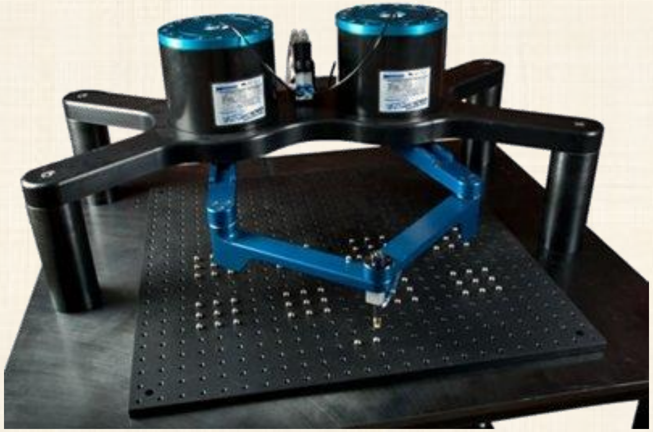




Objectives

RobEcolo

Design and control of an industrial wooden (parallel) robot



- **Repeatability** < 500 microns
- **Deformation** < 500 microns (under a payload of 1 kg)
- **Workspace of** 800 mm x 200 mm

RobEcolo Project

- **Bio-sourced materials:**
  - Little (even no) Environmental Impact (EI)
  - **Wood :** Good stiffness performance

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- **However**
  - Variation of the wood performance / dimensions

  with the atmospheric conditions / external sollicitations

RobEcolo Project

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- **However**
  - Variation of the wood performance / dimensions

  with the atmospheric conditions / external sollicitations

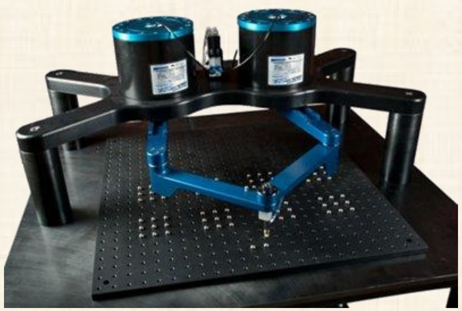
- **Challenge :**

  How to ensure the accuracy and stiffness of the robot even if wood properties vary ?

RobEcolo Project

The Choice of Wood

1



Wooden parallel robot with desired stiffness And accuracy

RobEcolo Project

1

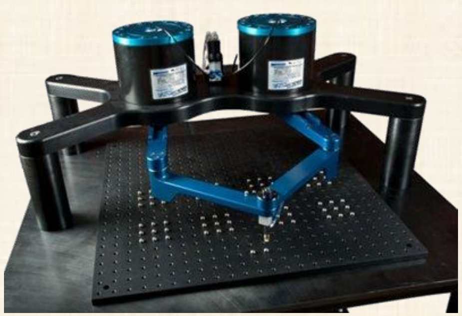
The Choice of Wood

2

Robust Design Approaches

↓

Predictive Elastostatic and Elastodynamic Model



Wooden parallel robot with desired stiffness And accuracy

RobEcolo Project

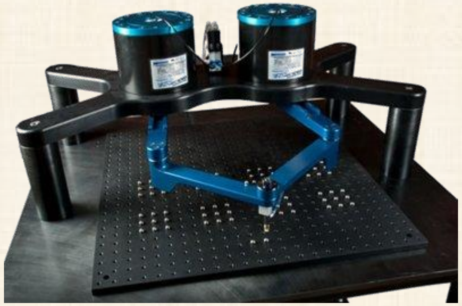
1 **The Choice of Wood**

2 **Robust Design Approaches**

↓

Predictive Elastostatic and Elastodynamic Model

3 **Sensor-based Control**



Wooden parallel robot with desired stiffness And accuracy

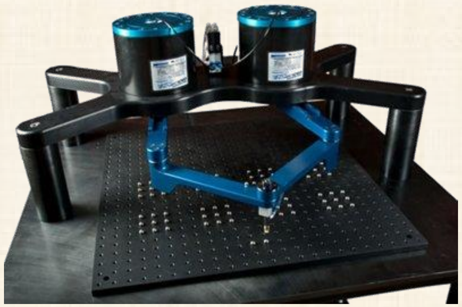
RobEcolo Project

1 **The Choice of Wood**

2 **Robust Design Approaches**

Predictive Elastostatic and Elastodynamic Model

3 **Sensor-based Control**



Wooden parallel robot with desired stiffness And accuracy

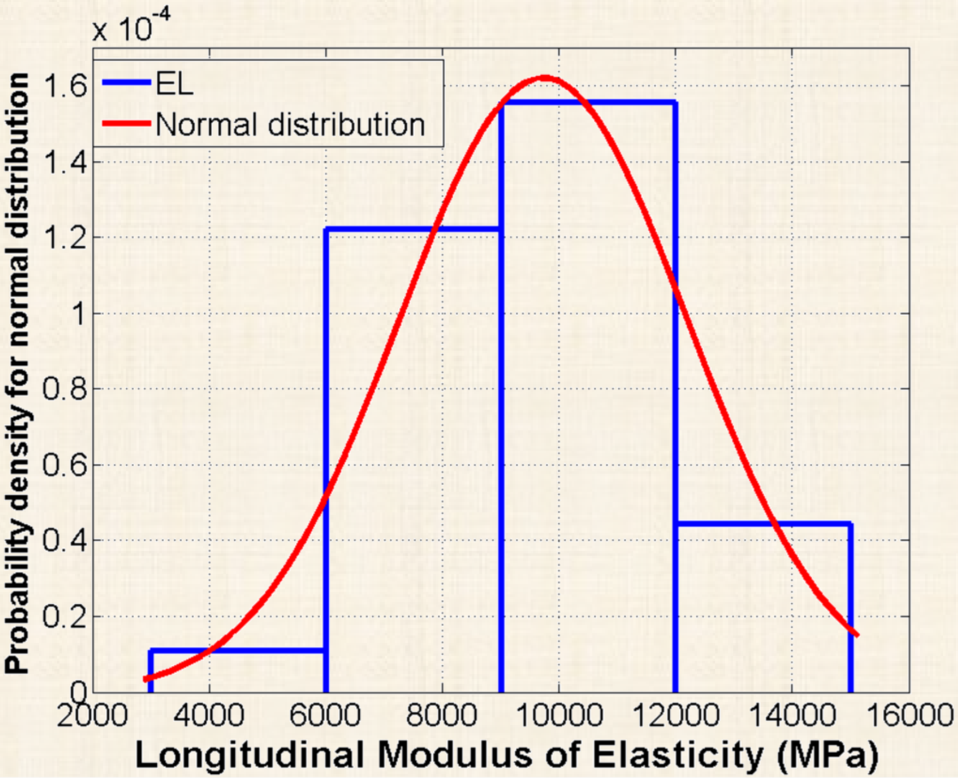
Outline

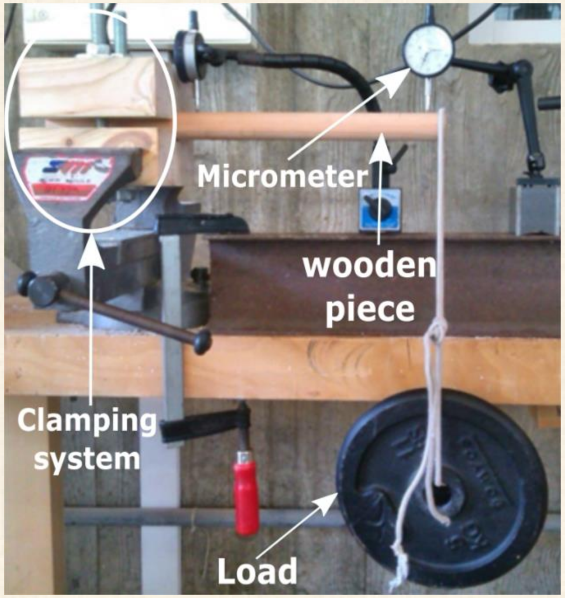
- Introduction
- Mechanical Properties of Wood
- Design Process of a Wooden Five-bar Mechanism
- Perspectives

Mechanical Properties of Wood

Bending Tests: Results

- Variable **Young's Modulus**





- **Mean value:**

$$\mu_{EL} = \mathbf{9732}\ MPa$$

- **Standard deviation:**

$$\sigma_{EL} = \mathbf{2462}\ MPa$$

Design of an Industrial Wooden Robot

Design Process: Methodology

Design of an Industrial Wooden Robot

Control-based Design

Robust Topology Optimisation

Design Process: Methodology

Design of an Industrial Wooden Robot

Control-based Design → **Robust Topology Optimisation**

↓

Dimensions of the Robot Links

Design Process: Methodology

Design of an Industrial Wooden Robot

Control-based Design → **Robust Topology Optimisation**

↓ **Dimensions of the Robot Links**

↓ **Shape of the Robot Links**

Design Process: Methodology

Design of an Industrial Wooden Robot

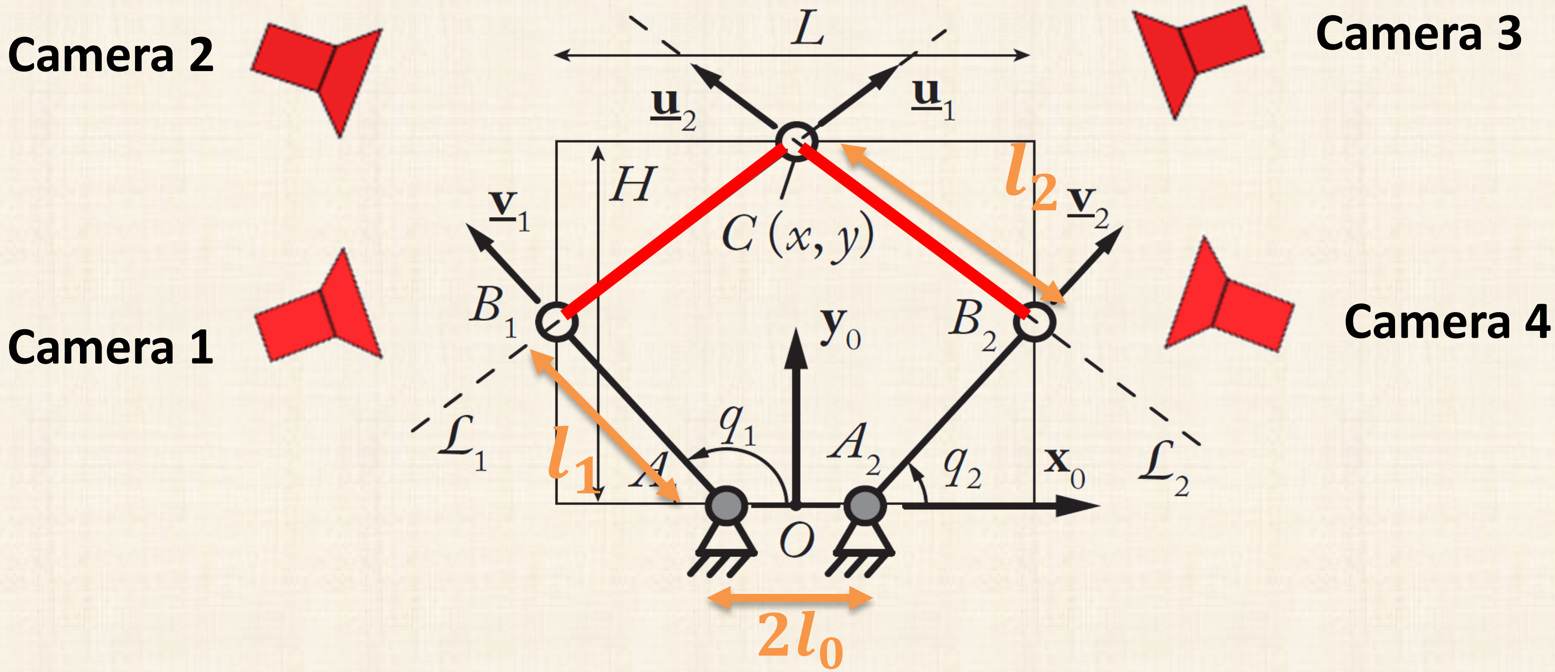
Control-based Design → **Robust Topology Optimisation**

Control-based Design ↓ **Dimensions of the Robot Links**

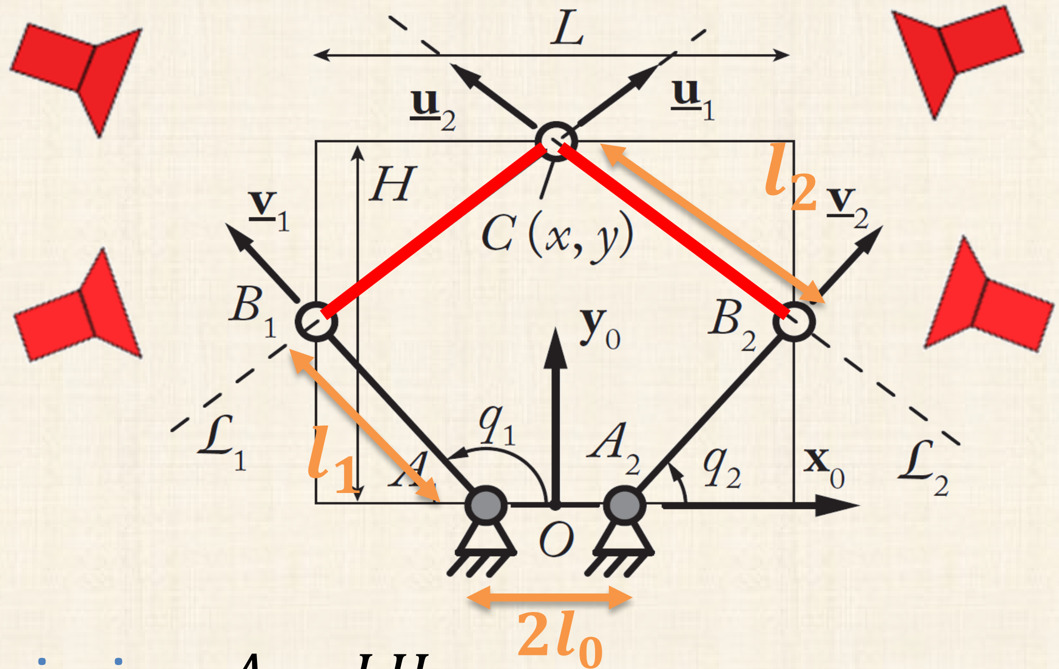
Robust Topology Optimisation ↓ **Shape of the Robot Links**

Reach the desired accuracy and stifness performances

Control-based Design



Control-based Design



minimise $A = LH$

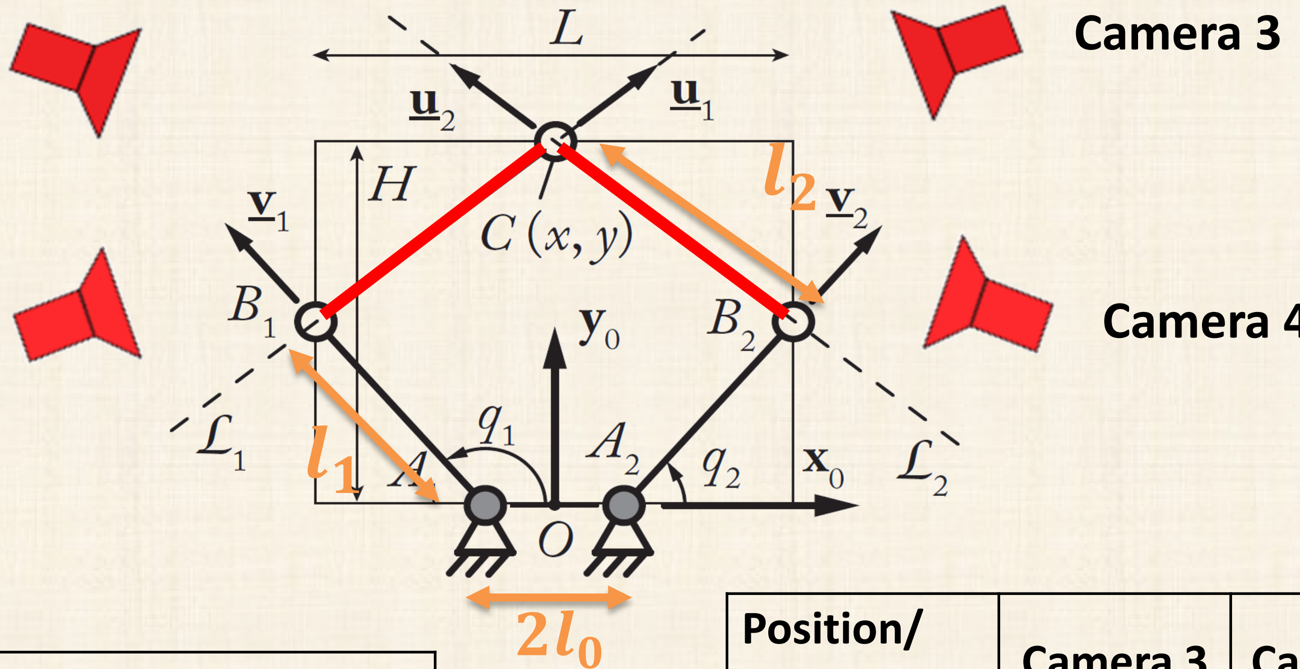
over $\mathbf{x} = [l_1 \quad l_2 \quad l_0 \quad X_{c1} \quad X_{c2} \quad X_{c3} \quad X_{c4}]^{\mathrm{T}}$

subject to $l_{W_L} \geq l_{W_0}$

$h_{W_L} \geq h_{W_0}$

L. Kaci et *al* . "Control-based Design of a Five-bar Mechanism". *(EuCoMeS2016)*. Nantes, France, September 2016.

Control-based Design



Geometric parameters		
l_0	$[m]$	0.125
l_1	$[m]$	0.280
l_2	$[m]$	0.400
A	$[m^2]$	**0.1372**

Position/ Orientation	Camera 3	Camera 4
x_c $[m]$	0.01	0.02
y_c $[m]$	0.5	0.5
z_c $[m]$	0.75	0.75
ϕ $[rad]$	0	0
θ $[rad]$	π	π
ψ $[rad]$	0	0

Reliable Topology Optimisation

Problem formulation

$$E(\|\mathbf{u}_\mathrm{e}\|) + \mathrm{k}\,\sigma(\|\mathbf{u}_\mathrm{e}\|) \leq \mathrm{u}_{\mathrm{max}}$$

- $E(.)$: expectation operator
- $\sigma(.)$: Standard deviation operator
- k: a positive real
- $\mathbf{u}_\mathrm{e}$: deformation vector at given nodes, for a fixed nodal loading $\mathbf{f}$

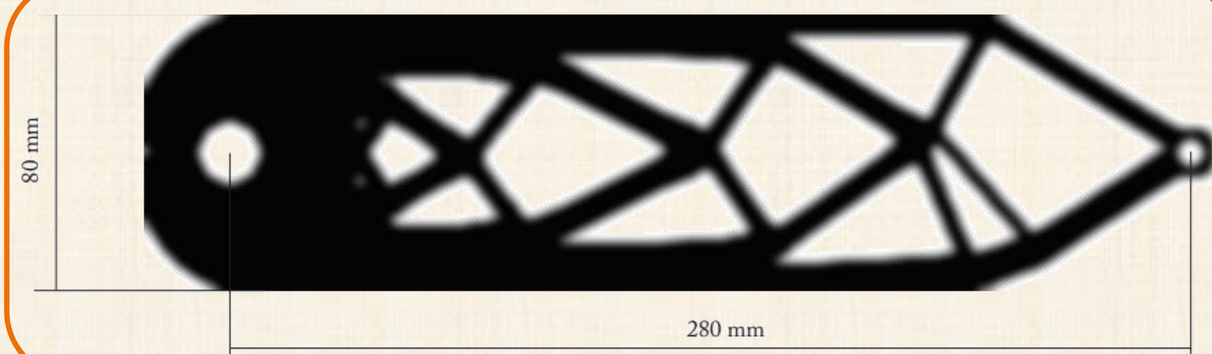
Reliable Topology Optimisation

1. Initial Design

Reliable Topology Optimisation

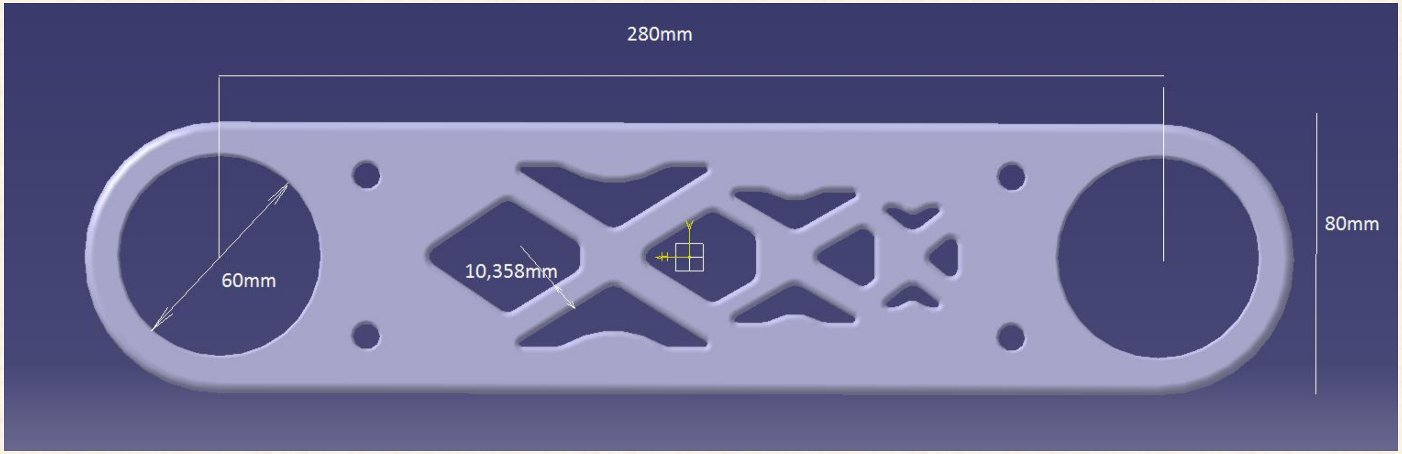
1. Initial Design

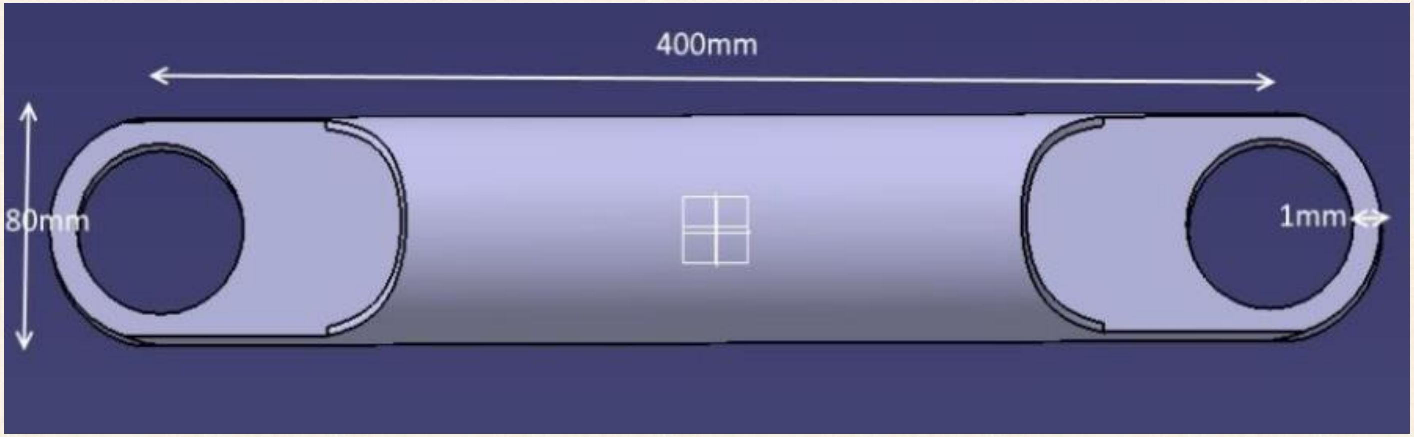
2. Final Design



CAD Model

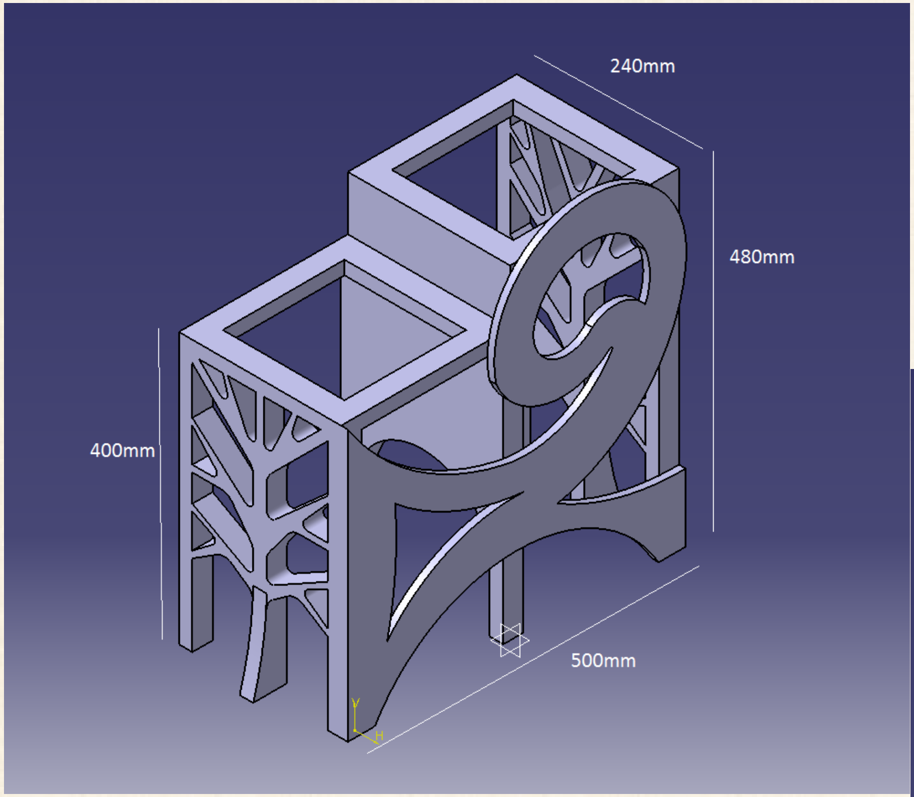
Robot Links

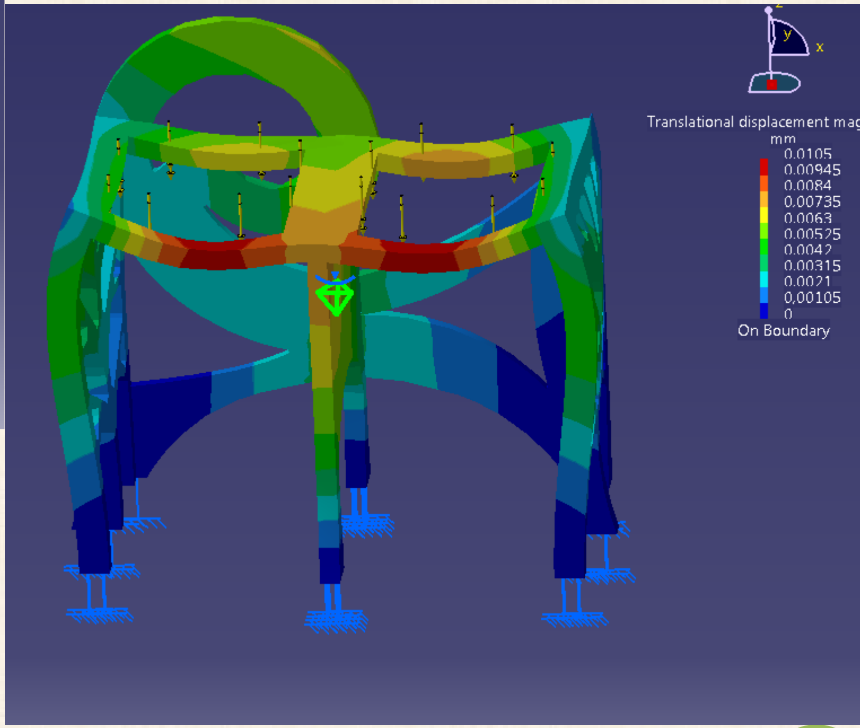




CAD Model

Robot Chassis

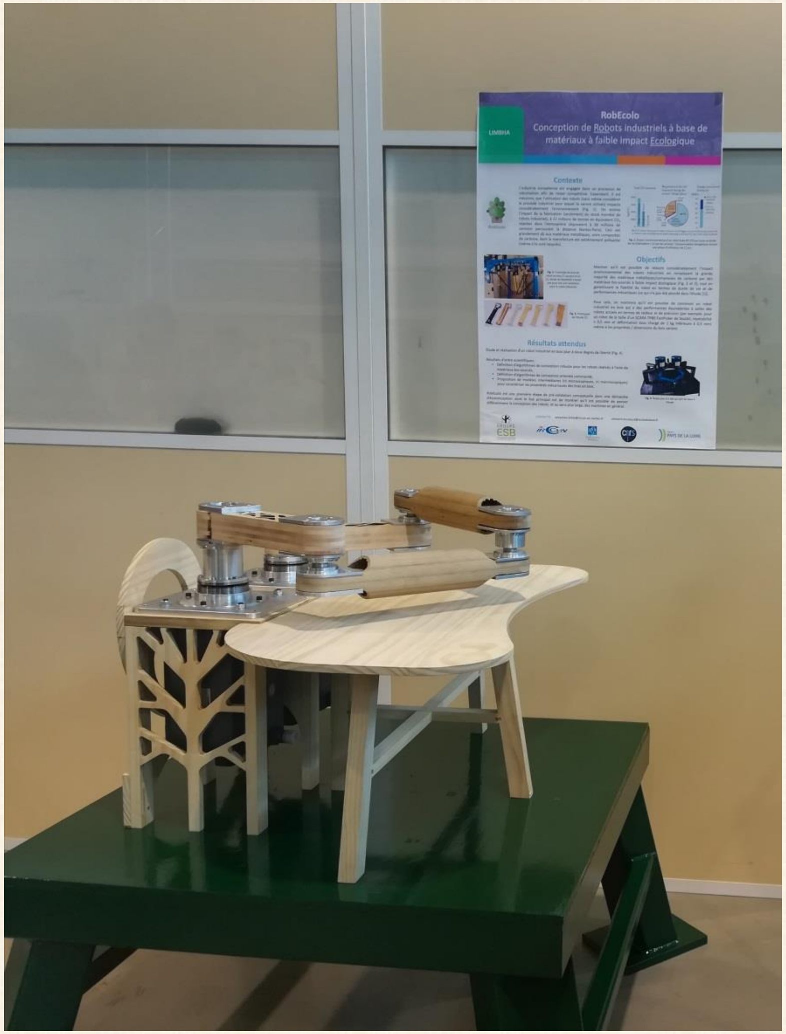




CAD Model

Wooden Robot

Final Prototype



Final Prototype

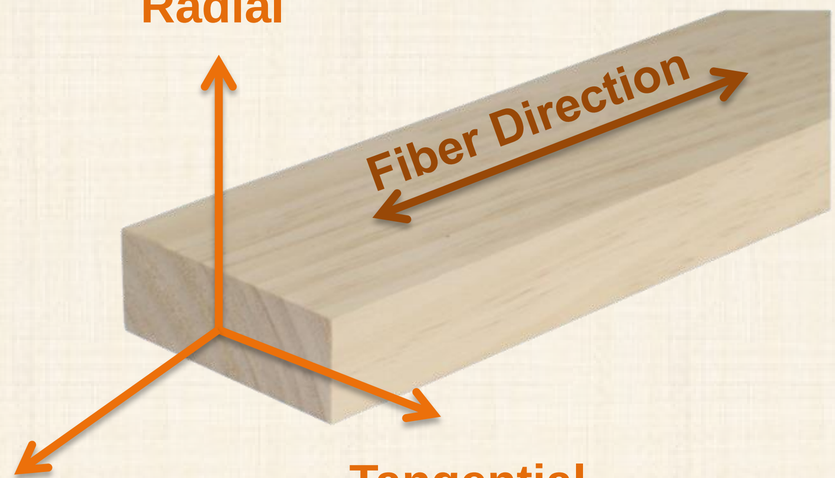
Perspectives

- **Develop of Sensor-based Controller**
- **Validate all theoretical developments**

Thank you !

Acetylated Wood: Accoya Pine

- Dimensional stability
- Durability



Orthotropic Material

- **Young's Moduli:**

E_L, E_R and E_T

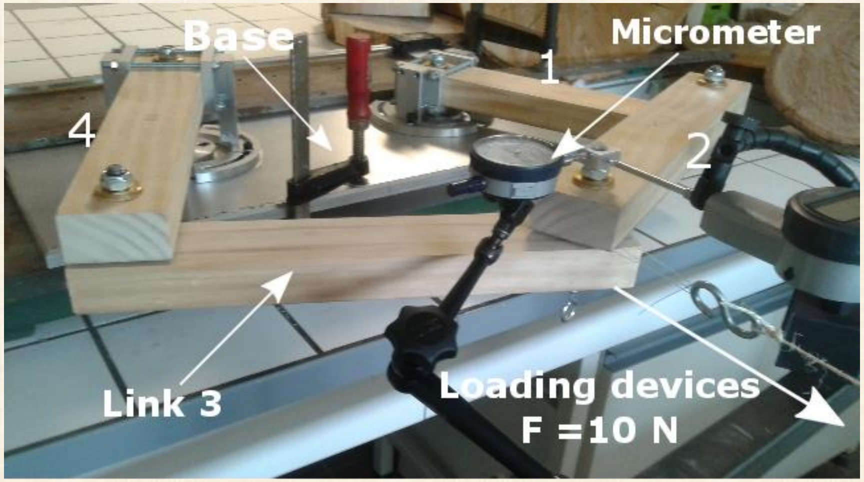
- **Poisson's ratios:**

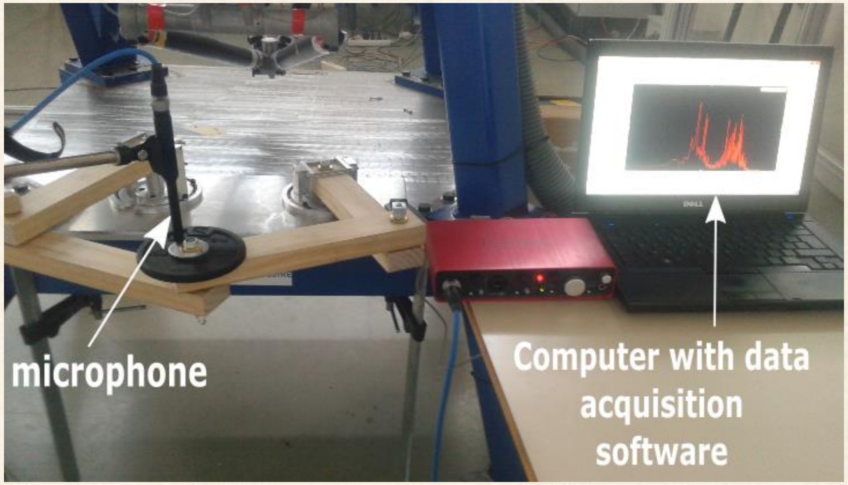
$\nu_{LR}, \nu_{LT}, \nu_{RT}, \nu_{RL}, \nu_{TL}$ and ν_{TR}

$$E_L \text{ and } \nu = \frac{\nu_{LR}+\nu_{LT}}{2}$$

Elastic Modelling of a Wooden Parallel Robot

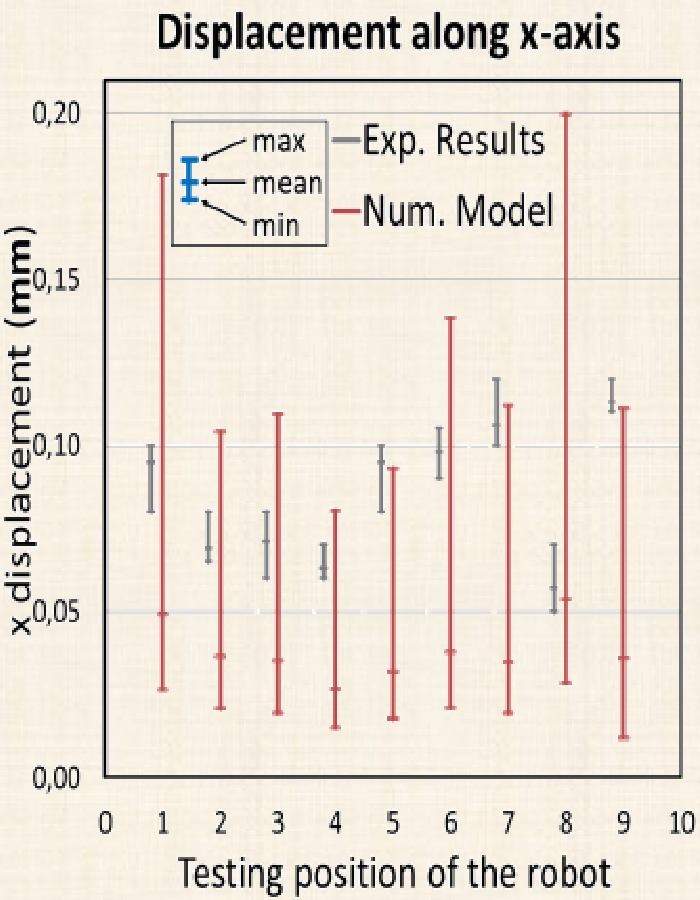
1. **Predictive Elastostatic and Elastodynamic Models => Monte-Carlo Method**
2. **Deterministic Models**

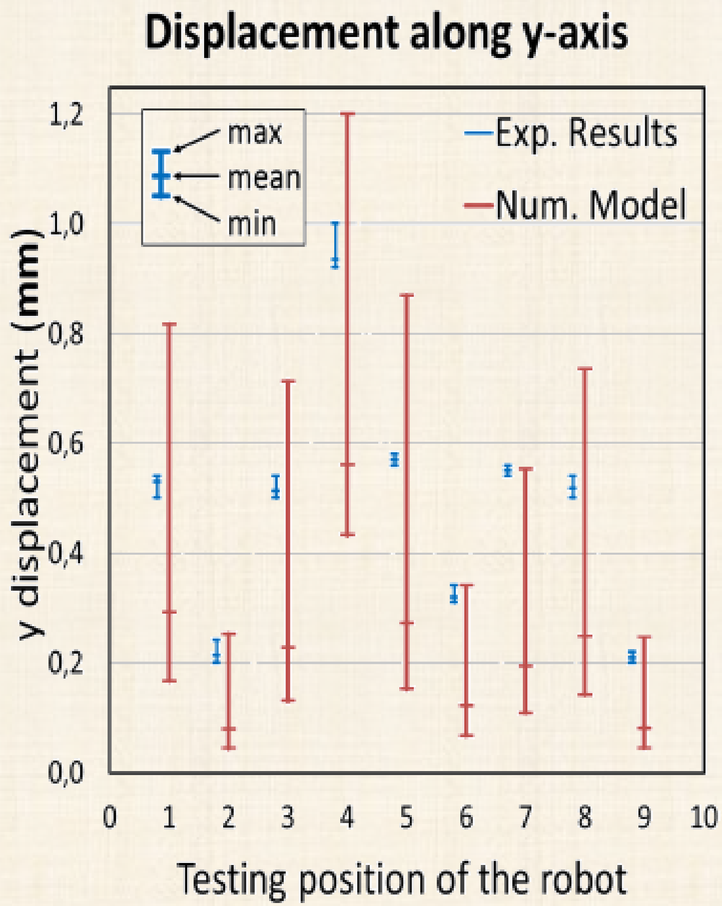




L. Kaci et al. "Elastostatic Modelling of a Wooden Parallel Robot," *(CK2017)*, May 22-24, 2017 Futuroscope-Poitiers, France.

Comparison exp /num

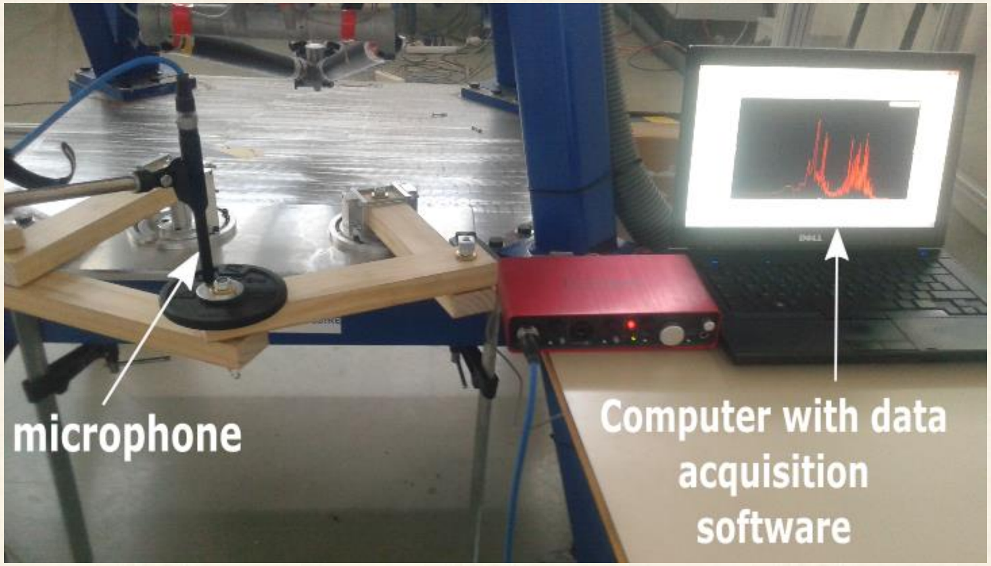




Exp : the mesures are repeated 10 times, 1 prototype

Num : random draws of rigidities, equivalent to « 40000 robots »

Comparison exp /num



Freq (Hz)	Num.mean	Num.min	Num.max	Exp
1	55.43	30.94	70.13	32
2	72.263	39.88	94.06	49
3	142.28	75.98	181.11	90
4	197.52	117.21	250.52	138
5	286.28	183.09	351.25	219