flexcycle

flexible robotic solutions for the recycling of soft materials

Project Approach & Overview

Manuel. G. Catalano
Istituto Italiano di Tecnologia – JOiiNT LAB
FlexCycle Coordinator

Funded by the European Union

Deformable Waste Challenge

2.2 Btons/year globally [1]

~15–20% deformable materials [1,2,3]

300–350 Mtons/year deformable waste [2,3,4]

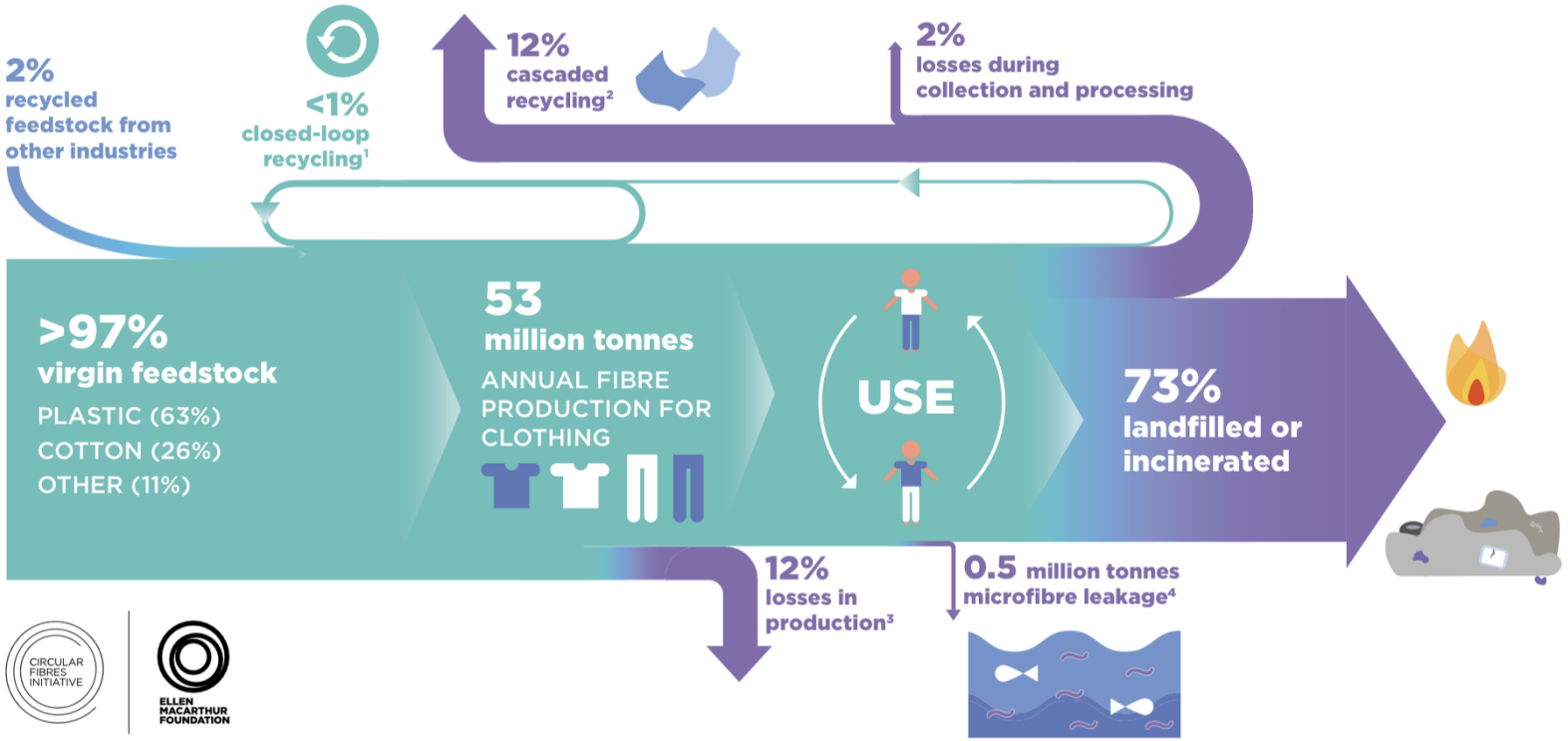
Textiles, Plastics (40–50% flexible), E-waste (including cables)

[1] World Bank – What a Waste 2.0 (https://datatopics.worldbank.org/what-a-waste/)
[2] OECD – Global Plastics Outlook (https://www.oecd.org/environment/plastics/)
[3] BCG – Textile Waste (https://www.bcg.com/publications)
[4] UN – Global E-waste Monitor (https://ewastemonitor.info/)
[5] Ellen MacArthur Foundation – A New Textiles Economy

Deformable Waste Challenge - Textile

CLOTHES

[5] **FIGURE 6:** GLOBAL MATERIAL FLOWS FOR CLOTHING IN 2015



1 Recycling of clothing into the same or similar quality applications
2 Recycling of clothing into other, lower-value applications such as insulation material, wiping cloths, or mattress stuffing
3 Includes factory offcuts and overstock liquidation
4 Plastic microfibres shed through the washing of all textiles released into the oceans

Source: Circular Fibres Initiative analysis – for details see Appendix B

One of the challenges

[5] Ellen MacArthur Foundation – A New Textiles Economy

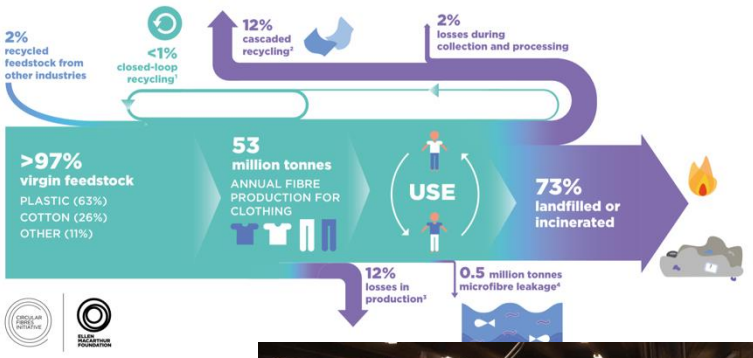
Deformable Waste Challenge – E-Wires

CABLES

The process works only with single cables

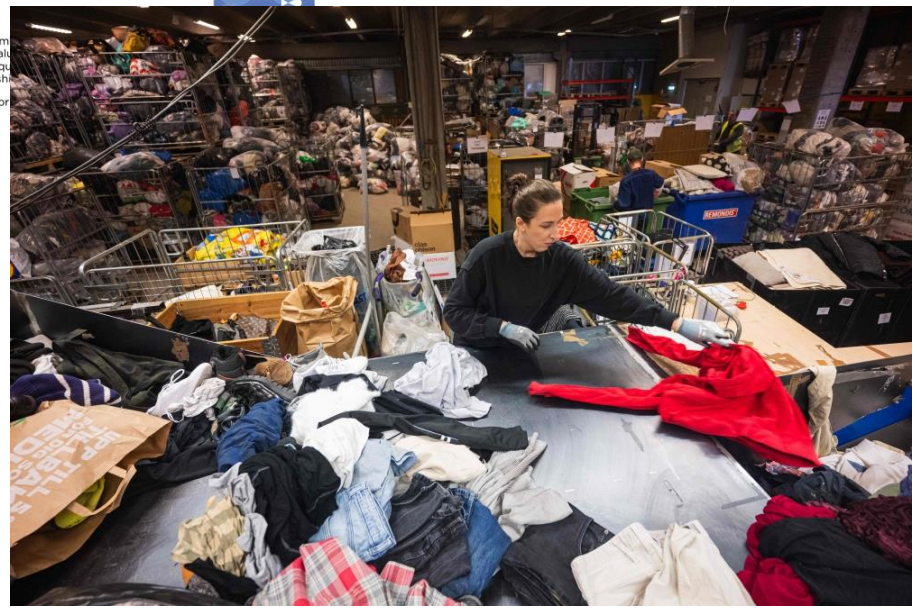
The Flexcycle **Problem**

FIGURE 6: GLOBAL MATERIAL FLOWS FOR CLOTHING IN 2015



1 Recycling of clothing into the same or sim
2 Recycling of clothing into other, lower-valu
3 Includes factory offcuts and overstock liqu
4 Plastic microfibres shed through the wash

Source: Circular Fibres Initiative analysis – for



Funded by the European Union

Horizon Europe Programme under Grant Agreement No 101189600. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EuropeanCommission. Neither the European Union nor the granting authority can be held responsible for them.

The Flexcycle **Problem**

The **first problem**, common to all recyclable goods, is that these materials, being “trash”, may exhibit different levels of initial degradation, requiring any automatic recycling process to be able to **flexibly** adapt to their condition.

Specific to soft materials, however, is the **second problem**, namely that the **flexible structure** of such materials presents substantial difficulties for handling them with conventional robots.

Funded by the European Union

Horizon Europe Programme under Grant Agreement No 101189600. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EuropeanCommission. Neither the European Union nor the granting authority can be held responsible for them.

The Flexcycle **Ambition**

FlexCycle will address the difficult problem of how to design and implement (robotic) systems that work with and without humans to improve **reuse** and **recycling** of different soft materials.

Flexcycle will address use cases which share common, but also distinct requirements:

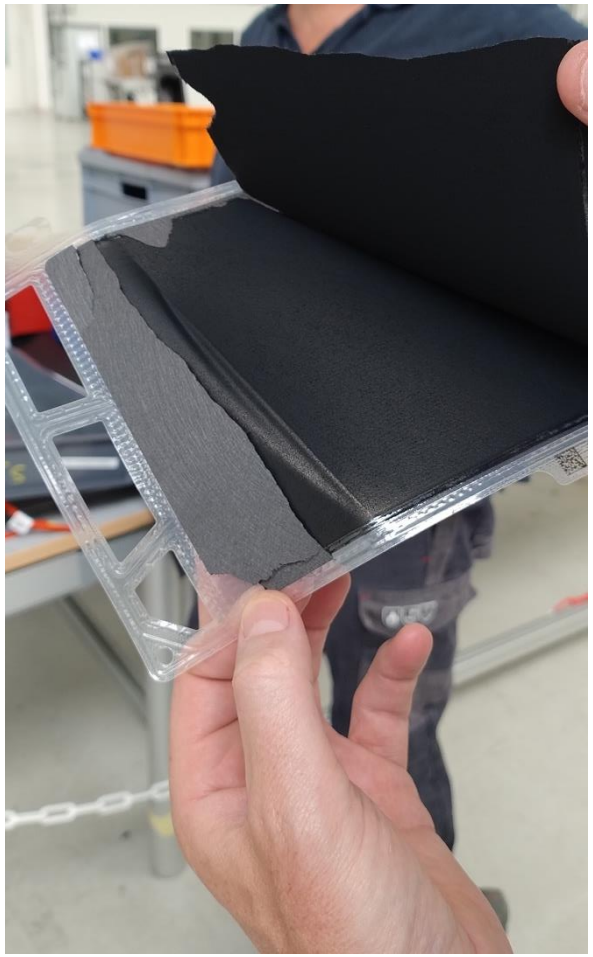
To enable the present
Cables
Clothing

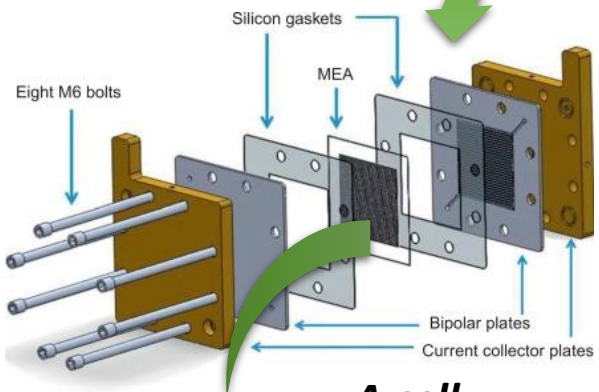
To enable the future:
Fuel Cells Membranes

Funded by the European Union

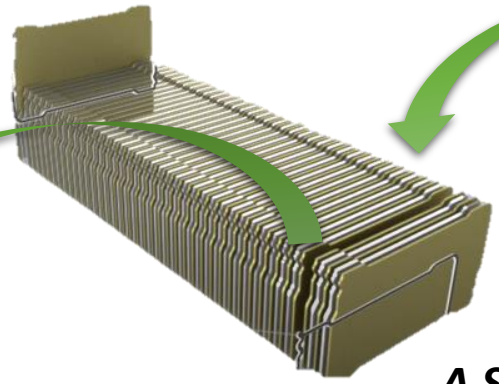
Horizon Europe Programme under Grant Agreement No 101189600. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EuropeanCommission. Neither the European Union nor the granting authority can be held responsible for them.

Deformable Waste Challenge – Batteries (Fuel Cells)

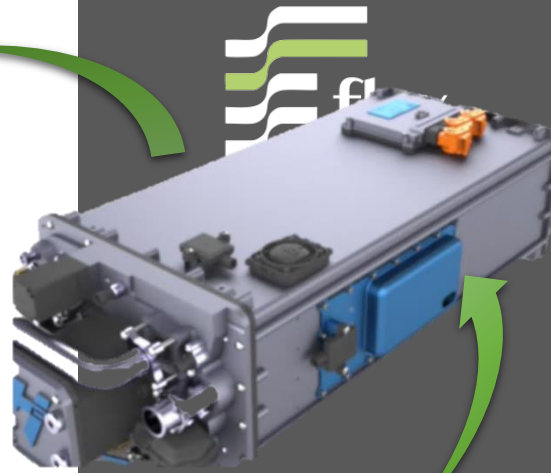




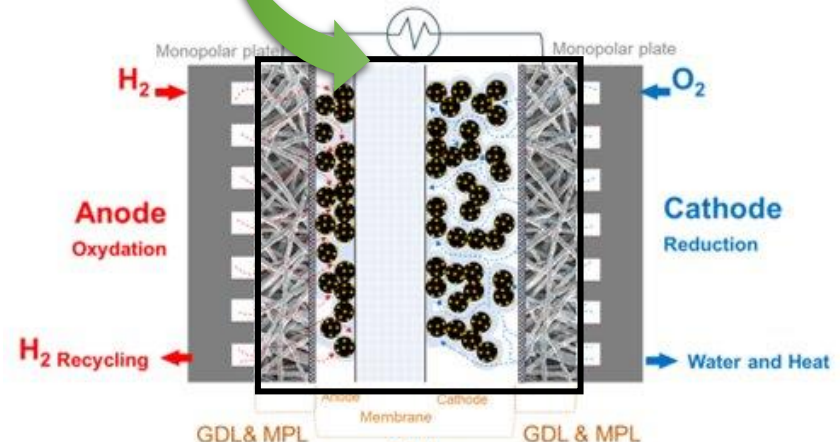
A cell



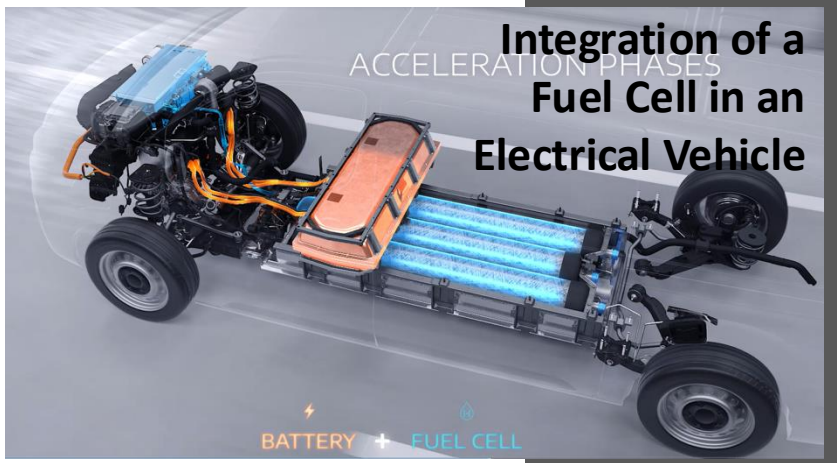
A stack



A StackPack



A Membrane Electrode Assembly (MEA)



Integration of a Fuel Cell in an Electrical Vehicle

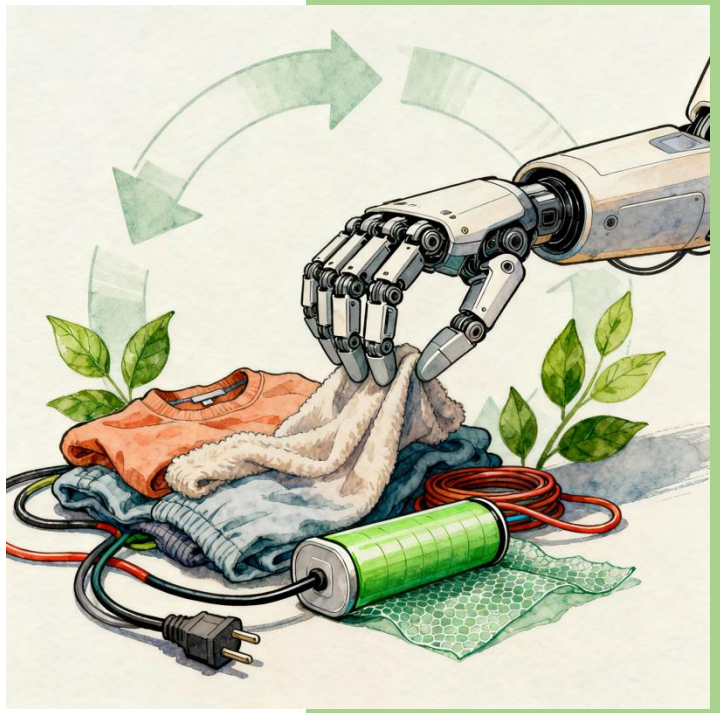
The Flexcycle **Scientific Challenge**

Flexcycle aim to address the problem of designing system components (SW & HW) that facilitate **easy transfer across the different use case domains:**

i) adaptive software (employing also machine learning) for sensing and robotic control

paired with

ii) flexible hardware, notably flexible types of grippers and tools



The Flexcycle **Consortium**

Science, technology development and innovation
IIT, JSI, TUM, CSIC, UGOE, and FHG.

Use-Cases Experts and Providers
ECYC, SYM, OSIT, and CAX

Expertise in Soft Components Design and Production
QBR

Socio-economic Impact
VMU

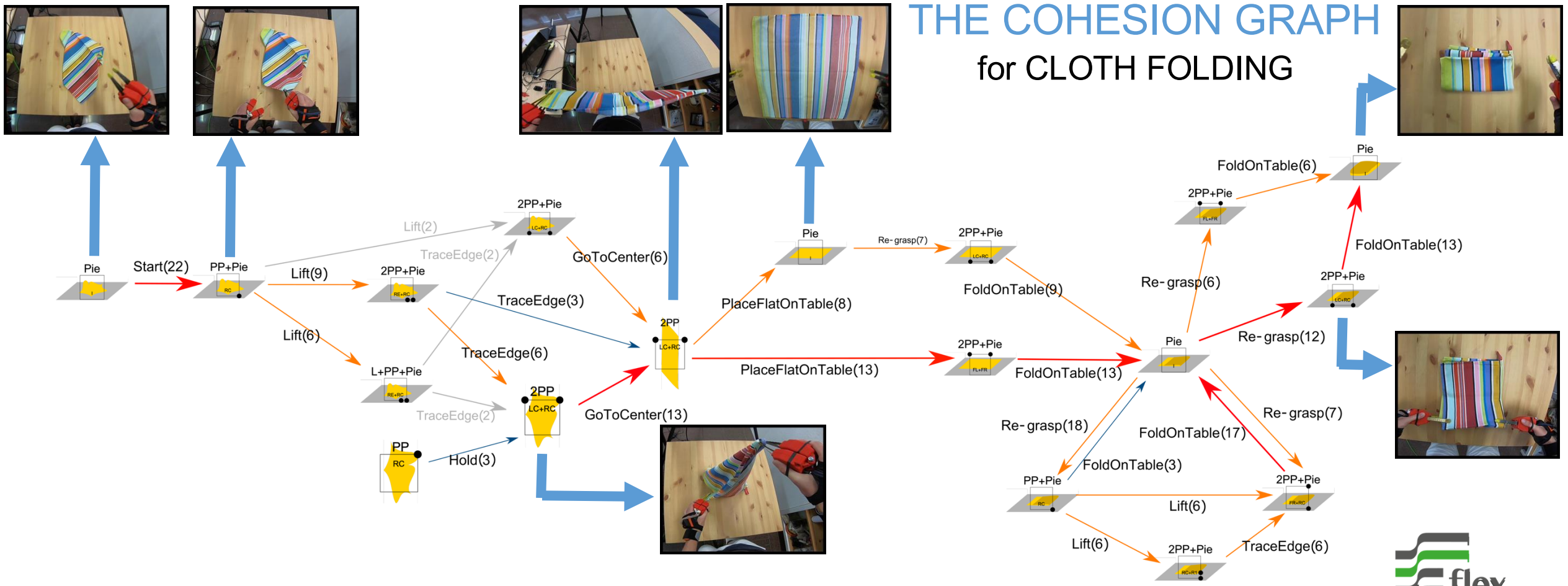
Core Components: **SOMASK**

Linking software to hardware by SOMASK “Soft-Material-Skills”

SOMASK name	Fundamental parameters
2D-sm: Pick up	Grasping location (1 or 2 hands), lifting height
2D-sm: Put down	Put down location, put down configuration, put down trajectory parameters f
2D-sm: Push away	Parameters for initial location, parameters for final location, hand position in item, pushing force
2D-sm: Straighten	Grasping locations (2 hands), pulling force
2D-sm: Fold	Grasping location (2 hands), folding line, trajectory parameters for 2 hands
2D-sm: Shake away	Grasping location (1 or 2 hands), lifting and shaking trajectory
2D-sm: Align (put on top aligned)	Grasping location (2 hands), trajectory in relation to another object with whic
2D-sm: Untangle	Grasping location, trajectory parameters

Core Components: **SOMASK**

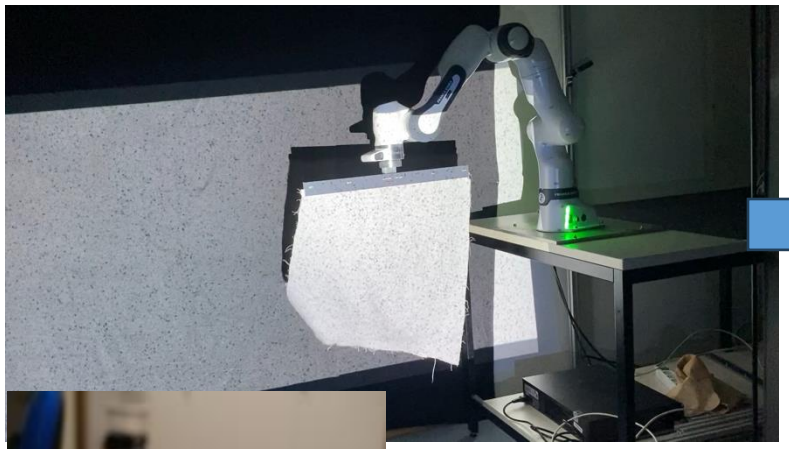
Useful to **identify state-action bindings** and build a **database of actions for Soft Material Skills (SOMASK)** common between use cases.



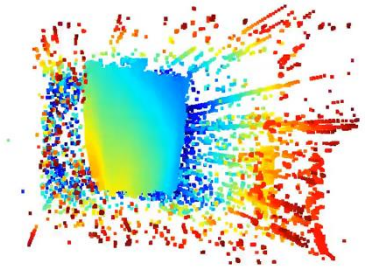
I. Garcia-Camacho, J. Borràs and G. Alenyà, **"Knowledge representation to enable high-level planning in cloth manipulation tasks"**, ICAPS Workshop on Knowledge Engineering for Planning and Scheduling, 2022

Core Components: **Modeling and Material Simulation**

Finite elements for modeling and identification of deformable objects and state action mapping using generative machine learning methods



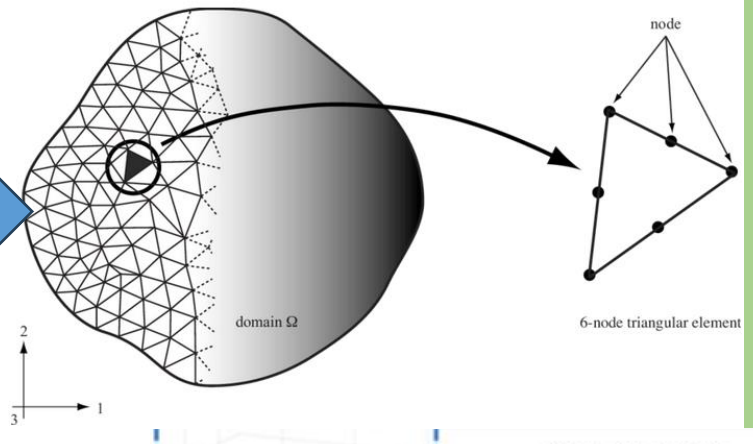
Starting point: 3 x Stereo + Structured Light)

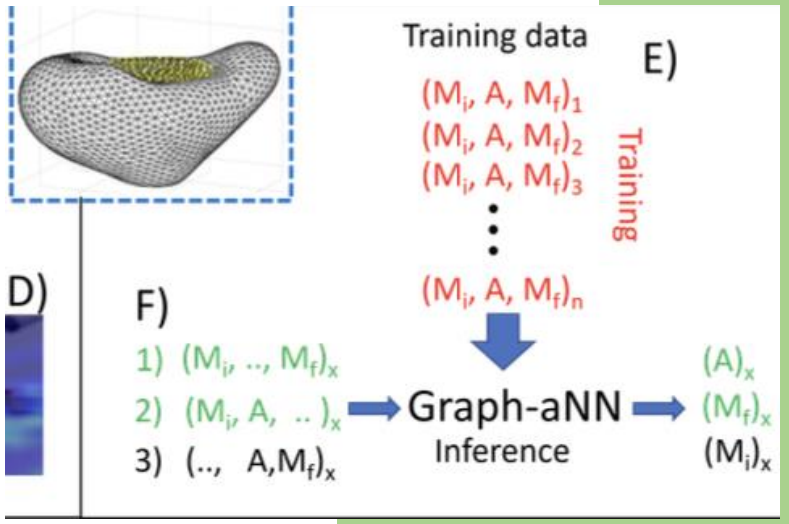


Extract the 3-D deformation pattern….

…make a 2-D finite element model

(and do the same with cable bending – not shown - for a 1-D model)





Core Components: **Sensing**

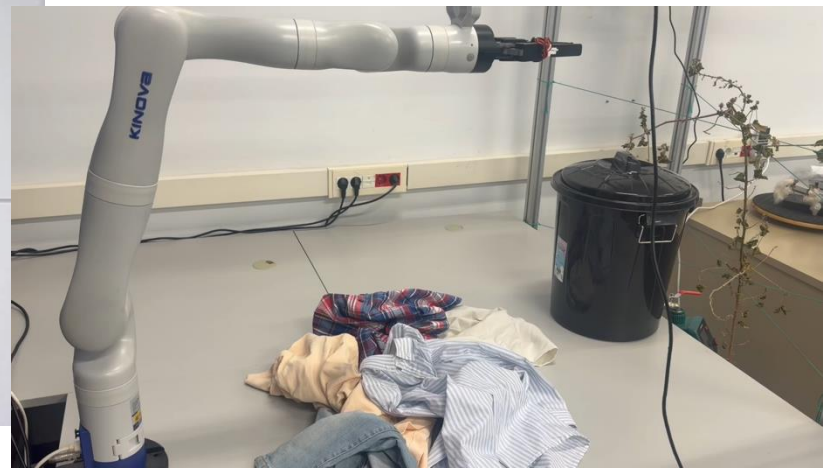
GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Cloth segmentation using foundational models

Button detection

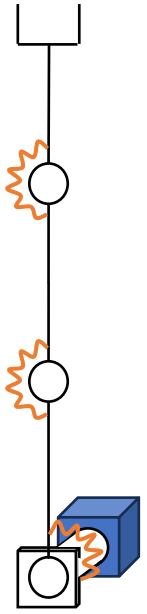
Zipper detection



• Core Components: **Novel Models for Grasp Planning**

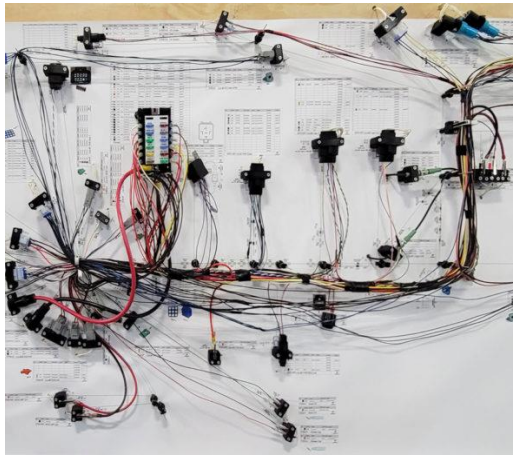
R-SIP Problem

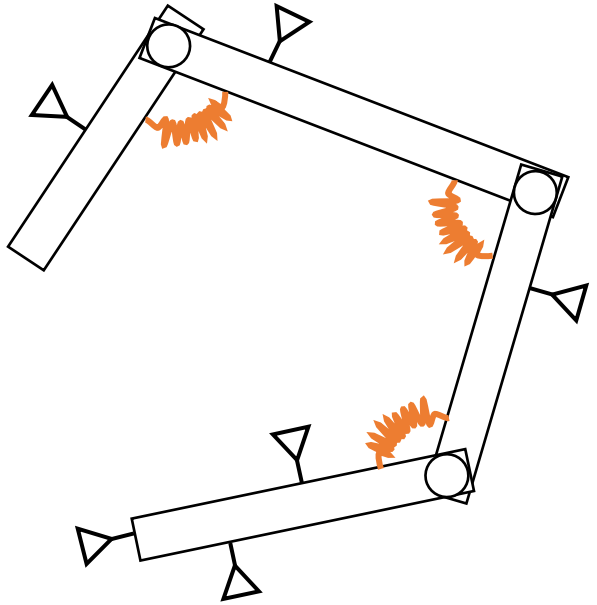
Robust Semi – Infinite Programming Problem



$$G(x_{eq}) \triangleq \left[\bar{G}(x_{eq}) \quad \tilde{G}(x_{eq})\right]^T = [\tau_{eq} \quad 0]^T$$

Form Closure for Soft objects





$$\boldsymbol{C}X = 0 \Rightarrow X = \boldsymbol{K}v$$

$$\boldsymbol{N}^T\boldsymbol{G}^T\boldsymbol{K}\boldsymbol{v} \geq 0$$

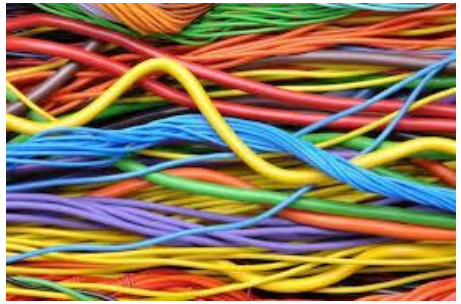
Definition *A set of contact constraints is defined Form-Closure if, for all object motions* $\boldsymbol{v} \in \mathbb{R}^d$*, at least one contact constraint is violated.*

Funded by the European Union

Horizon Europe Programme under Grant Agreement No 101189600. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Commission. Neither the European Union nor the granting authority can be held responsible for them.

Core Components: **Handling Tools**

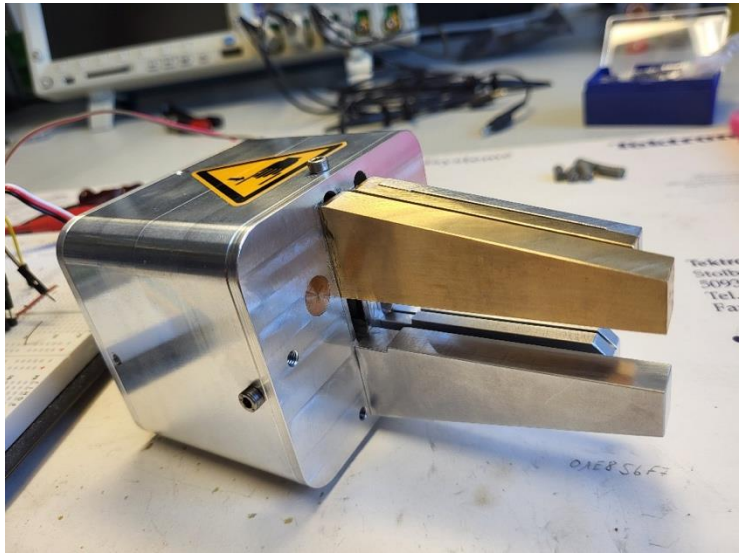
Specific tools for:



Robotics Gripper and Cutter

PhD student Konstatin Möller

Goal: Cable cutting and handling

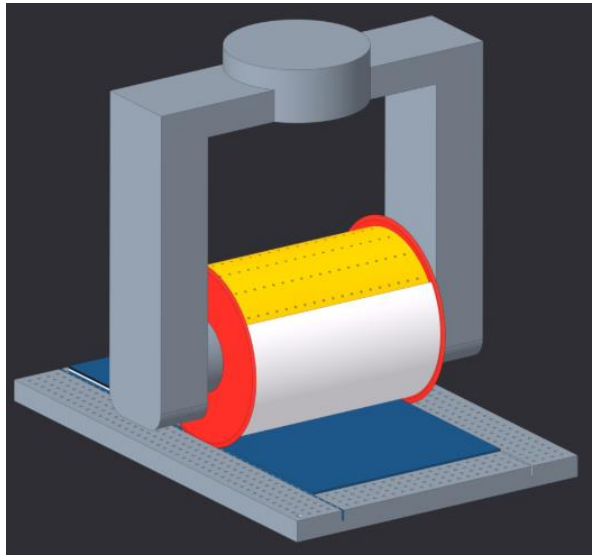


GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN

Custom Pneumatic Cutter

TUM MRMI

Initial design of the vacuum drum gripper

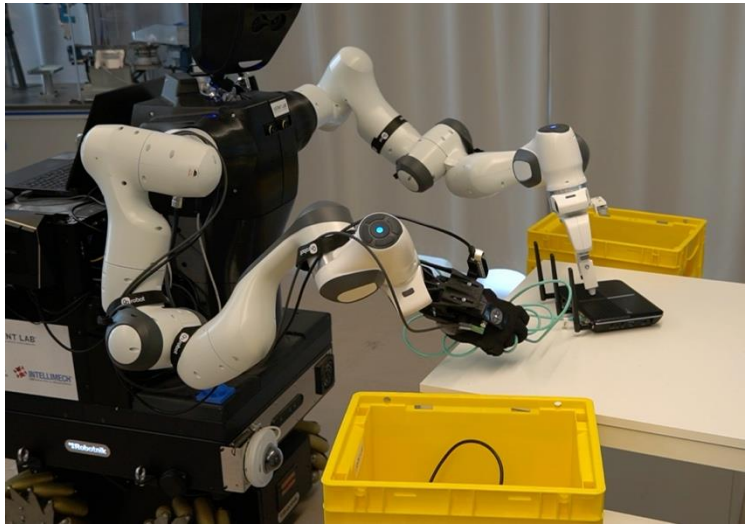


Jožef Stefan Institute
Ljubljana, Slovenia

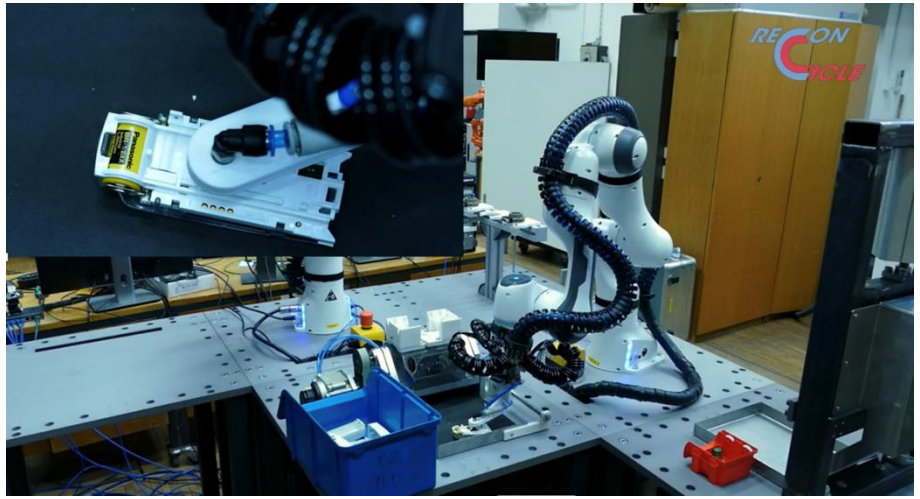
flex cycle

Core Components: **Handling Tools**

Flexible and adaptive End-Effectors



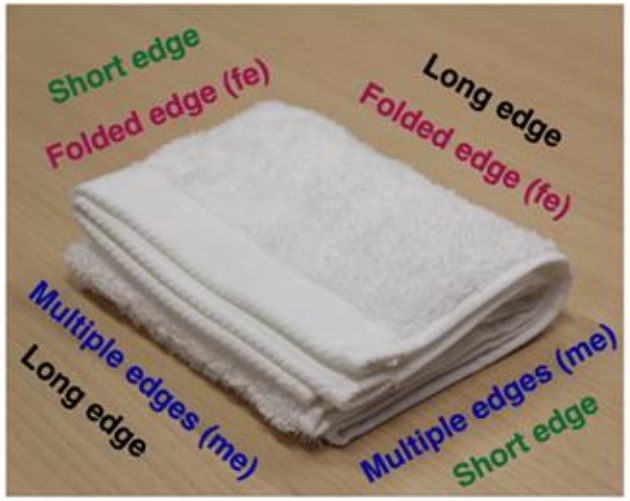
Modular Setups and Flexible Fixtures

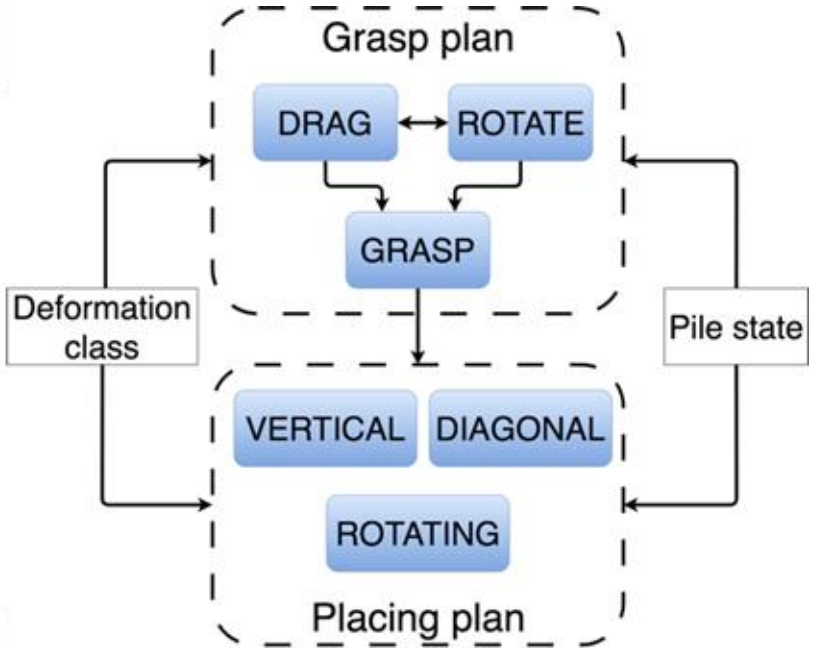


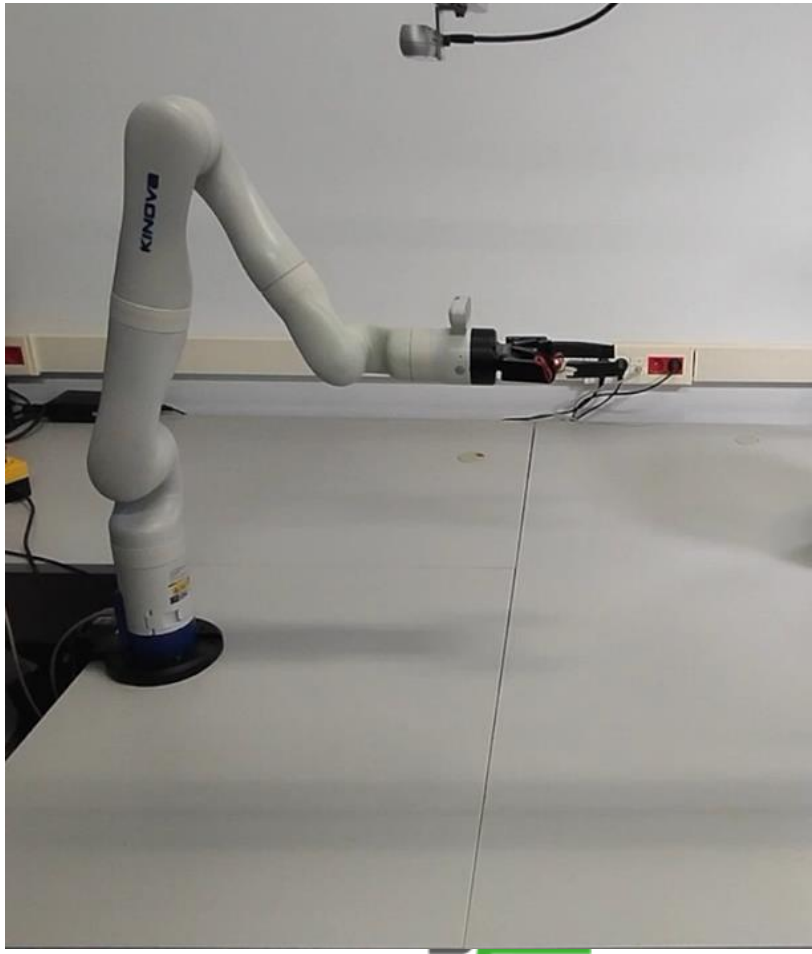
Core Components: Task and Motion Planning for deformable elements

TAMP systems link **symbolic task planning** with **motion-level feasibility**.
Integrate **cloth deformation** and physical properties as **geometrical constraints**.

Example

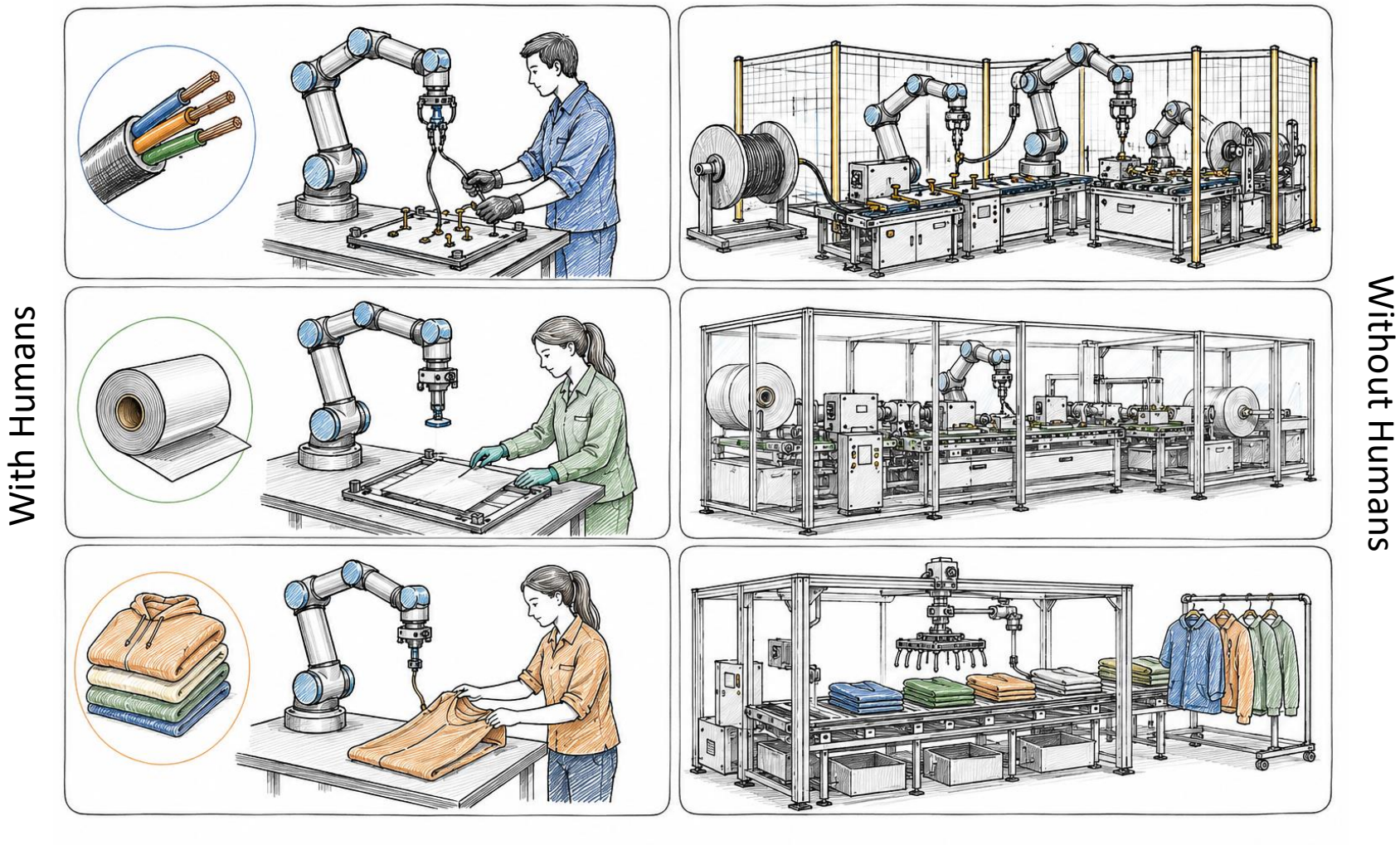






I Garcia-Camacho, J. Borràs and G. Alenyà, **"Deformation-aware task and motion planner for piling clothes"**

The Flexcycle **Demonstrators**



Funded by the European Union

Horizon Europe Programme under Grant Agreement No 101189600. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or EuropeanCommission. Neither the European Union nor the granting authority can be held responsible for them.

The Flexcycle **Impact**

Flexcycle will address the impact of an increase in automation in the soft material recycling (and reuse) industry
on the **social, economic and environmental aspects in view of the Green Deal**
(f.e., improved productivity, quantity & quality of recycling as well as effects of the workforce and environmental impact).

HOW

Mixed-methods approach:

1) **Case analysis** of clothing, cables, and fuel cell companies
2) **Content analysis** of technical solutions developed
3) **Content analysis** of EU regulations, policies, and best practices
4) **Focus groups and semi-structured interviews** and then qualitative data analysis techniques **to extract themes, patterns, and sentiments from stakeholder interviews and focus group discussions.**
5) **Modelling** - to extrapolate the company level impacts to the broader soft material recycling sector.

VYTAUTAS MAGNUS UNIVERSITY
MCMXXII

flexcycle

www.flexcycle.eu

flex cycle