Towards the eco-design of robotic manipulators using raw plant materials

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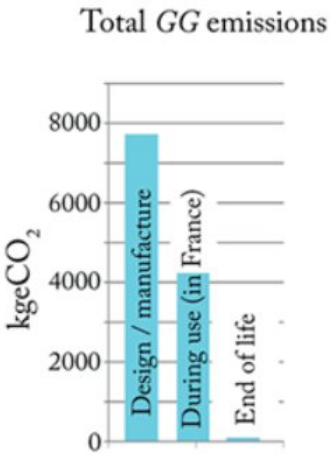
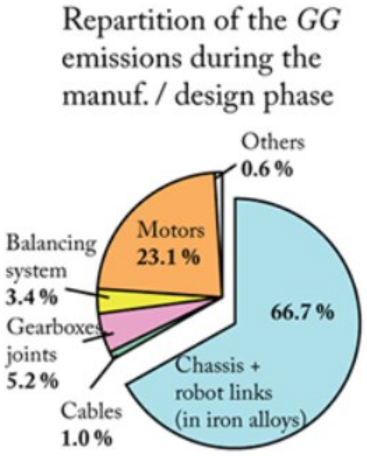
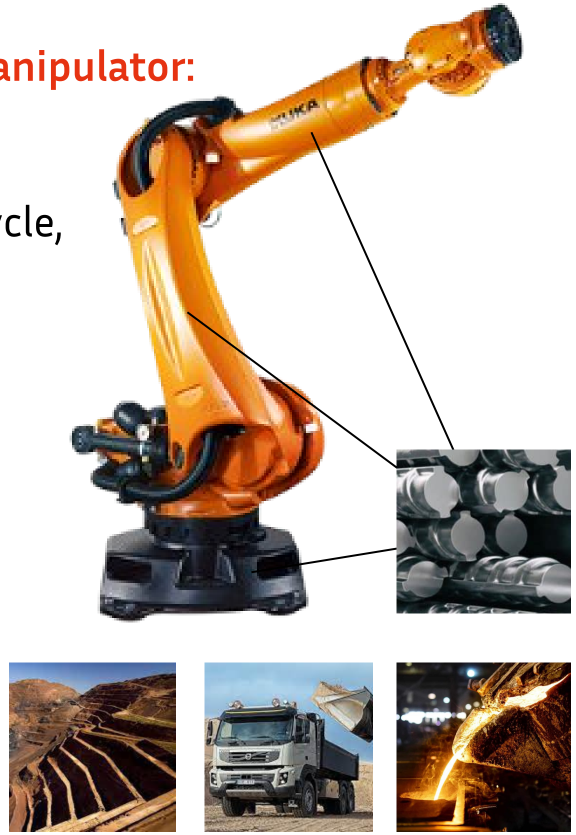
Question: industrial manipulators and ecology

Ecological impact of an industrial manipulator:

- IFR: 2,7M d'unités, +10-12% / an
- Impact at each phase of the life cycle, fabrication ++







Assumptions:

- The demand of robots will continue increasing
- Legislation will be more constraining concerning the eco. impact of robots

How can we lower the impact of an industrial manipulator, during its manufacture and end of life ?

Disclaimer: This is one out of many research avenues !

From serial rigid to parallel continuum

Amount of material (Limb, joints, actuator size)

Serial rigid collaborative

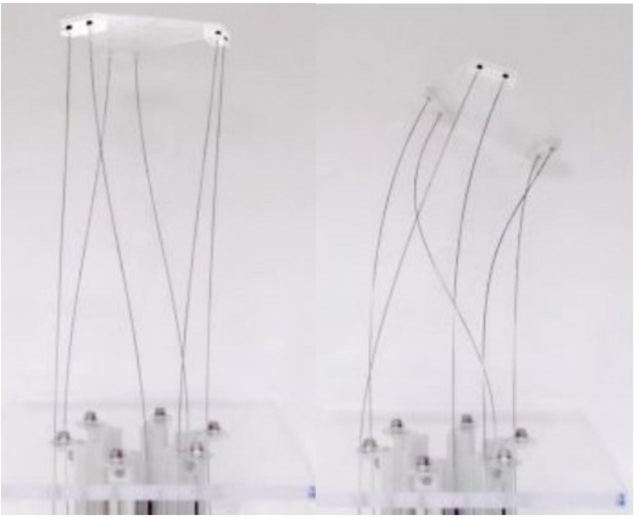
Aluminium

Parallel rigid

Carbon fiber composites

Parallel continuum

Nitinol (Ni-Ti)



But impactfull materials, production impact ++ or end of life - -

Main concept

Use of raw plant materials:

- Can have interesting performances
- Require few resources to grow
- Are flexible by nature
- Are bio-degradable

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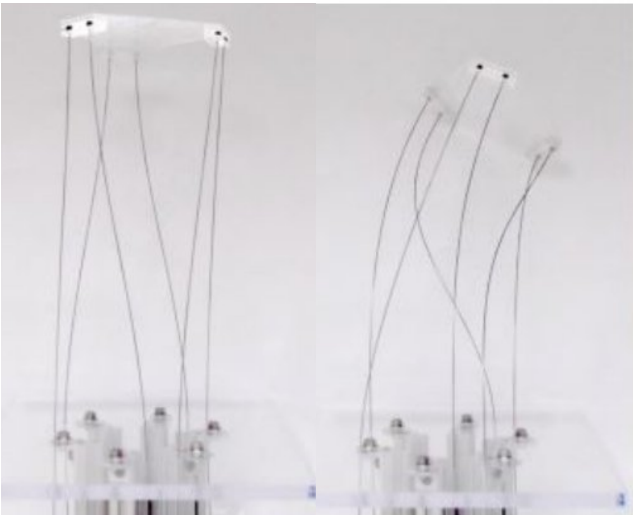
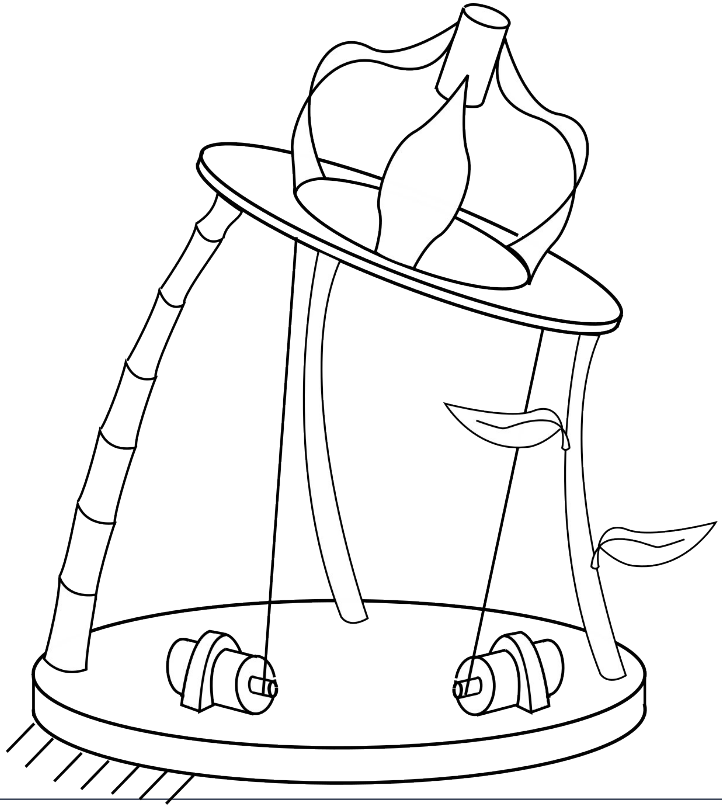
Tools, technologies, methodologies of soft and continuum robotics





Raw plant-based materials

[Wicker] [Bamboo] [Potato]

The case of wicker wood and bamboo...

Choice of the material : Wicker wood and bamboo

Overview:

- **Renowned mechanical properties:** Wicker wood has been used in basket making and other handcrafts for thousands of years. Bamboo is widely used in structures such as huts, bridges and scaffoldings.
- **Great availability and low cost:** Can be cultivated in many different climates.
- **Fast growth:** Harvest age: 1 year (Wicker wood), 1-3 years (Bamboo).
- Many different species and treatments available, choice depends on the desired usage.

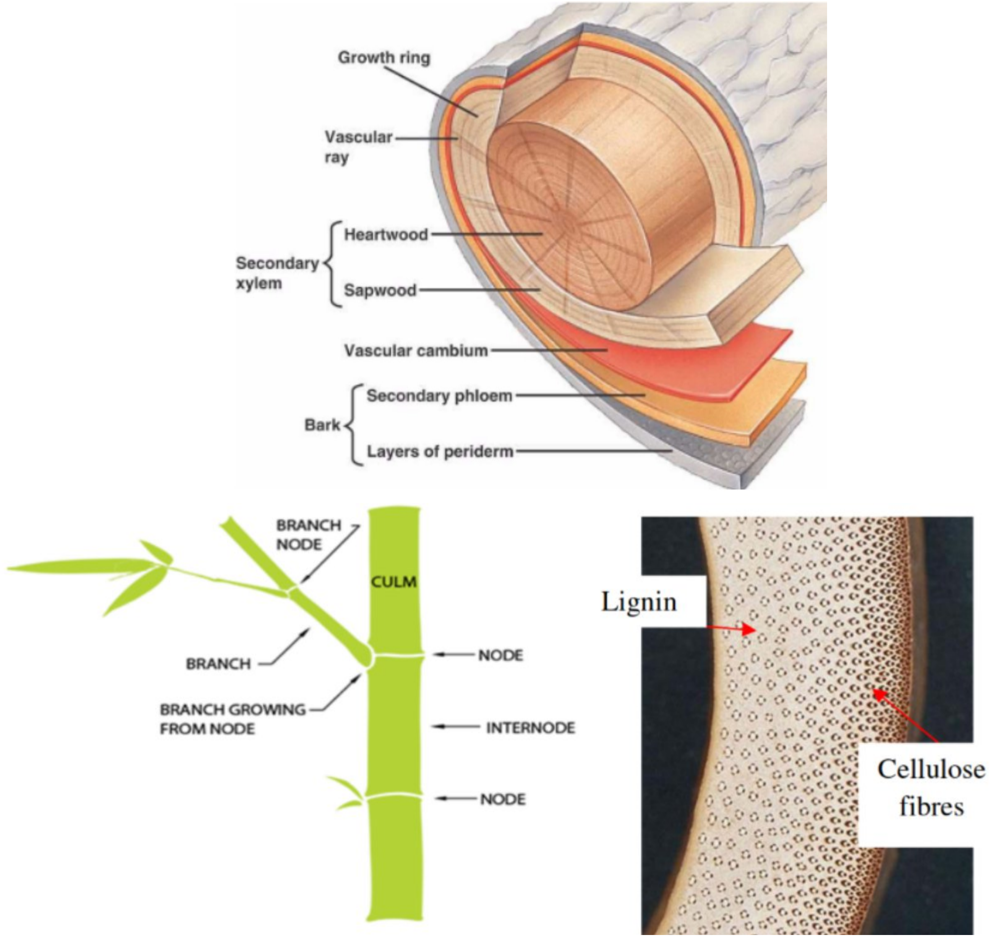
Wicker wood in basket making

Bamboo scaffolding

Choice of the material : Wicker wood and bamboo

Challenges:

- Complex structure: Non-linear viscoelastic behavior, orthotropic nature.
- Variation of the mechanical properties due to many factors : Species, age, growth conditions, **temperature**, **humidity**, etc.
- Natural decay: Susceptible to moisture and pest attacks if not stored properly.
- Dependence on the crop cycle: fresh material can be of unavailable at certain periods of the year.



Wood and bamboo structure

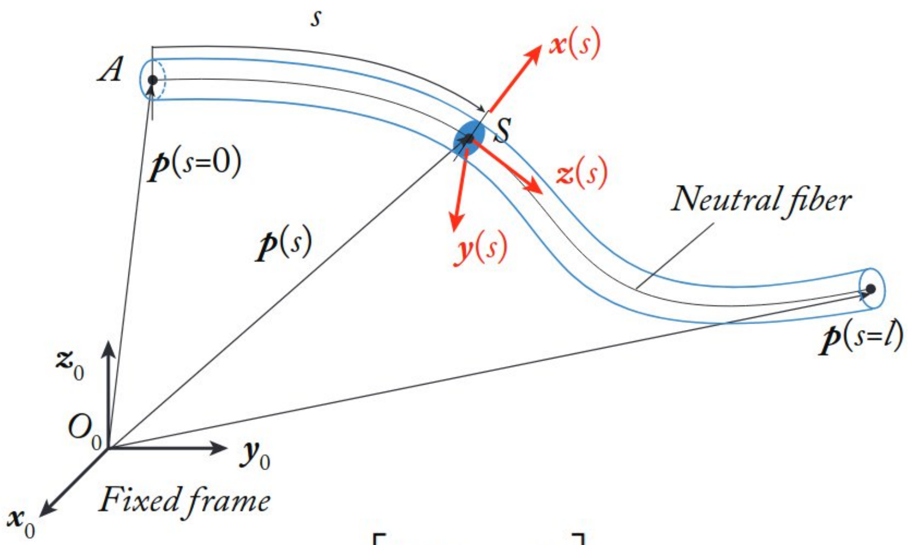
Modeling: Cosserat Model

Overview:

- Widely used in the soft and continuum robotics community
- Handles complex, non-linear behavior

Mathematical formulation :

- Body = Set of continuously rigid cross-sections stacked along a material line
- Set of ODEs coupled with constraint equations
- Requires numerical integration methods to solve boundary-value problems
- Equilibrium between internal and external forces:
  - Internal : Material stiffness and deformation
  - External: Gravity, interaction forces, actuation inputs, etc



$$g(s) = \begin{bmatrix} R(s) & p(s) \\ 0 & 1 \end{bmatrix}$$

$$\begin{cases} p'(s) &= R(s)v(s) \\ R'(s) &= R(s)\hat{u}(s) \\ v(s) &= K_{se}^{-1}R^T(s)n(s) + v^*(s) \\ u(s) &= K_{bt}^{-1}R^T(s)m(s) + u^*(s) \\ n'(s) &= -f(s) \\ m'(s) &= -p'(s) \times n(s) - l(s) \end{cases}$$

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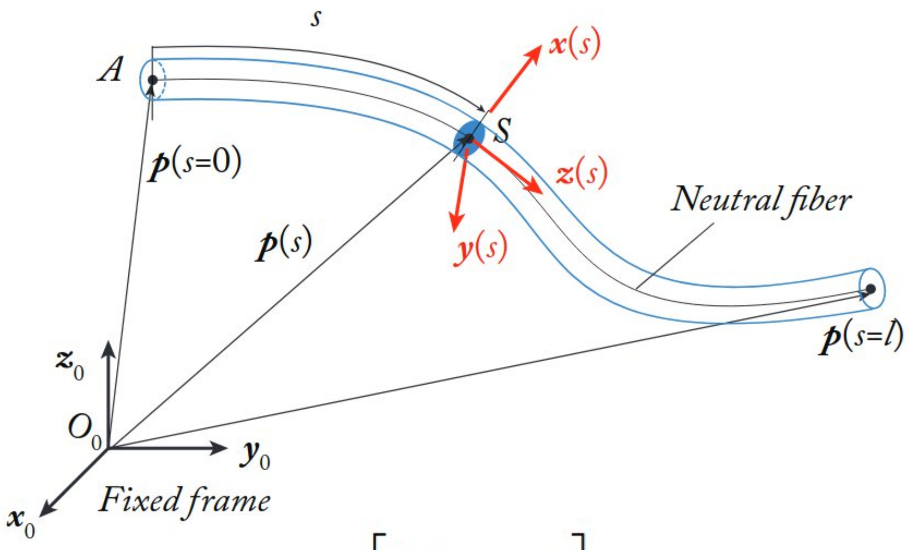

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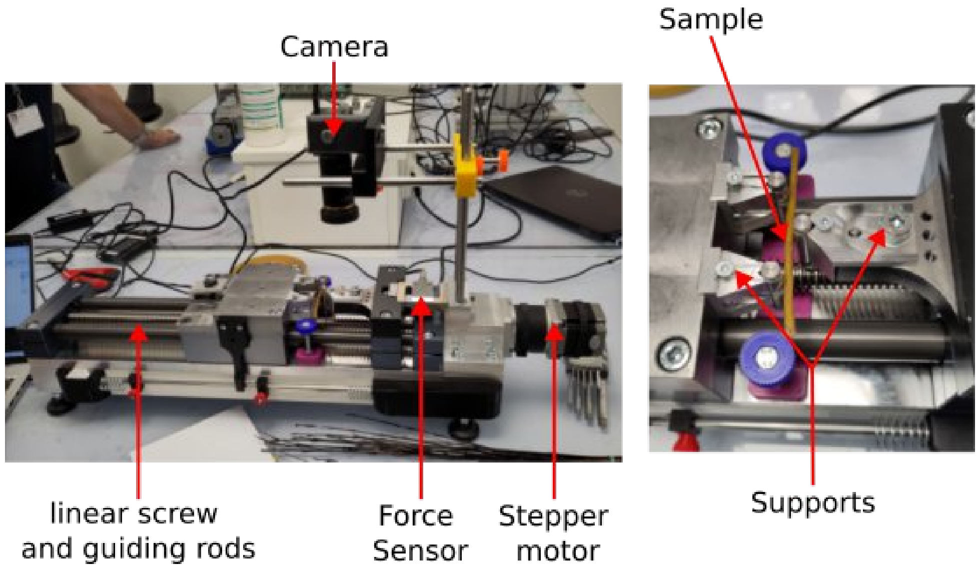
Mechanical characterization of the material

Goal:

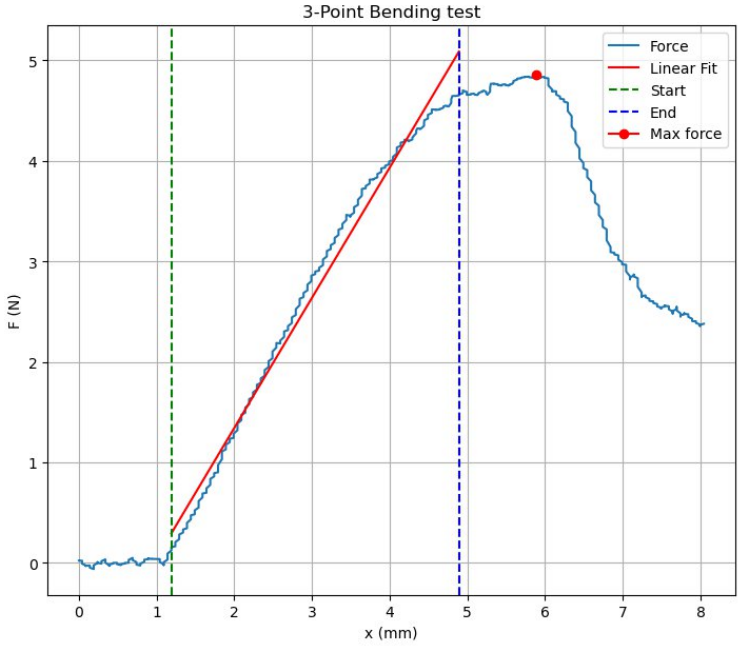
- Estimate the average mechanical properties of the material (Bending modulus, bending strength) and their variations

Methods:

- 3-Point bending test with vision measurement system:



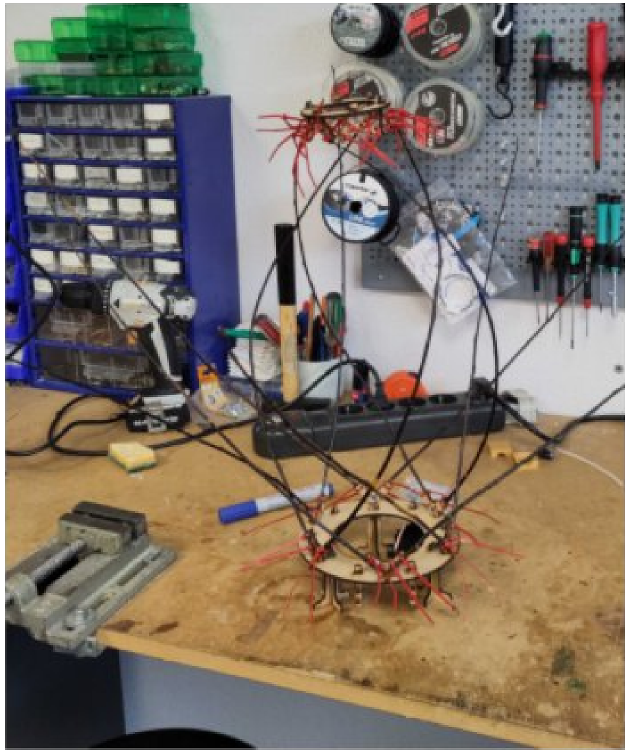
Test setup

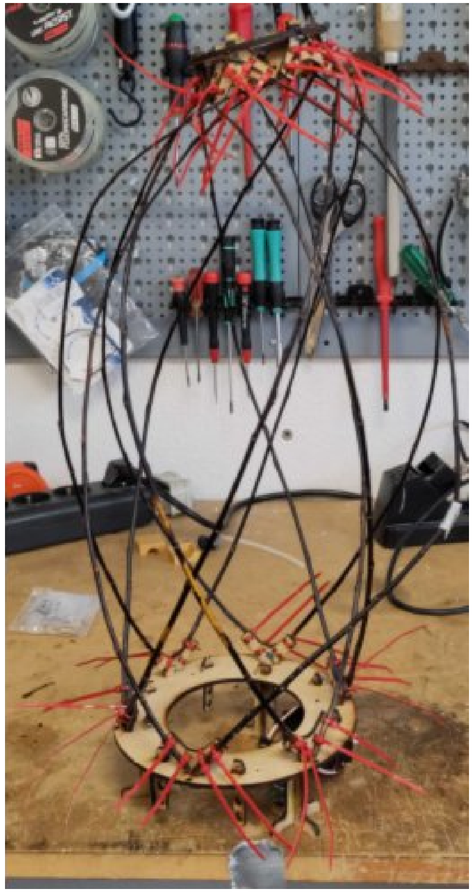


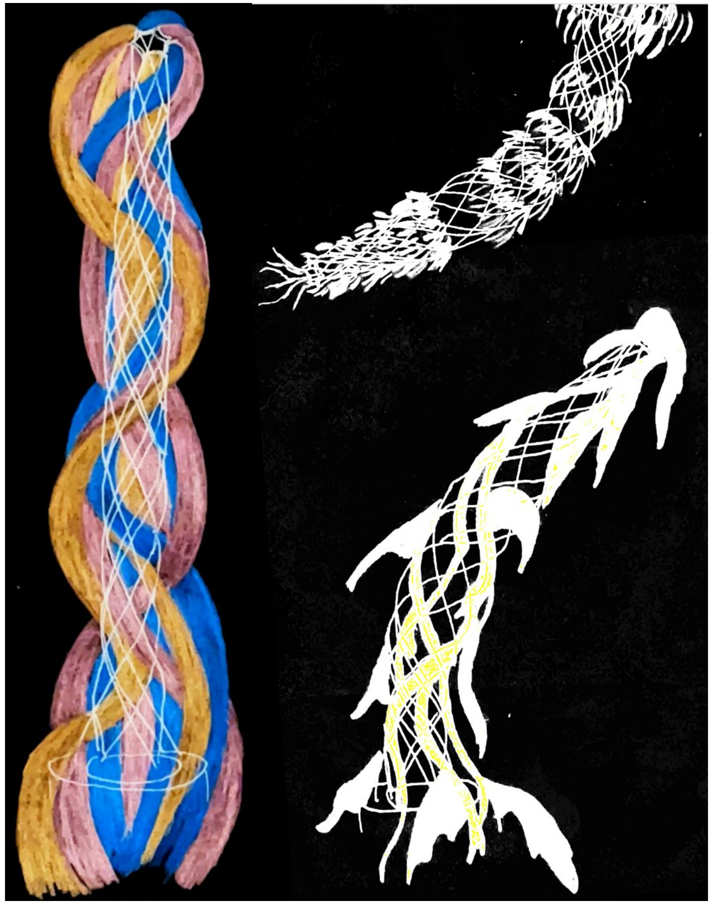
Force-displacement diagram

First prototype

Assembly:







Future work

Structure:

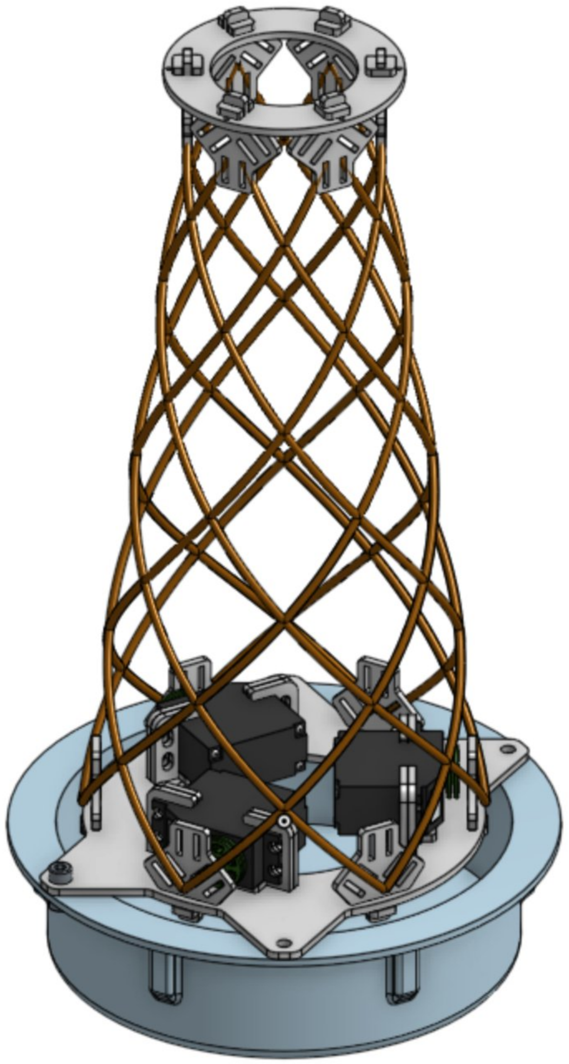
- Optimize the structure design to account for variations in the rods.

Model:

- Cosserat rod model + probabilistic approach (to estimate the mechanical properties of the flexible rods) + sensitivity matrices

Control:

- Use of robust control methods and exterioceptive measurements (Vision based, EM tracking,...) to take into account uncertainty and variations of the model parameters.

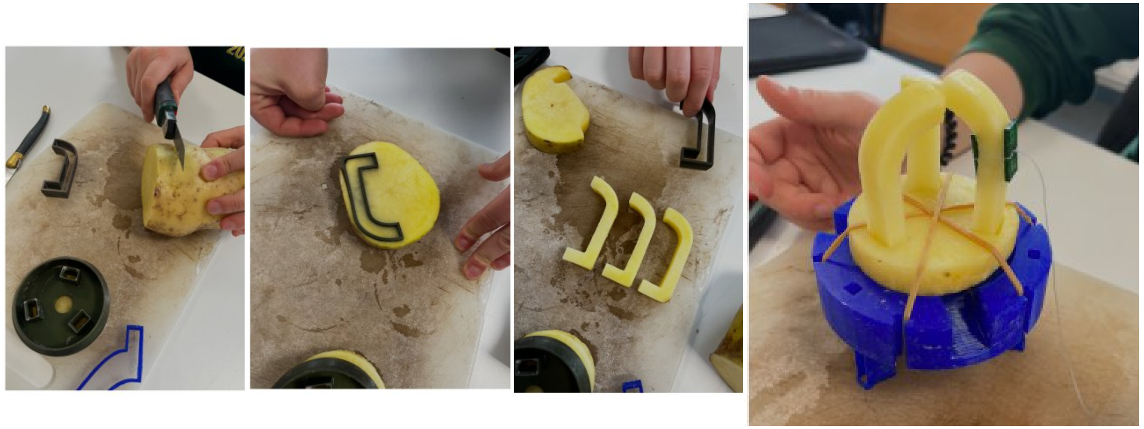


The case of the potato …

Context of the project

Student project at Centrale lille

- 12 students
- 3 semesters



Context: Raw plant-based materials will degrade in time but sometimes too slowly for research

Objectives:

- Develop a fast degrading deformable manipulator
- Evaluate the pros/cons of raw vegetal material

Questions:

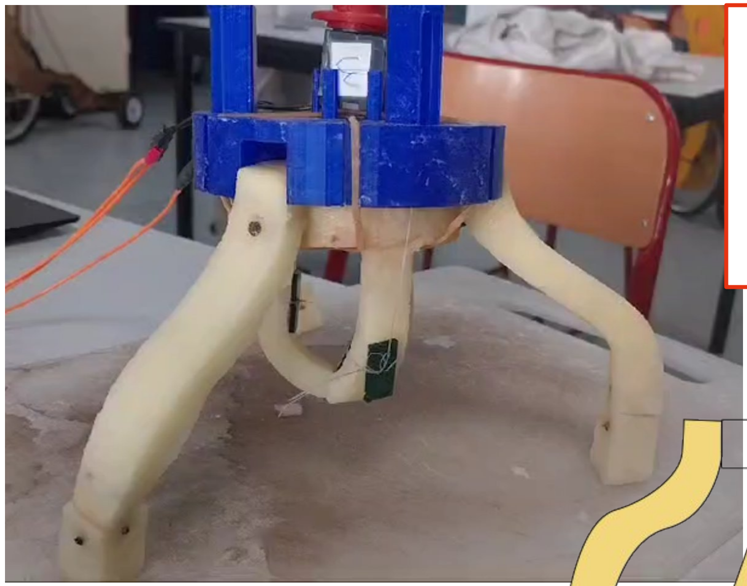
- Raw potato as a, building material for deformable robots ?
- Leads to lower ecological impact ?

Life cycle analysis

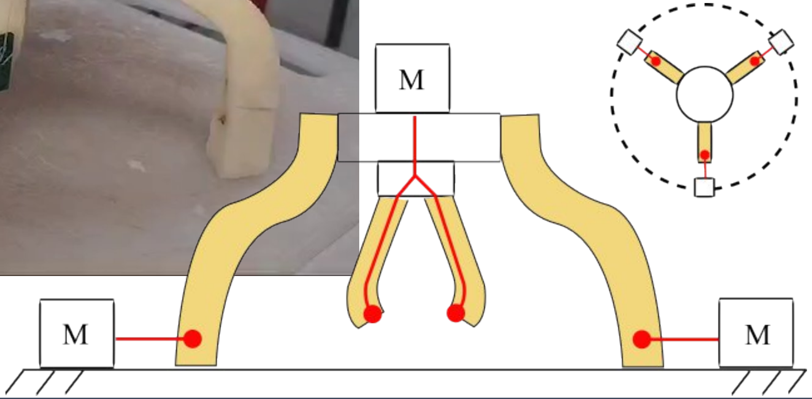
Software: SimaPro,
Database: EcoInvent

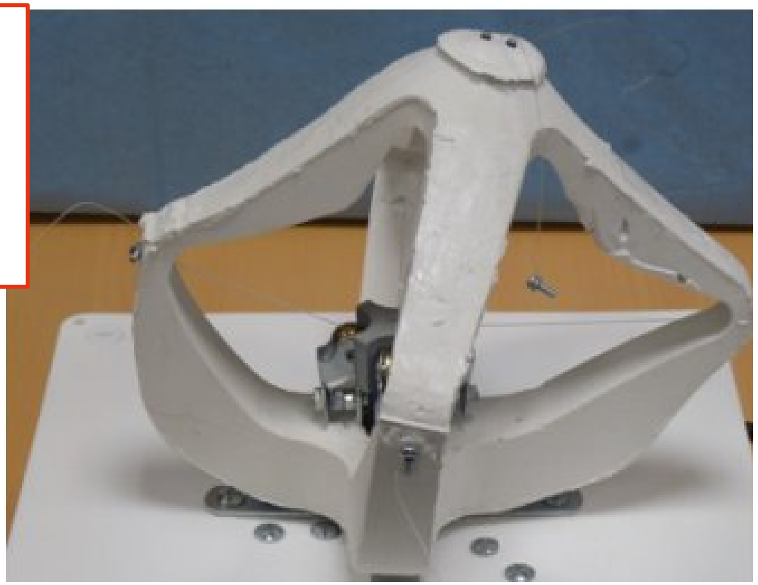
Case studies:

Material: EcoFlex silicone



Specifications:
- Workspace: 50x50mm
- Payload: 100g
- Comparable electronics/motors
- Comparable size/mass

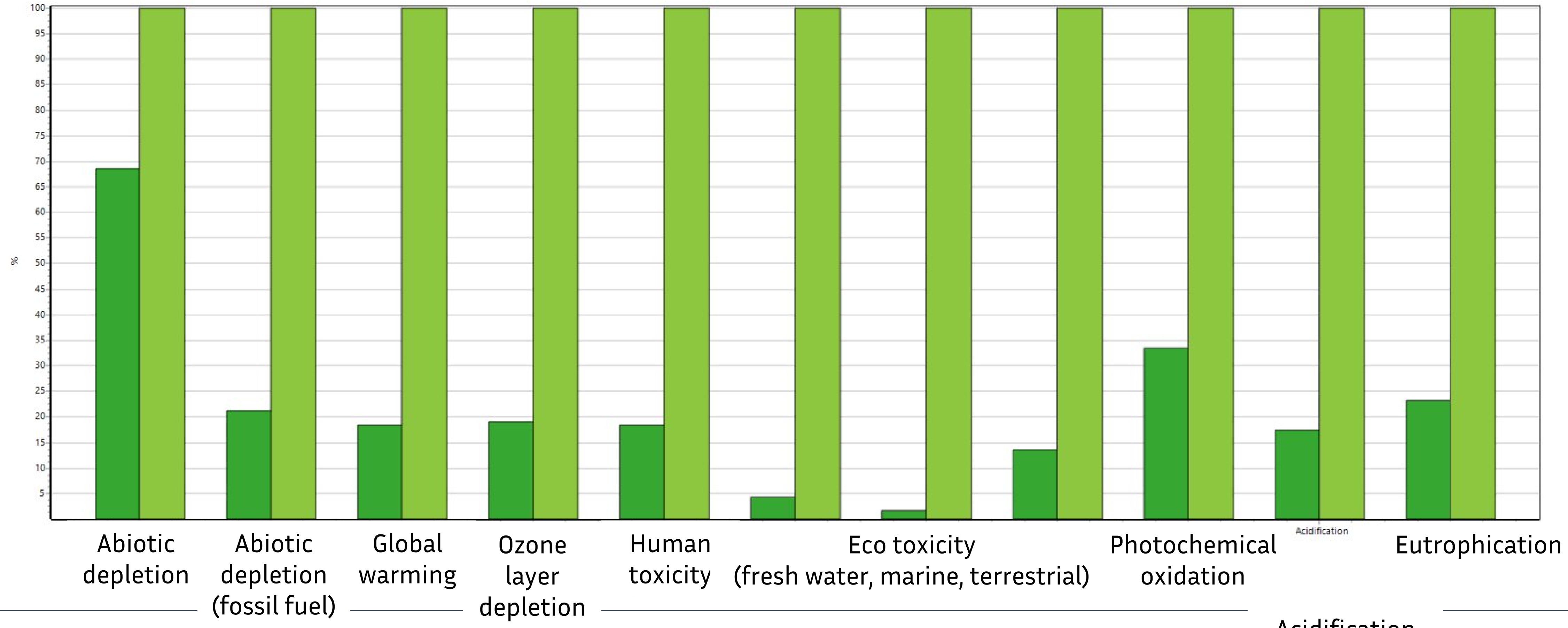




The potato robot

The “Diamant” robot

Comparison of robots: potato vs silicone



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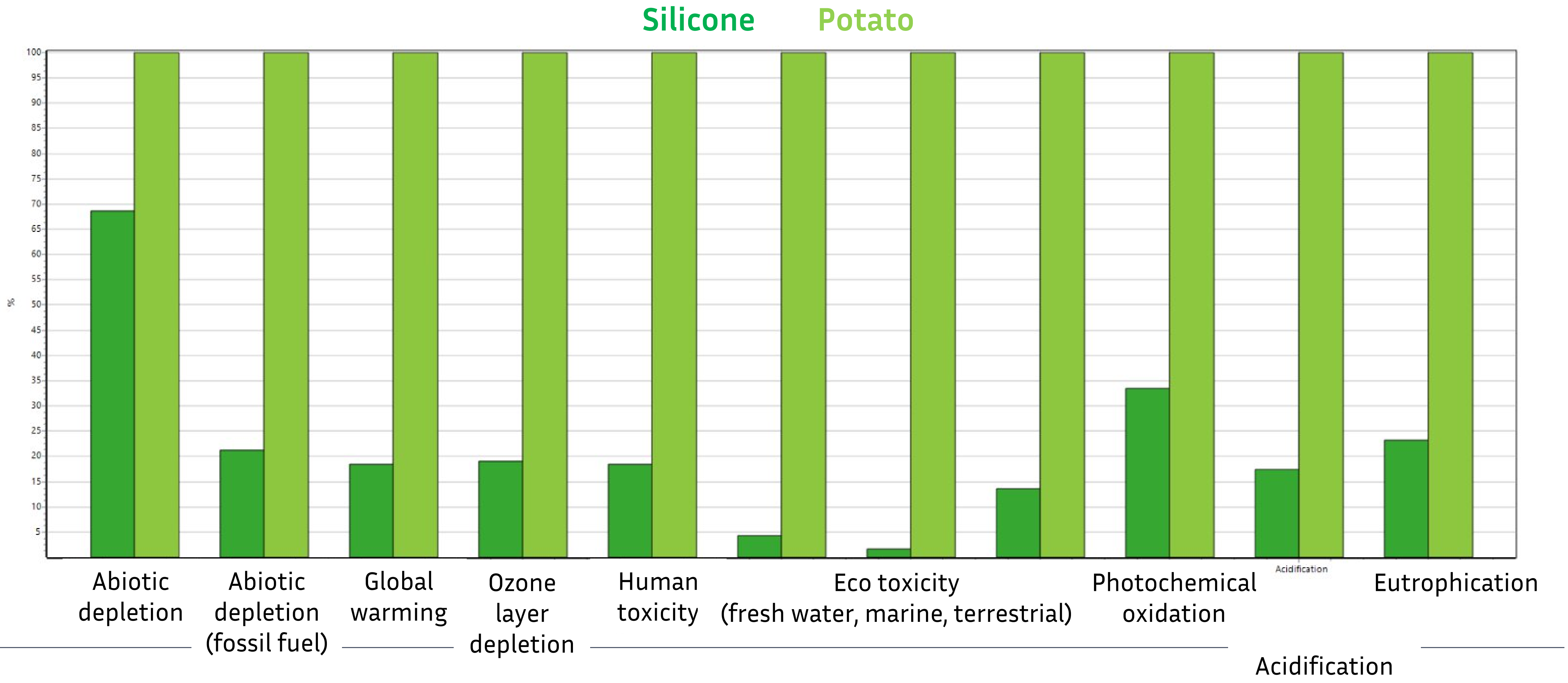
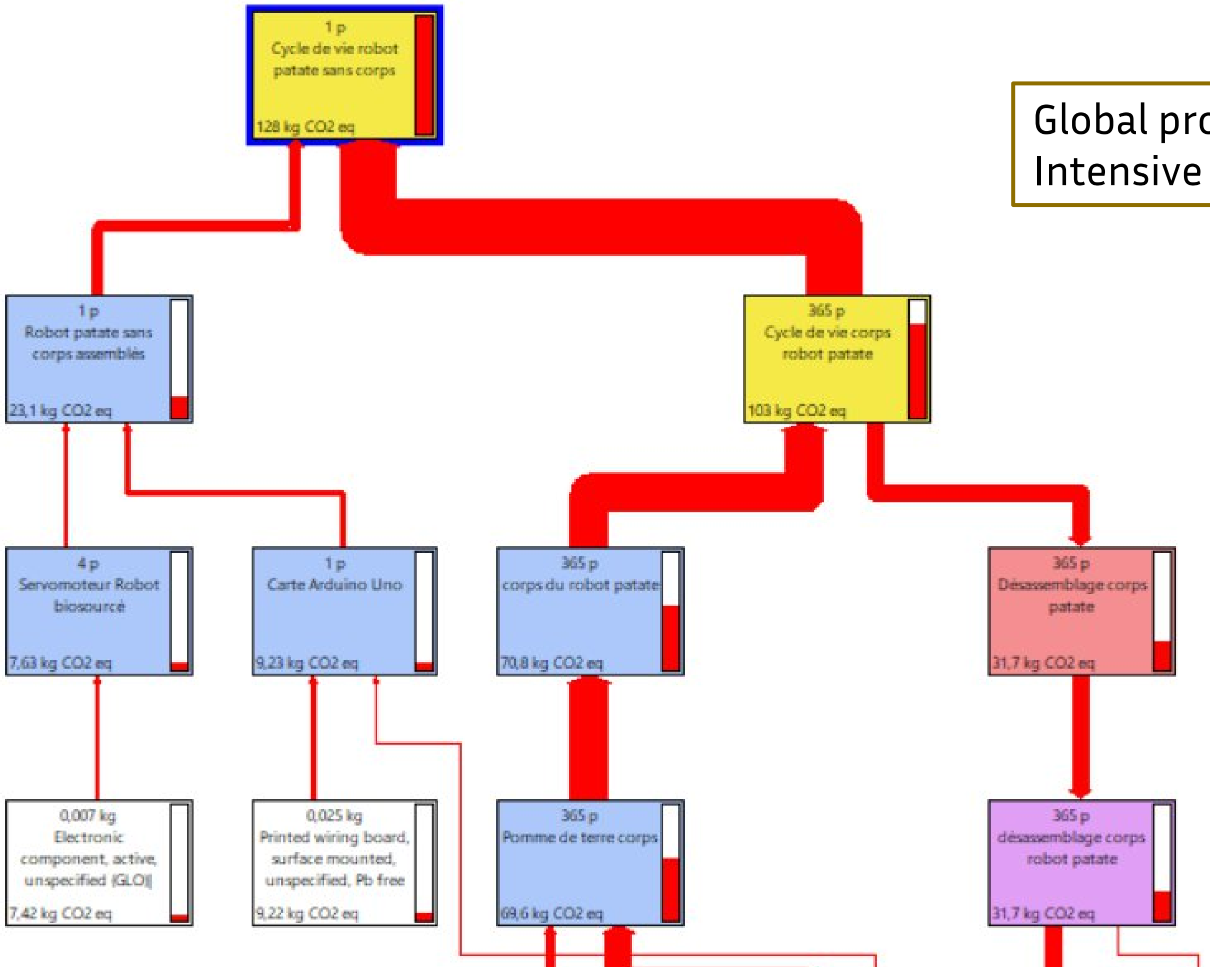
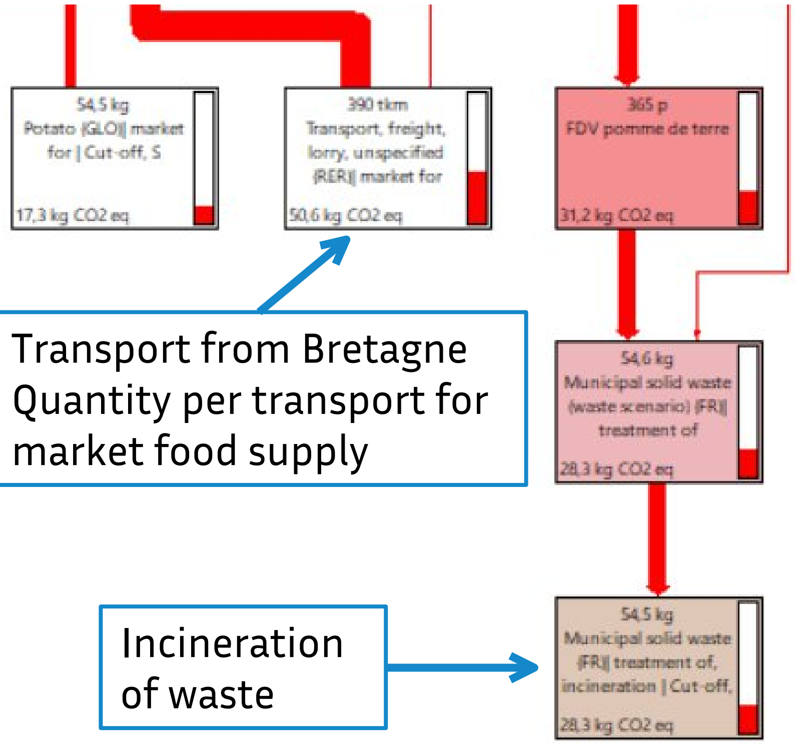


Focus on global warming

1.4kg of potato for 150g of robotic parts lasting 2hr =511kg per year



Global prod. practices: Intensive agriculture



Transport from Bretagne
Quantity per transport for market food supply

Incineration of waste

LCA-informed iterations on the robot

Iterating on the end-of-life

- Compost feasibility ?
  Cannot handle large amount of potato
- Some silicone (EcoFlex) can be composted (industrial conditions)

	Impact sur la toxicité humaine* (DALY)	Réchauffement climatique (kg de CO_2 équivalent)
Compost de 365 corps en pdt	4.2e-9	2.98
Incinération de 365 corps en pdt	1.66e-7	30.01
Incinération 1 corps en silicone	1.35e-9	0.274

Iterating on bio-sourced material:

- Carrots produced in Paris
- With French prod. standards

	Production carotte	Production patate	Transport carotte	Transport patate
Réchauffement climatique (kg de CO_2 équivalent)	10.6	17.3	11.1	50.6

Conclusion

To wrap up

On the use of raw plant materials

- Accessible, cheap and requires few energy to produce/grow
- But complex to use in a controlled quantitative manner:
  - Variability of properties between two flexible elements
  - Degradation over time
  - Mechanical behavior beyond what is considered in soft robotics (viscoelastic, plastic, etc.)

On the life cycle analysis:

Using raw plant material does not necessarely mean lowering the impact

- Importance of the mechanical part life time
- Importance of the production site: the most local, the best

Perspectives

Raw plant material: A rich source of research topics for roboticists:

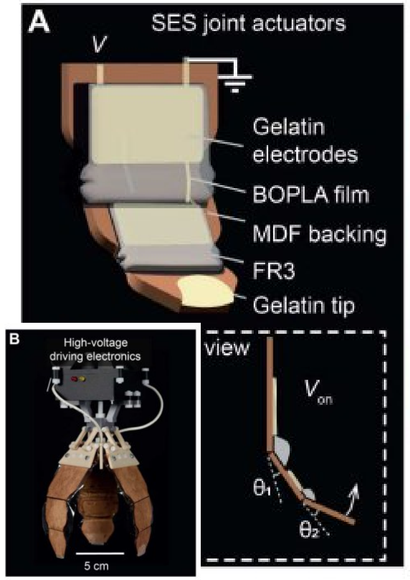
- Several research questions:
  - How to account for variability in a robot static/dynamic model ?
  - How to compensate or exploit this variability, through design or control ?
  - How to model degradation and manage it through control ?
  - Considering plant materials change following the fabrication site, what methodologies to account for various plant materials ?

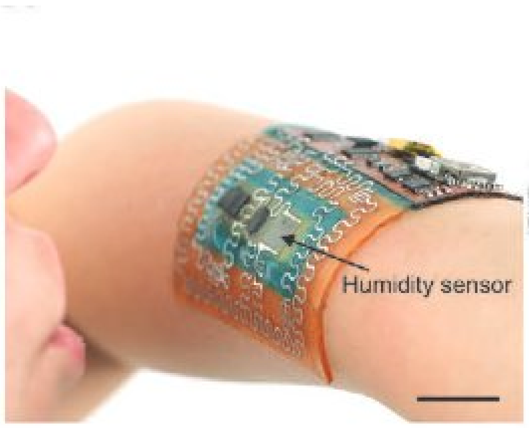
- Requires and promote multi-disciplinary collaboration: continuum mechanics, material, biology

Raw vs transformed: the optimal material (performance vs ecological impact) might be in the middle, more LCA needed

Electronics and actuators:

Bio-sourced and/or bio-degradable options exist but need development





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Thank you for your attention