



ROMANDIC

SCAN ME!



BENCHMARKING CLOTH MANIPULATION: ENABLING COMPARISON THROUGH STANDARDIZATION

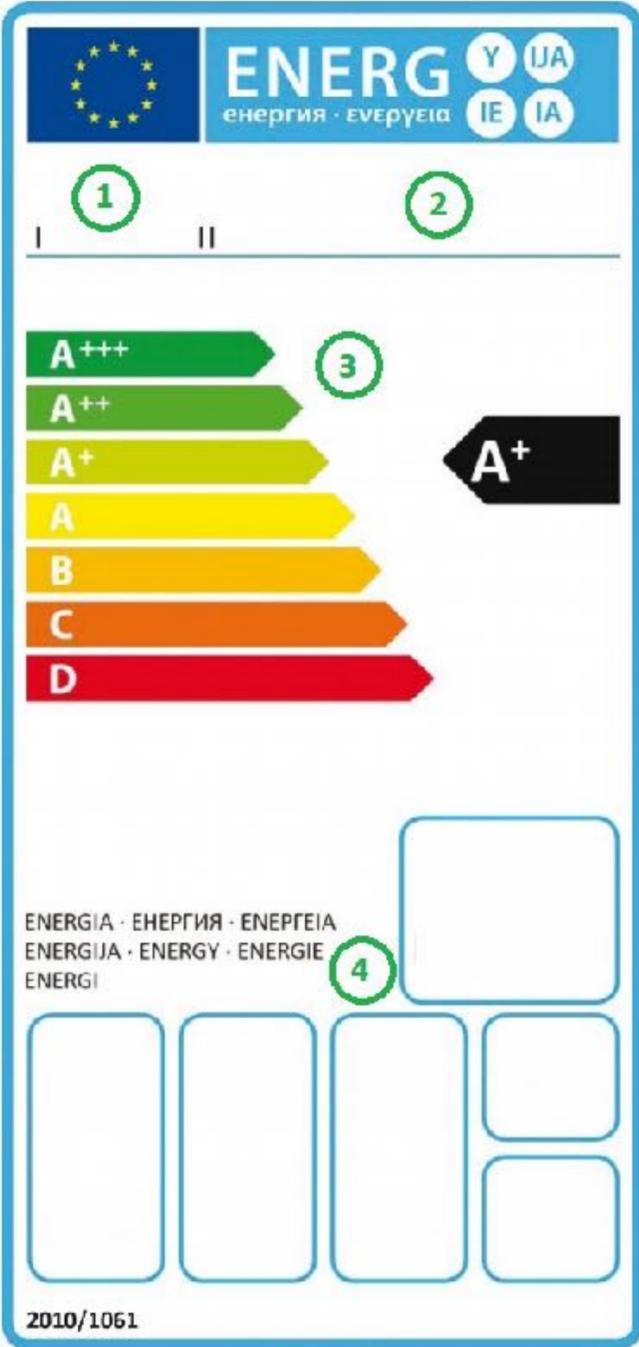
IRENE GARCIA-CAMACHO

HOW CAN WE ASSES ROBOTIC
MANIPULATION SYSTEMS?

BENCHMARK:

“Systematic standard process for evaluating something by comparison”

BENCHMARK STANDARDS

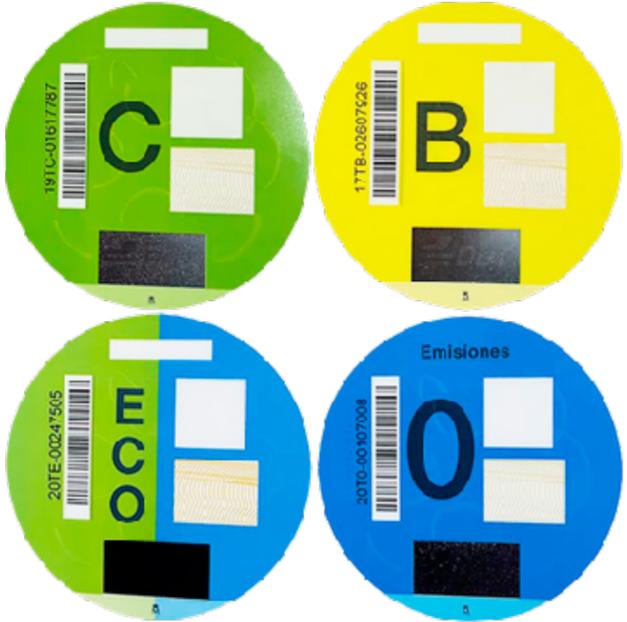


Energy efficiency

water resistance activity chart

Water Resistant	✓	✓	✗	✗	✗	✗	✗	✗
Resistant to 50M/165'	✓	✓	✓	✓	✓	✓	✗	✗
Resistant to 100M/330'	✓	✓	✓	✓	✓	✓	✓	✗
Resistant to 200-300M/660'	✓	✓	✓	✓	✓	✓	✓	✓

Water resistant



Environmental car emissions



Cybersecurity level



ISO standards

BENCHMARKS AND DATABASES IN ROBOTICS

Machine learning

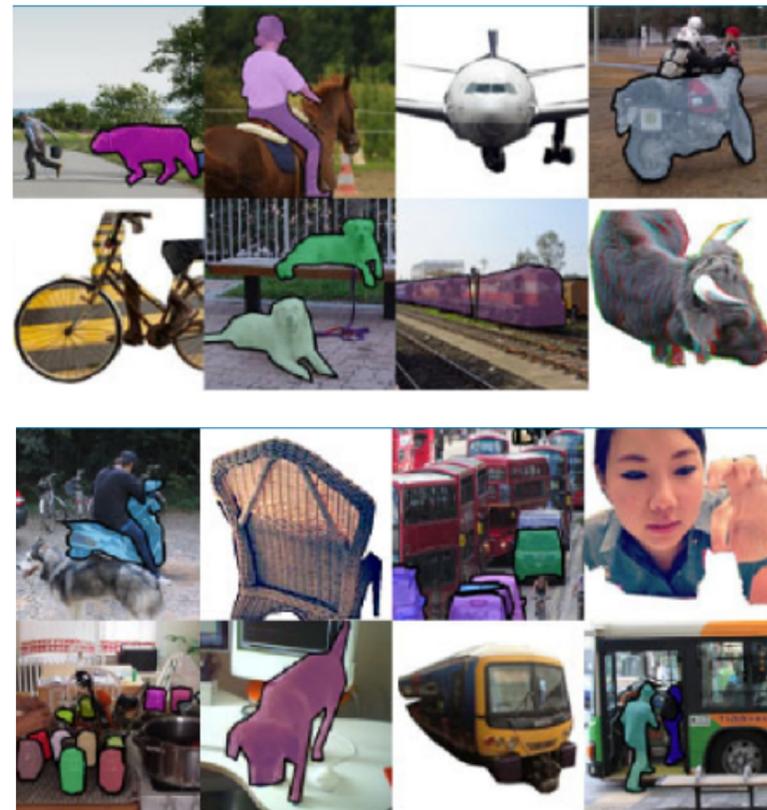


Benchmark suit for
ML models



Benchmark resources for
natural language systems

Computer Vision



COCO

(Object detection
and segmentation)

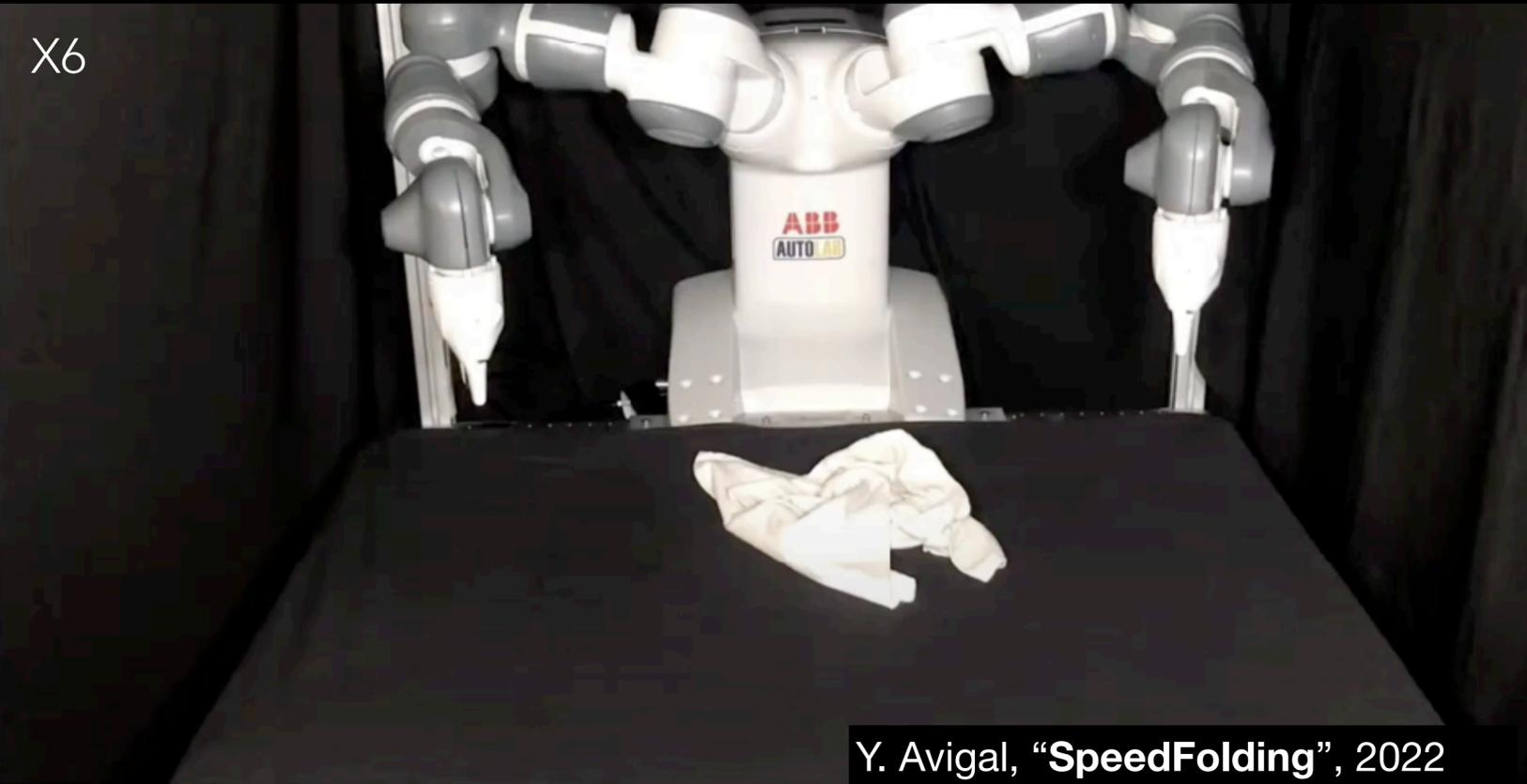
Cloth manipulation



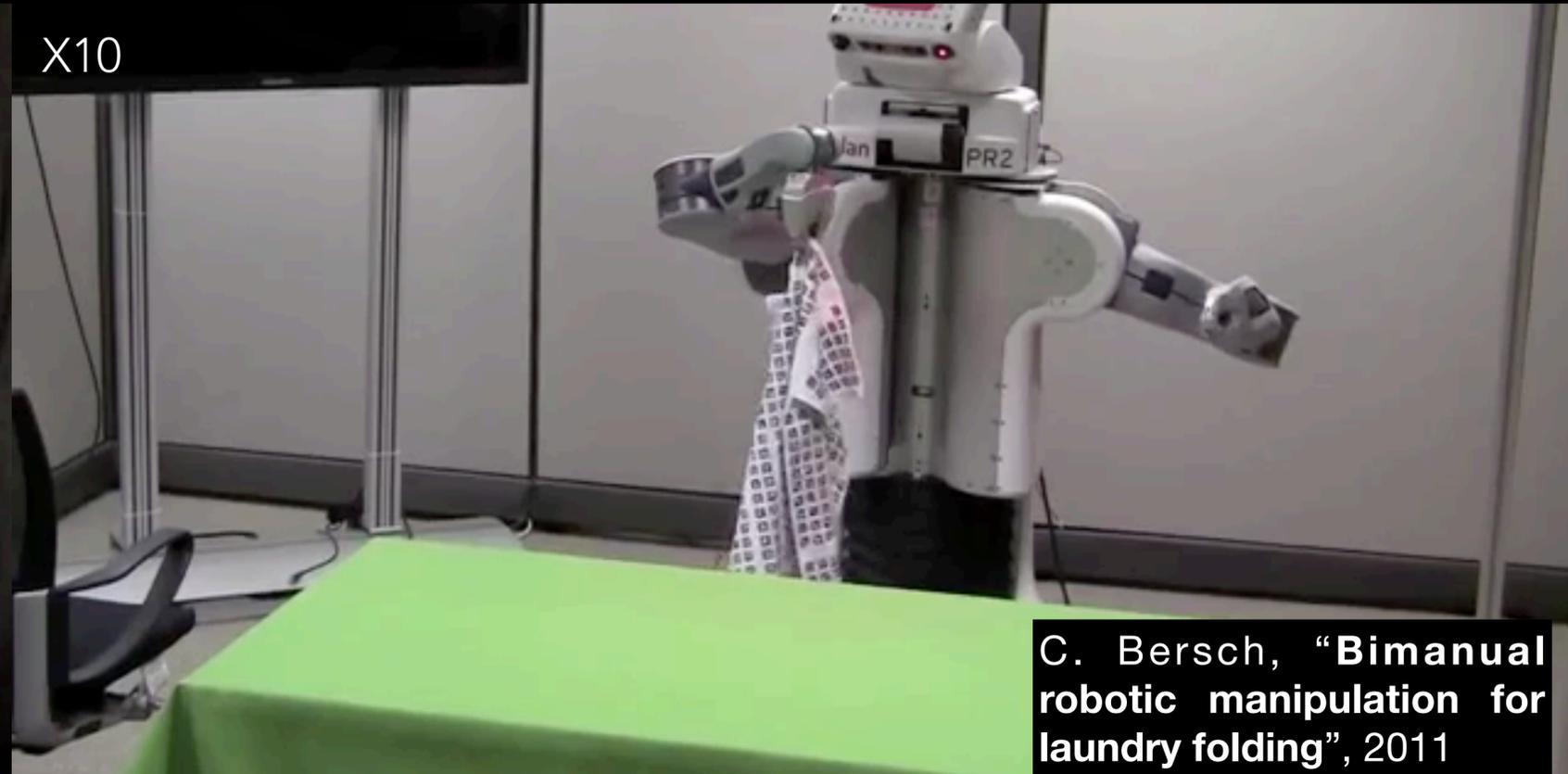
ClothesNet

(Simulated cloth object dataset)

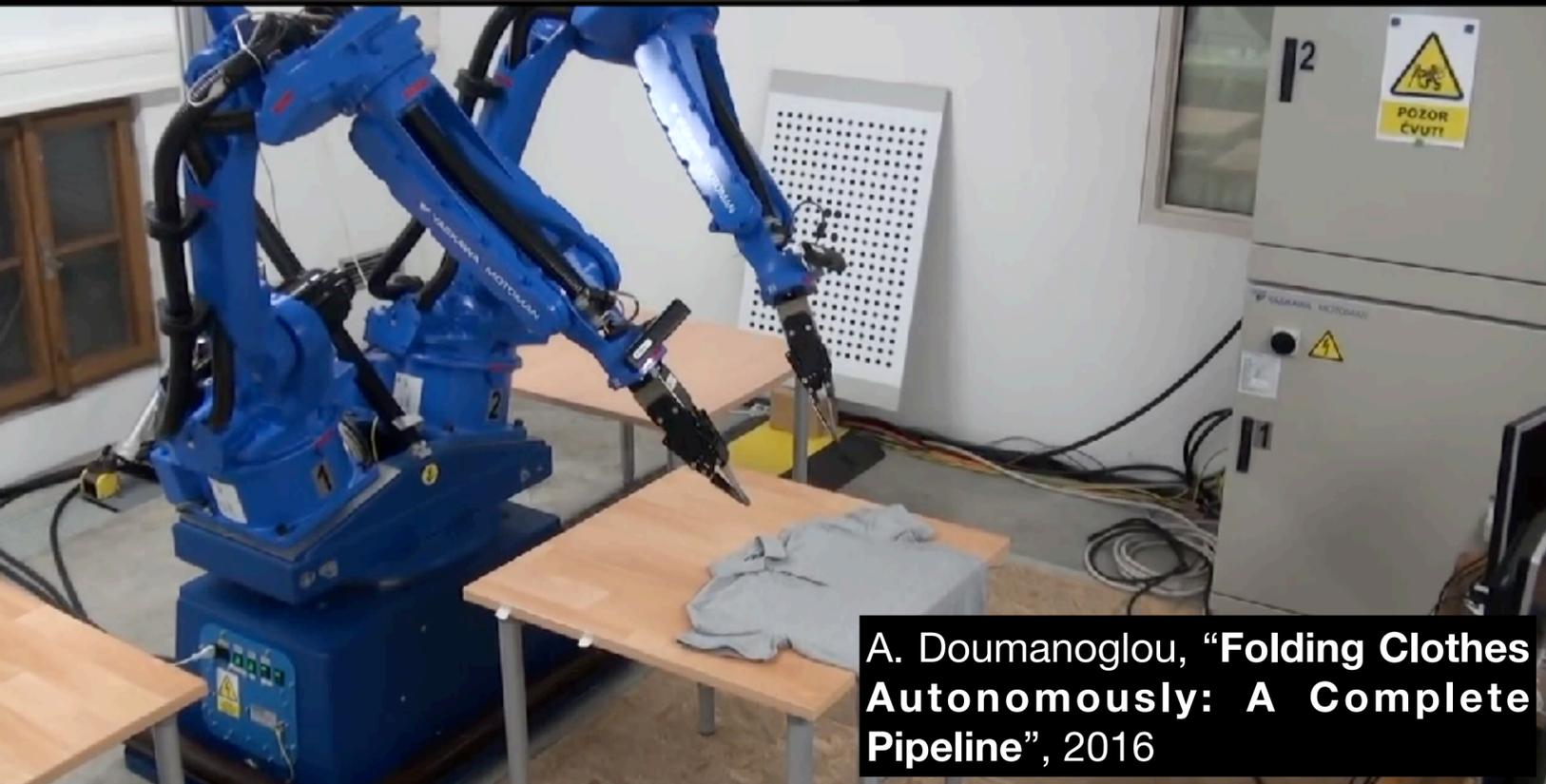
HOW CAN WE DESIGN BENCHMARKS
FOR CLOTH MANIPULATION?



Y. Avigal, "SpeedFolding", 2022



C. Bersch, "Bimanual robotic manipulation for laundry folding", 2011



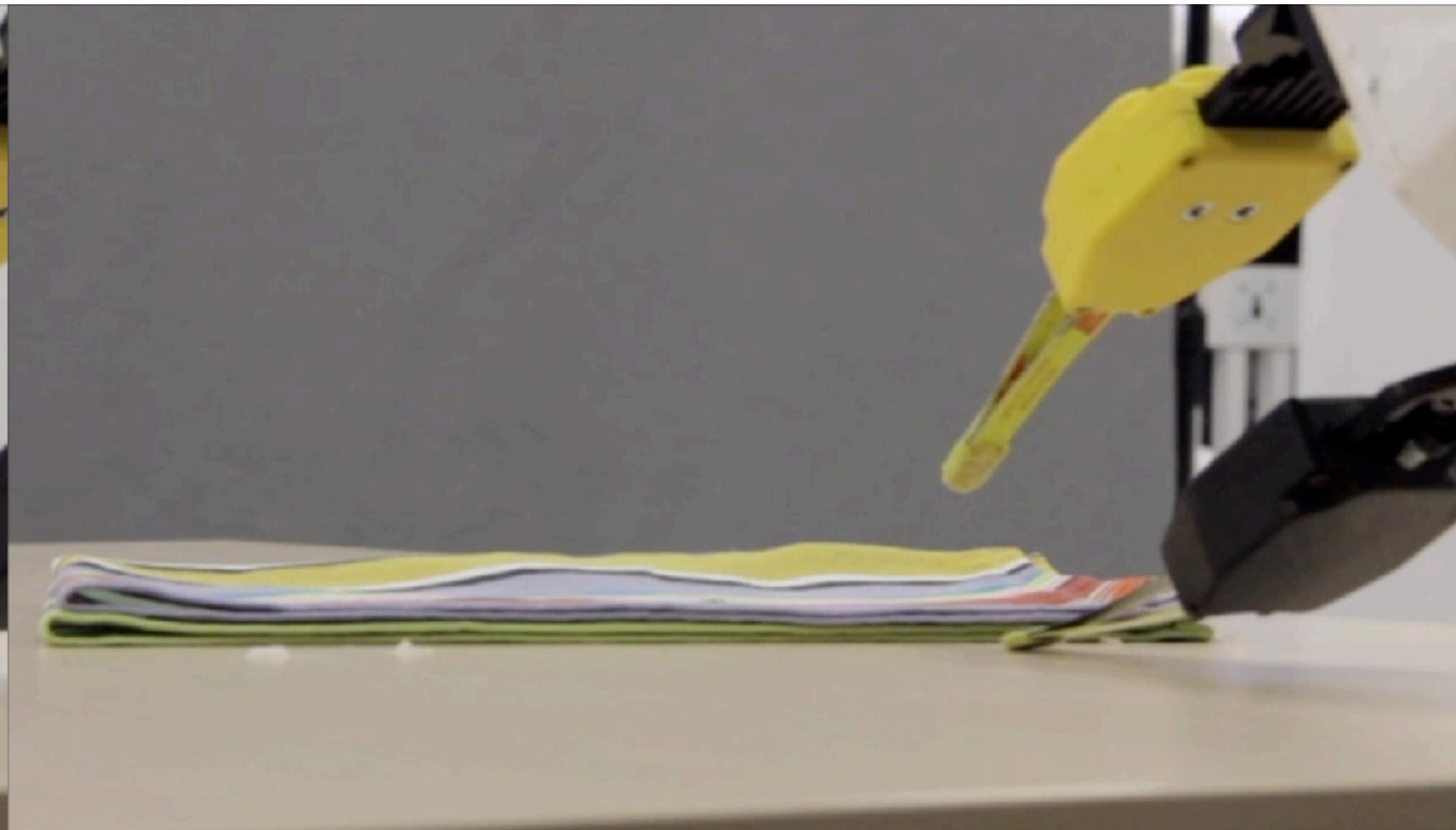
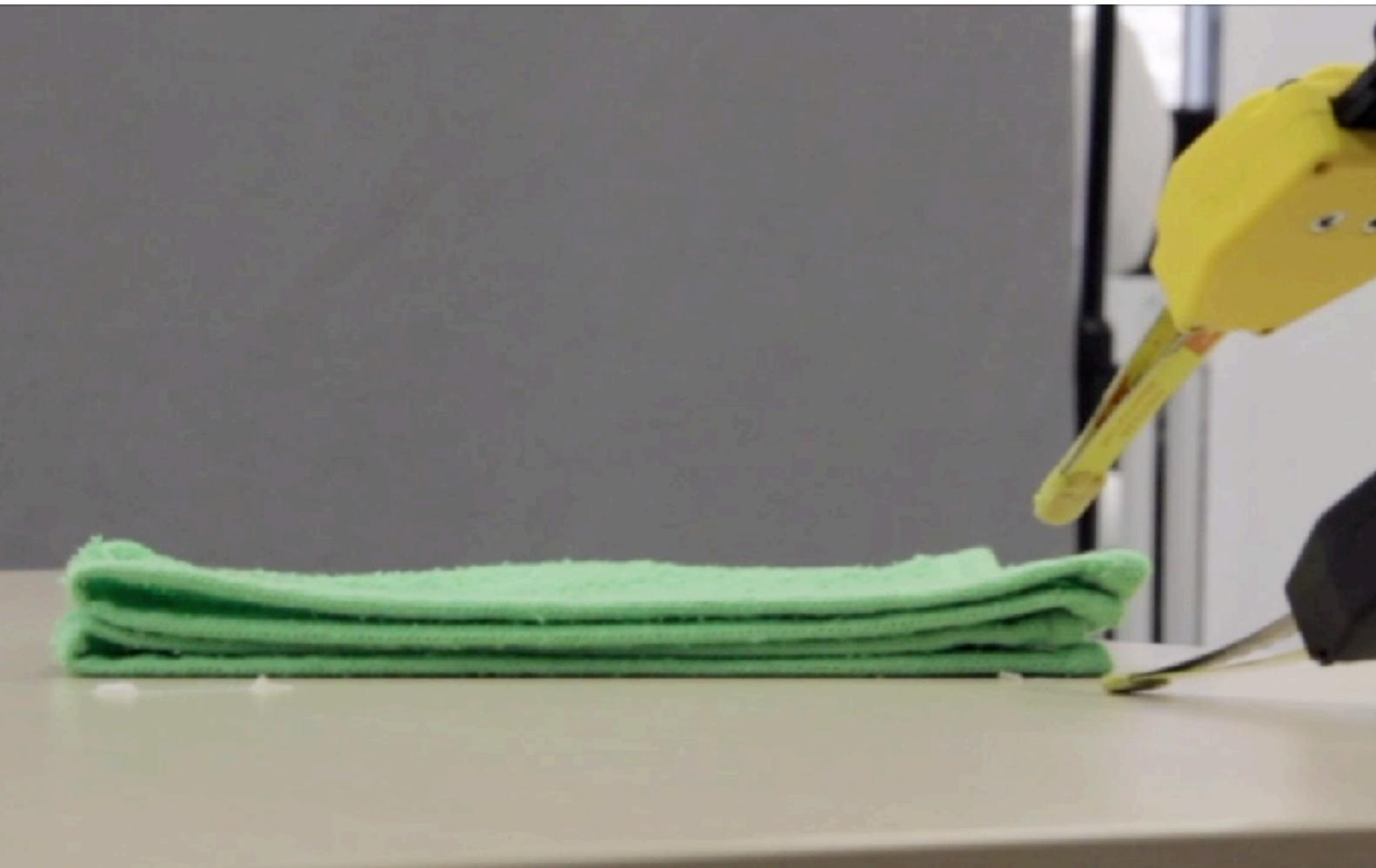
A. Doumanoglou, "Folding Clothes Autonomously: A Complete Pipeline", 2016



E. Honnold, "Robotic laundry folding", 2018

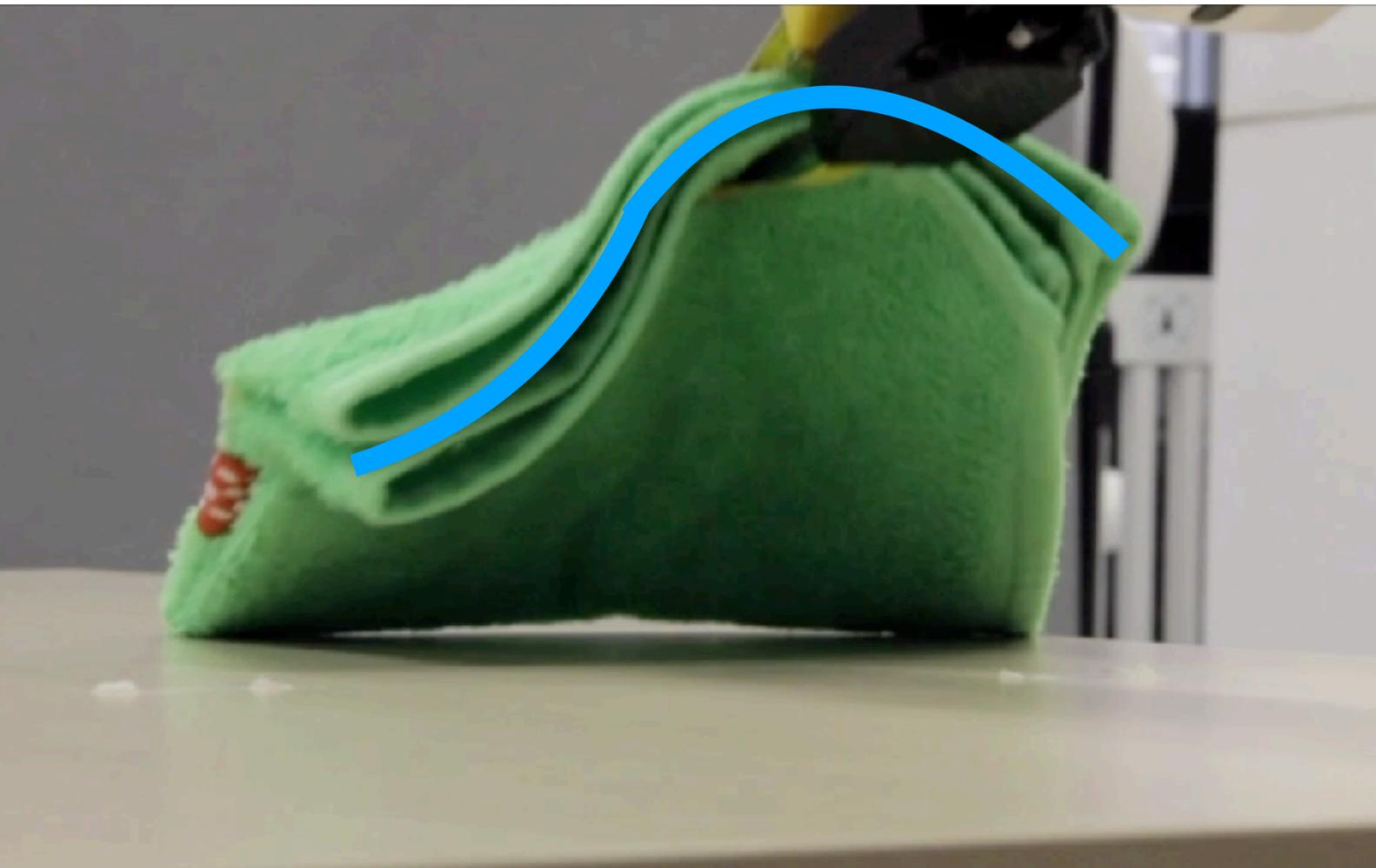
OBJECT SETS FOR MANIPULATION

Same manipulation but different behavior



OBJECT SETS FOR MANIPULATION

Same manipulation but different behavior



OBJECT SETS FOR MANIPULATION

The experimental results of the first grasping experiment are shown in Table 1. Overall, the grasping success rate varies from 76.7% to 93.3% on different types of clothing. This difference can be attributed into the difference of clothes materials. In other words, the thickness and stiffness variation of clothes' materials brings different challenges to grasping. Specifically, the sweaters and t-shirts performed the best (93.3%,90%) while jeans and shirts obtained the lowest scores (78.3%,76.7%). The reason is two-fold: firstly, the more stiff the clothing material is, the more difficult the grasping is; and also, the more wrinkles the clothing configuration has, the easier the grasping is. On average, the proposed

Sun et. al. 2018



Fig. 9: Our test set of clothing articles.

Cusumano et. al. 2011

V. EXPERIMENTS

After tuning the parameters on a training set of 3 towels⁷, we ran 50 trials over a wide variety of previously unseen towels. In particular, the test set comprised 25 distinct colors/patterns, 16 distinct materials, and 11 distinct sizes (with lengths ranging from 32 to 78 cm and widths ranging from 32 to 48 cm).⁸ Each of the 25 towels in the test set

Maitin et. al. 2010

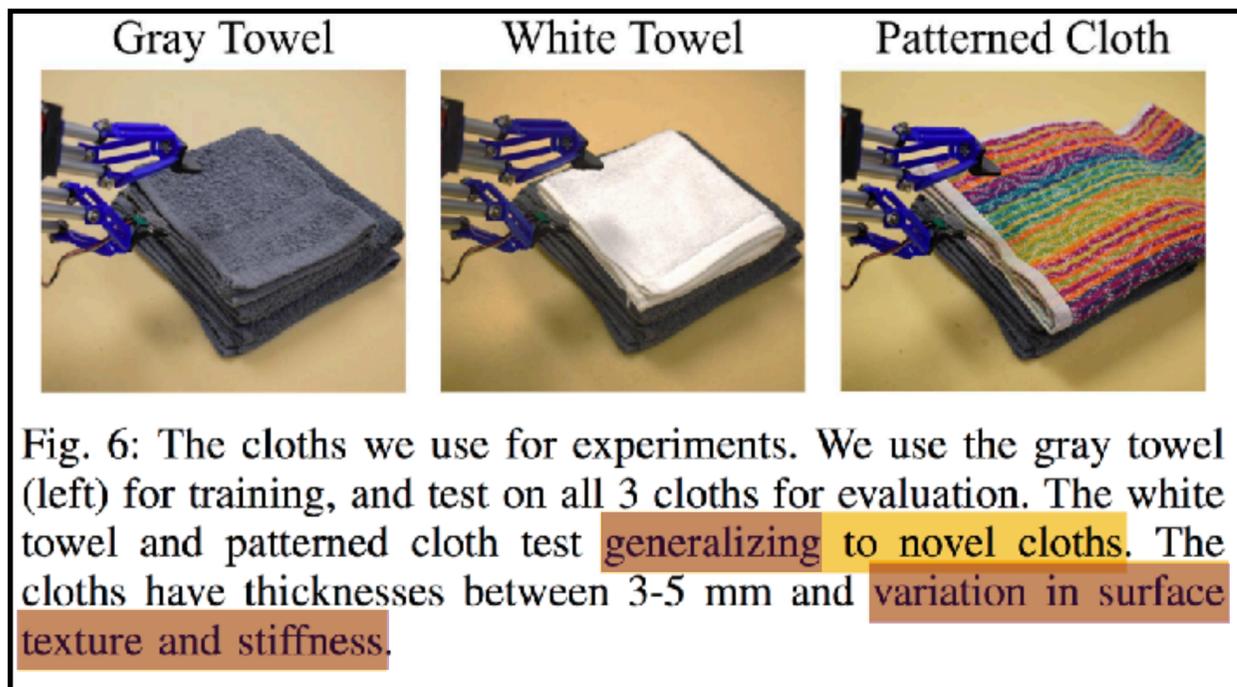


Fig. 6: The cloths we use for experiments. We use the gray towel (left) for training, and test on all 3 cloths for evaluation. The white towel and patterned cloth test generalizing to novel cloths. The cloths have thicknesses between 3-5 mm and variation in surface texture and stiffness.

Tirumala et. al. 2022

D. Generalization to Unseen Garments

We explore how SpeedFolding, trained on a single t-shirt, can generalize to garments unseen during training. In these experiments we use (1) a t-shirt with a different color and stiffness and (2) a rectangular towel with a different color compared to the original t-shirt. We evaluate SpeedFolding

Avigal et. al. 2022

OBJECT SETS FOR MANIPULATION

The experimental results of the first grasping are shown in Table 1. Overall, the grasping varies from 76.7% to 93.3% on different clothes. This difference can be attributed into the difference of

clothes material

To evaluate the effectiveness of our deformable manipulation framework, we use 6 benchmarks with different clothes, which have different material characteristics and shapes.

the best

Moreover, we use different initial goal states depending on the lowest scores (78.3%, 76.7%).

Jia et. al. 2017

Ha et. al. 2021



Fig. 9: O

V. EXPERIMENTS

After tuning the parameters on a training set of 3 towels⁷, we ran 50 trials over a wide variety of previously unseen towels. In particular, the test set comprised 25 distinct colors/patterns, 16 distinct materials, and 11 distinct sizes (with lengths ranging from 32 to 78 cm and widths ranging from 32 to 48 cm).⁸ Each of the 25 towels in the test set

Maitin et. al. 2010

fabric manipulation tasks on two different physical robotic systems. Results also suggest robustness to fabrics of various colors, sizes, and shapes. See <https://tinyurl.com/fabric-manipulation>.

Ganapathi et. al. 2021

Evaluating Real-World Unfolding. Finally, we fine-tune and evaluate our simulation models from Tab. 1 with real-world experience on a pair of UR5 arms. Task generation is automated using the robot arms by randomly grasping the cloth at height 0.50m then dropping it back on the workspace. We use a 0.35m × 0.45m cloth for Normal Rect, a 0.40m × 0.70m bath towel for Large Rect, and a 0.45m × 0.55m T-shirt for Shirt.

Ha et. al. 2021

any slow algorithms, and simpler and faster algorithms which assume knowledge of the handling conditions. In our case, a brief description of geometrical properties, a brief description of parameters describing the weight

Action
Pick&
Fling

were conducted to evaluate the proposed algorithm using a towel with the following orange, size 28cm x 28cm, thickness per unit 0.015g/cm², coefficient of friction rate 0.028cm/gf. All experiments were

Salleh et. al. 2006

We proposed a cloth grasp point detection algorithm which has been shown to have very high precision and a very reasonable rate of recall while being highly robust to variation in material, size, and appearance due to relying only on geometric cues. The reliability and robustness of

Maitin et. al. 2010



4 EXPERIMENTAL RESULTS

The proposed approach is tested using a considerable number of fabric pieces of different materials, shape, and colour. Both simulation and experimental tests are conducted to verify the efficiency of the

Zacharia et. al. 2008

eralization to Unse
xplore how SpeedF
eralize to garments
ents we use (1) a
stiffness and (2) a rectang
compared to the original t-shirt. We evaluate Spe

can perform different part
process. As our algorithm is not based on a geometrical model of the garment to be unfolded, it is general enough to be used with any category of garment, from towels and blankets to trousers or shirts, and with any number of folds.

Weng et. al. 2021

Estevez et. al. 2017

Fig. 6: The cloths we use for experiments. We use towel (left) for training, and test on all 3 cloths for evaluation. towel and patterned cloth test generalizing to novel cloths have thicknesses between 3-5 mm and variation in surface texture and stiffness.

Tirumala et. al. 2022

Avigal et. al. 2022

Amount of variation?

HOW CAN WE STANDARDIZE CLOTH OBJECT
SETS FOR ENABLING COMPARISON?

MANIPULATION OBJECT SETS

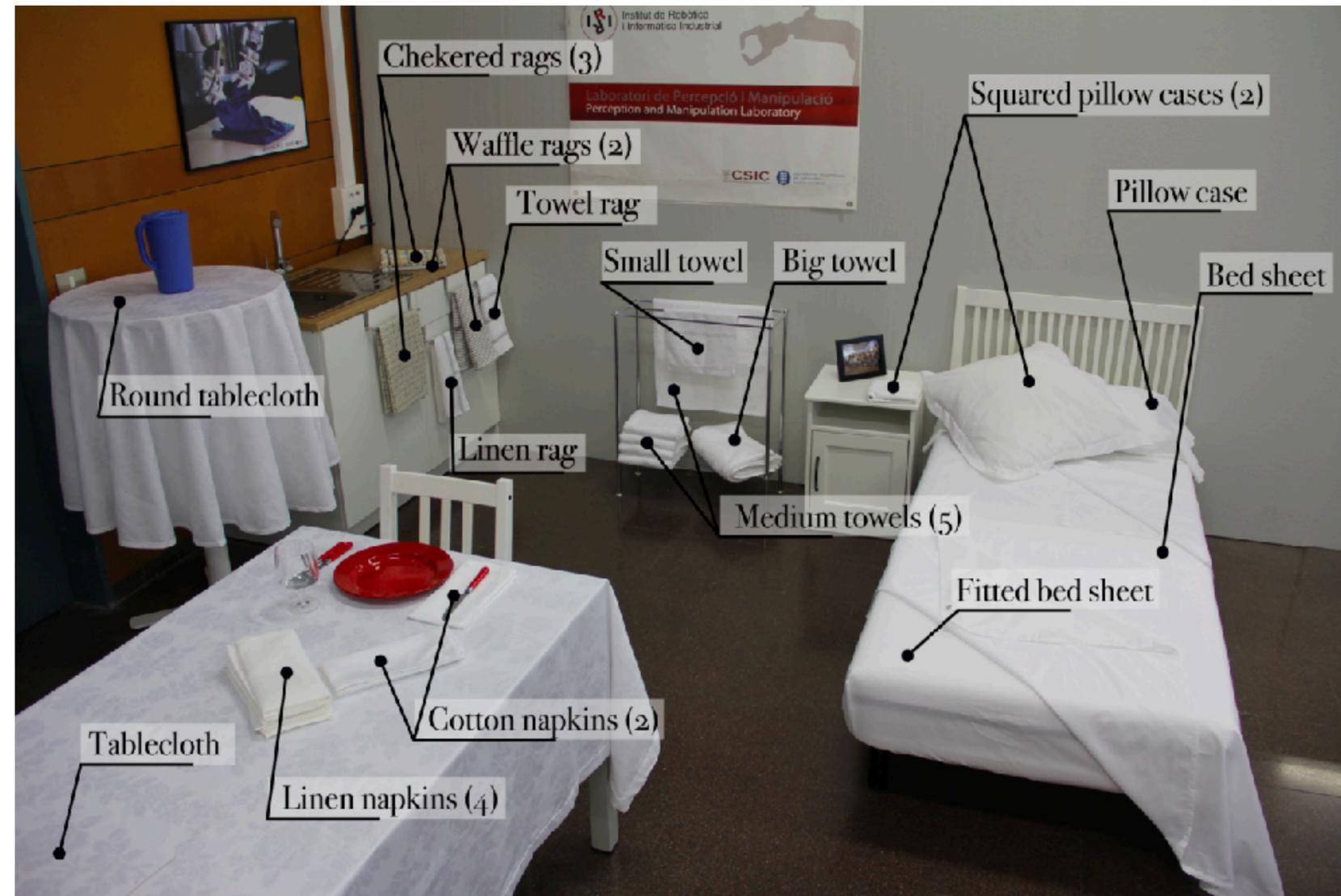
YCB Object Set



Rigid objects

Calli, et. al, 2015

Household Cloth Object Set



Textile objects

Garcia-Camacho, et. al. 2022

TEXTILE CHARACTERIZATION

- ▶ Measurement systems CRITERIA:

- ▶ General
- ▶ Non-destructive
- ▶ Easy-to-use
- ▶ Repeatable

SCAN ME FOR VIDEOS AND DETAILS!



<http://www.iri.upc.edu/groups/perception/#ClothStandardization>

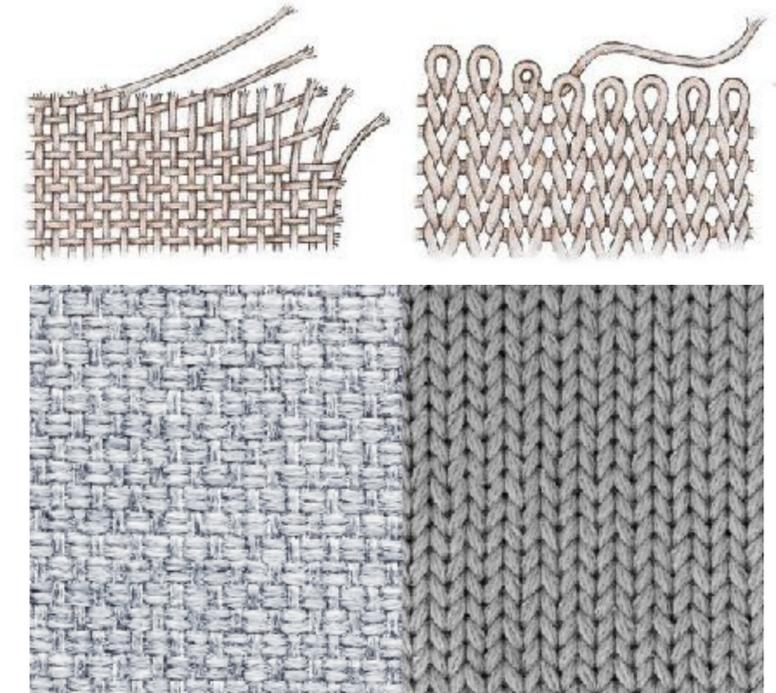
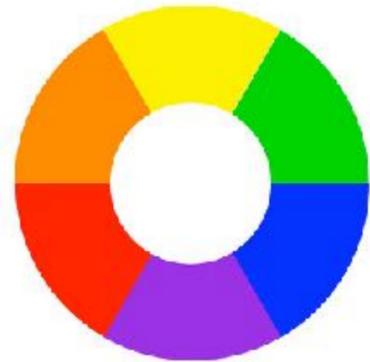
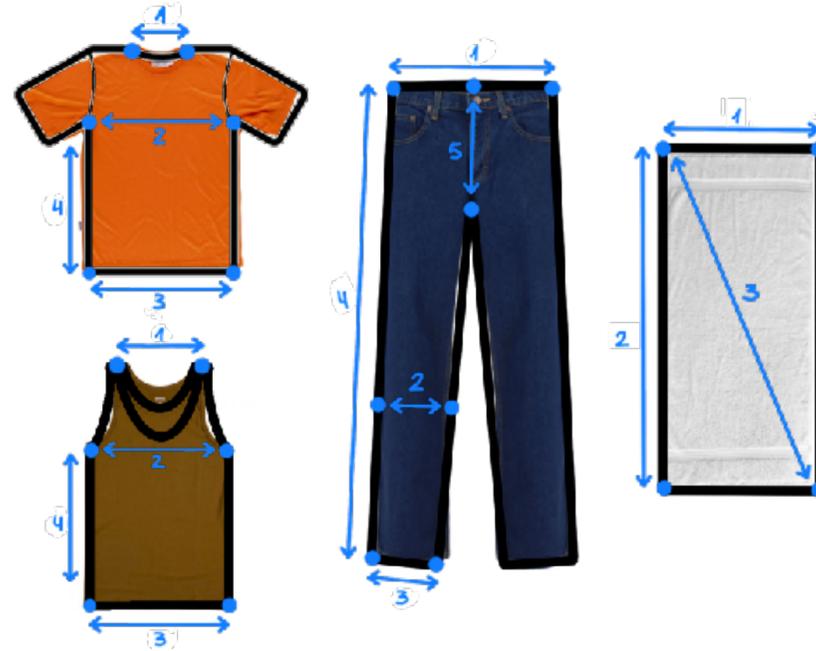
- ▶ Physical and mechanical properties

I. Garcia-Camacho, A. Longhini, M. Welle, G. Alenyà, D.. Kragic and J. Borràs, "**Standardization of cloth objects and its relevance in robotic manipulation**", 2024 IEEE International Conference on Robotics and Automation (ICRA)

TEXTILE CHARACTERIZATION

▶ Physical properties:

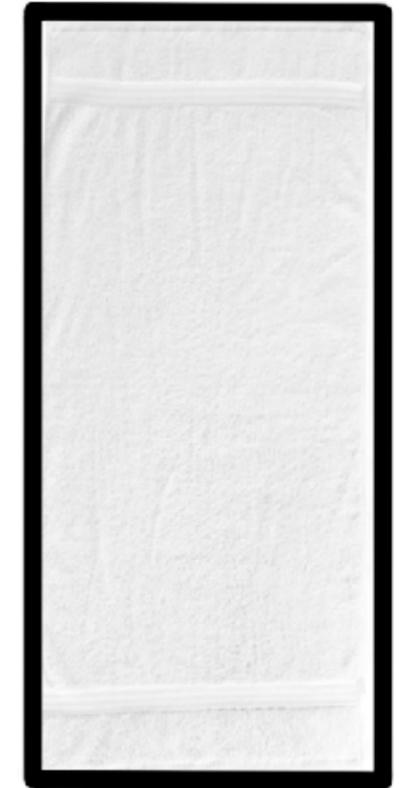
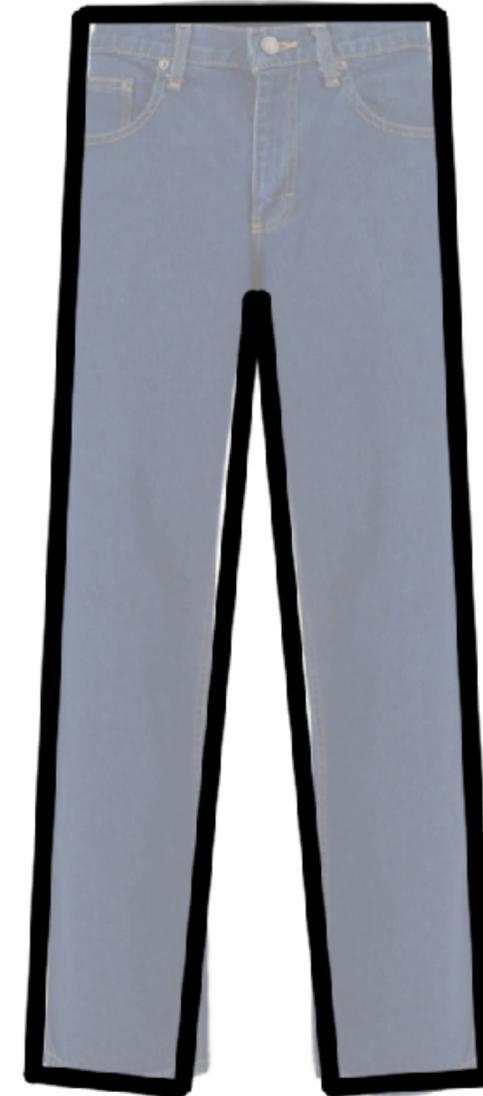
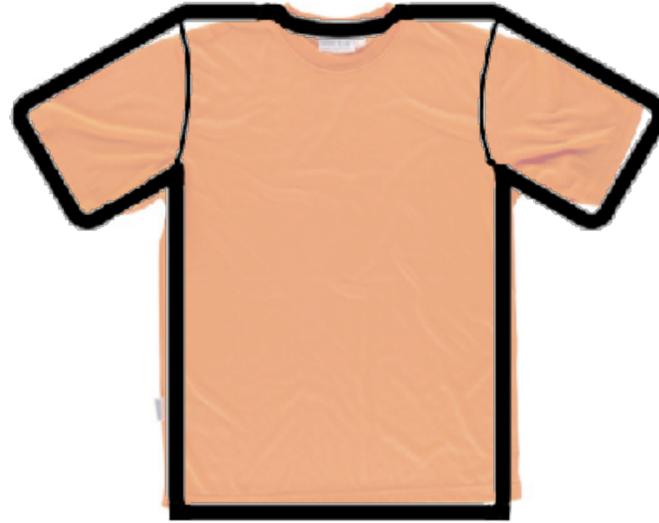
- ▶ Shape
- ▶ Size
- ▶ Weight
- ▶ Color
- ▶ Fabric material
- ▶ Construction technique



TEXTILE CHARACTERIZATION

- ▶ Physical properties:

- ▶ Shape

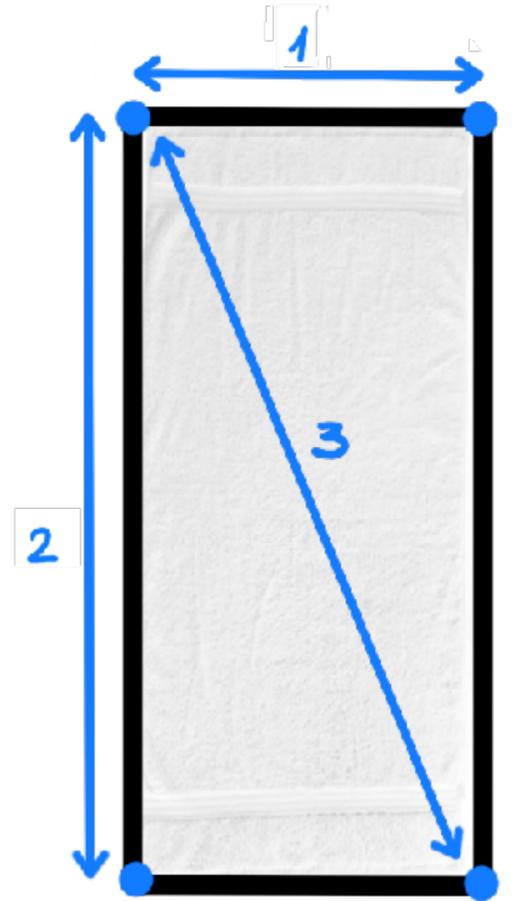
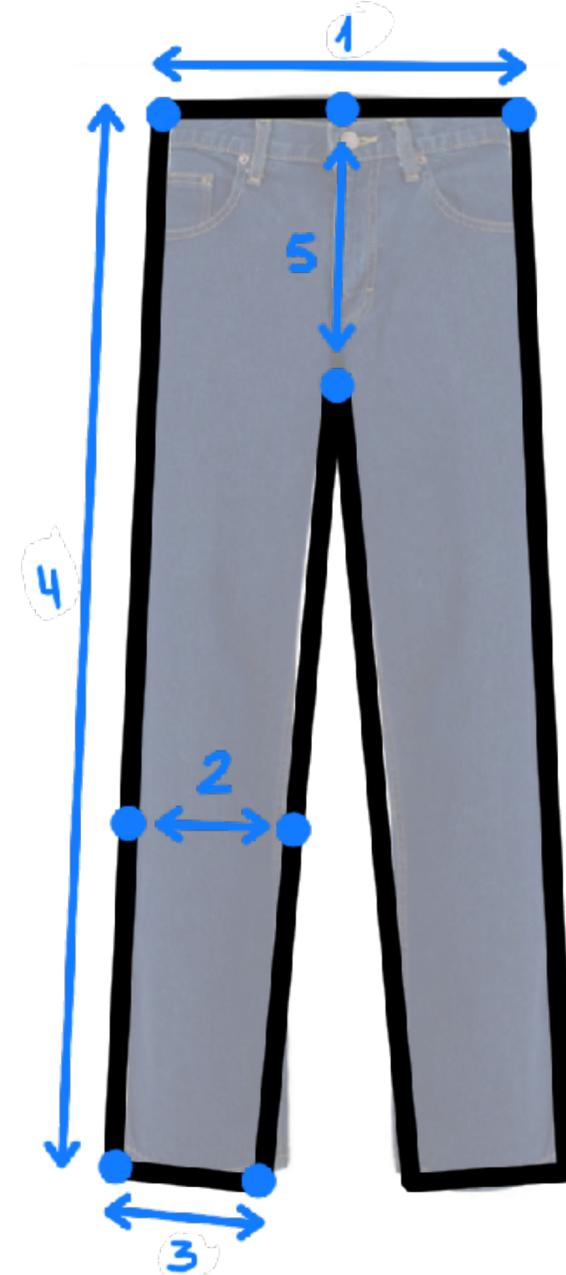
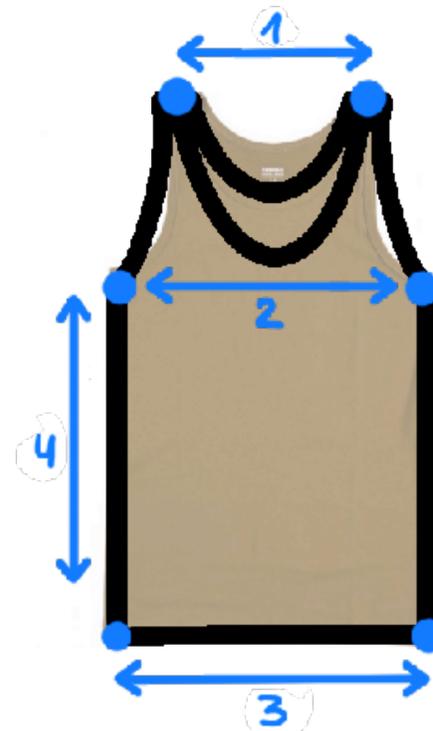
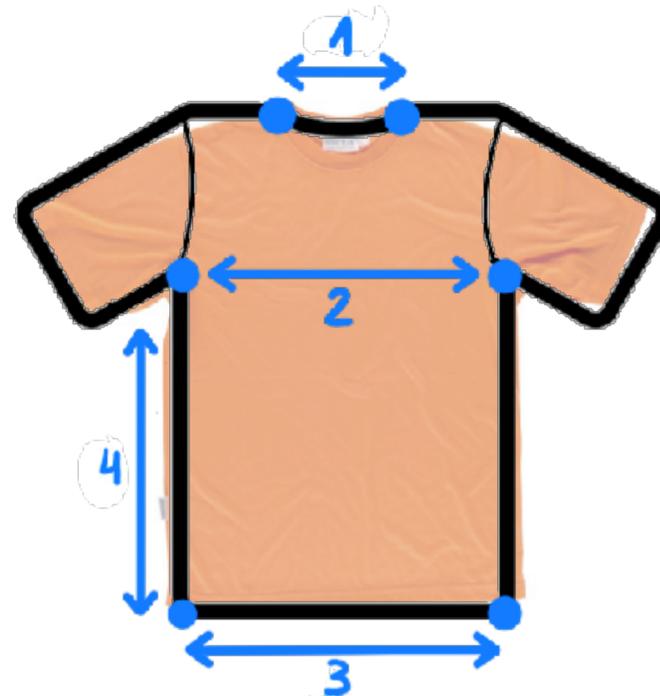


TEXTILE CHARACTERIZATION

- ▶ Physical properties:

- ▶ Shape

- ▶ Size



TEXTILE CHARACTERIZATION

- ▶ Physical properties:

- ▶ Shape

- ▶ Size

- ▶ Weight



TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

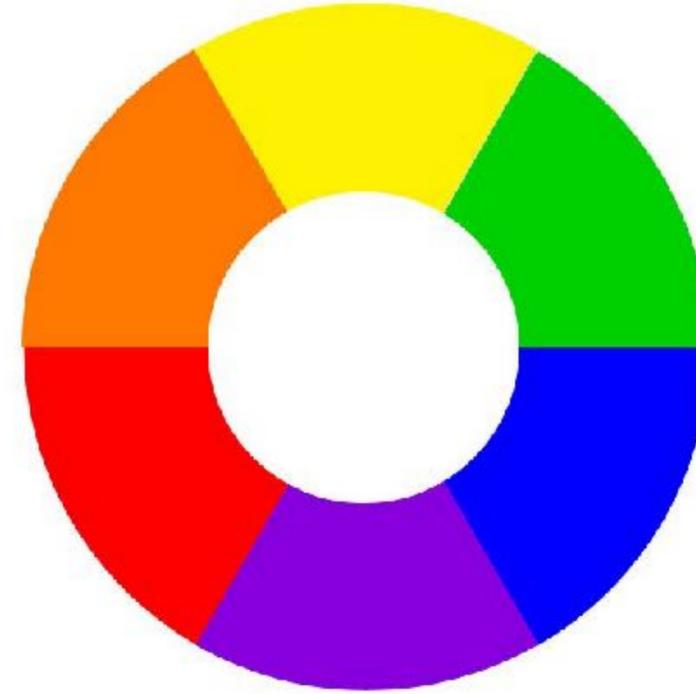
- ▶ Physical properties:

- ▶ Shape

- ▶ Size

- ▶ Weight

- ▶ Color



TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

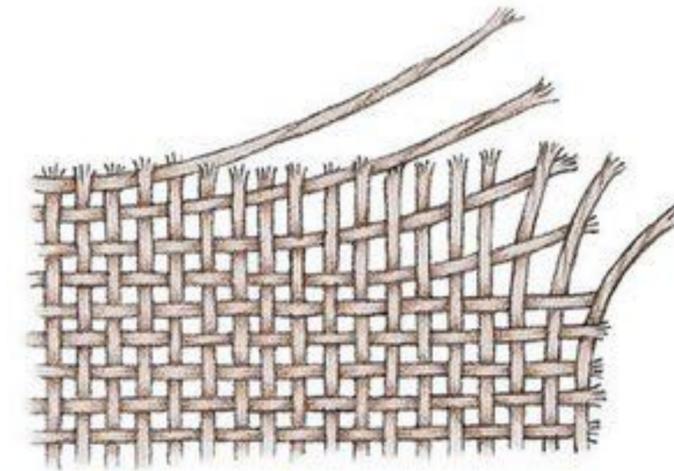
- ▶ Physical properties:
 - ▶ Shape
 - ▶ Size
 - ▶ Weight
 - ▶ Color
 - ▶ Fabric material



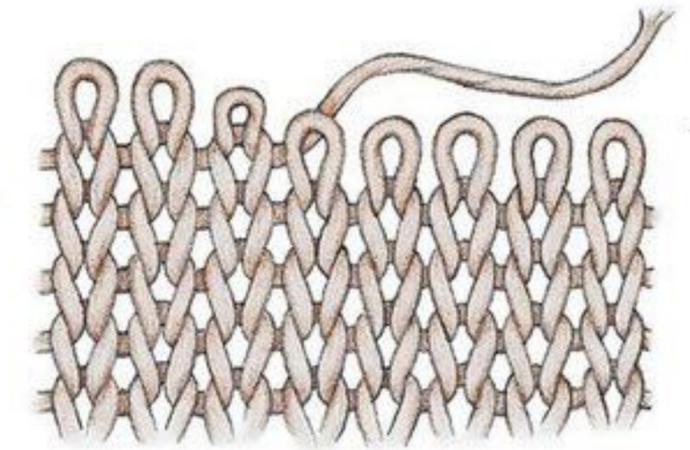
TEXTILE CHARACTERIZATION – PHYSICAL PROPERTIES

- ▶ Physical properties:

- ▶ Shape
- ▶ Size
- ▶ Weight
- ▶ Color
- ▶ Fabric material
- ▶ Construction technique



Woven yarn



Knitted yarn



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- ▶ Mechanical properties:
 - ▶ Stiffness

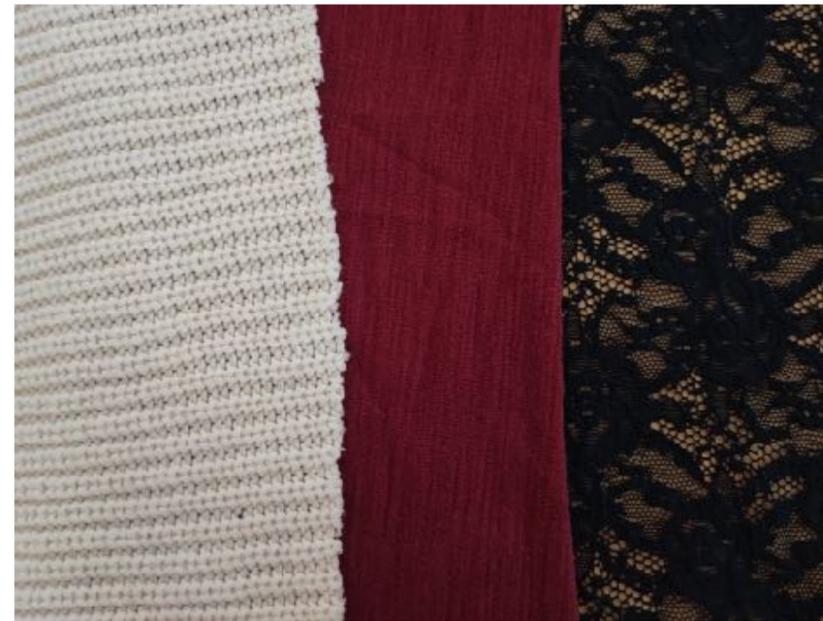


TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- ▶ Mechanical properties:

- ▶ Stiffness

- ▶ Friction



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- ▶ Mechanical properties:

- ▶ Stiffness

- ▶ Friction

- ▶ Elasticity



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

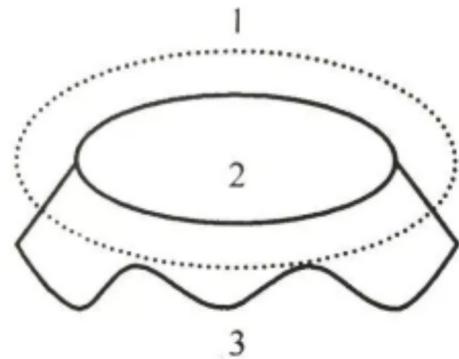
▶ Mechanical properties:

- ▶ Stiffness
- ▶ Friction
- ▶ Elasticity

Textile industry

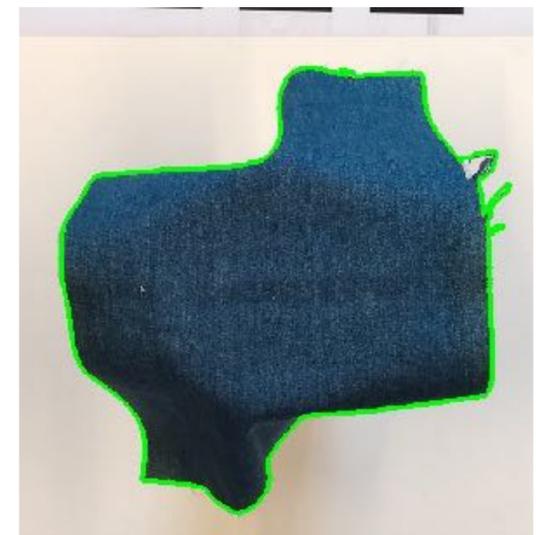
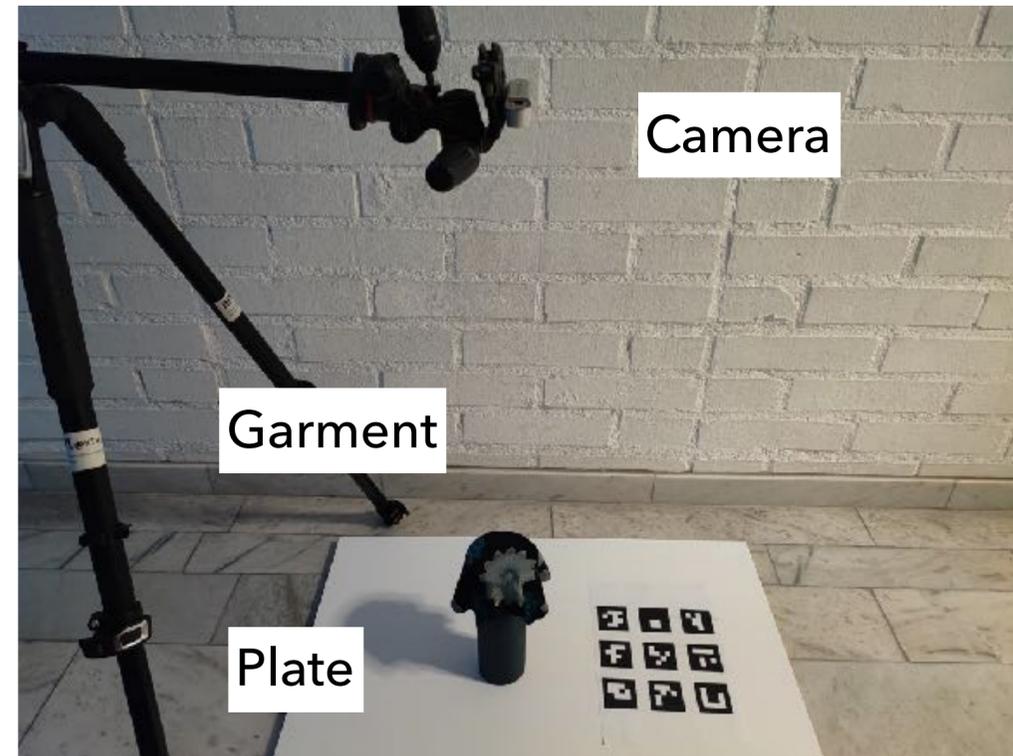


Cusick et. al. 1968



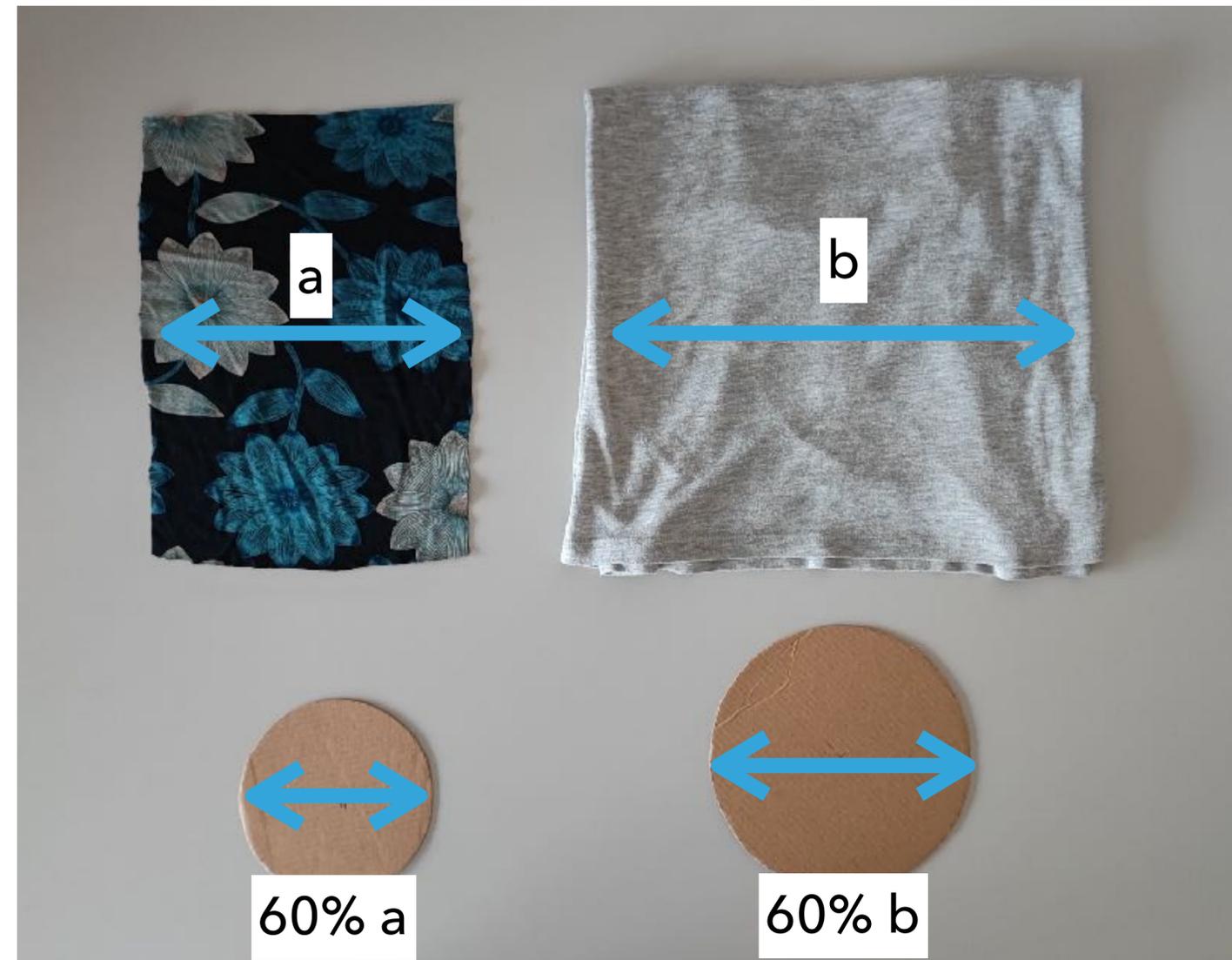
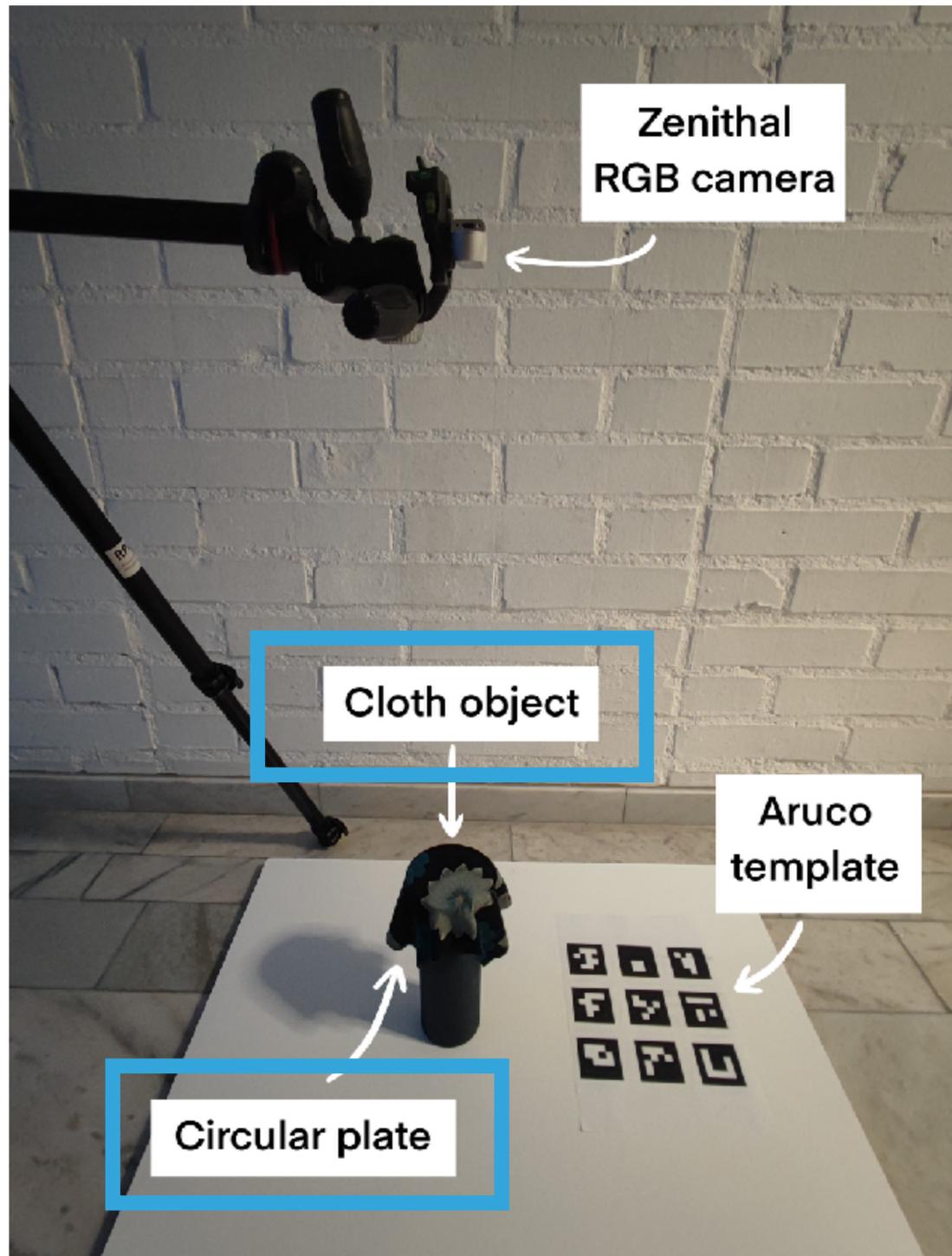
$$stiffness = \frac{A_3 - A_2}{A_1 - A_2}$$

Proposed method



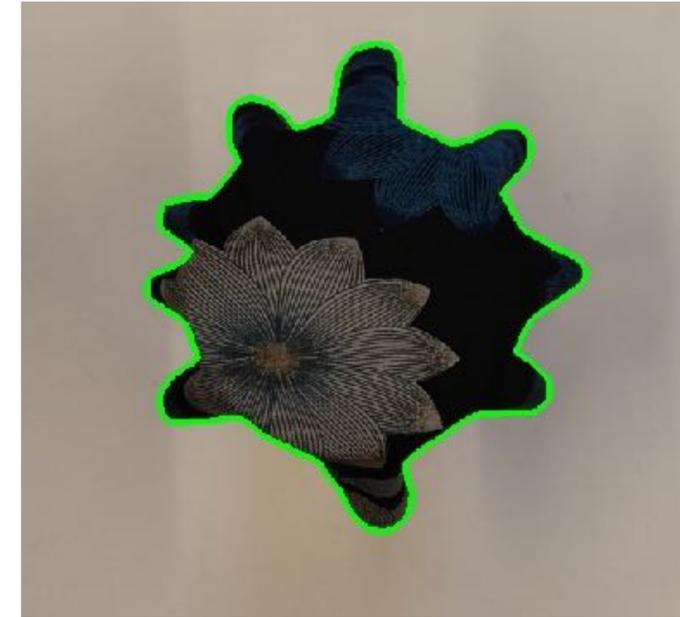
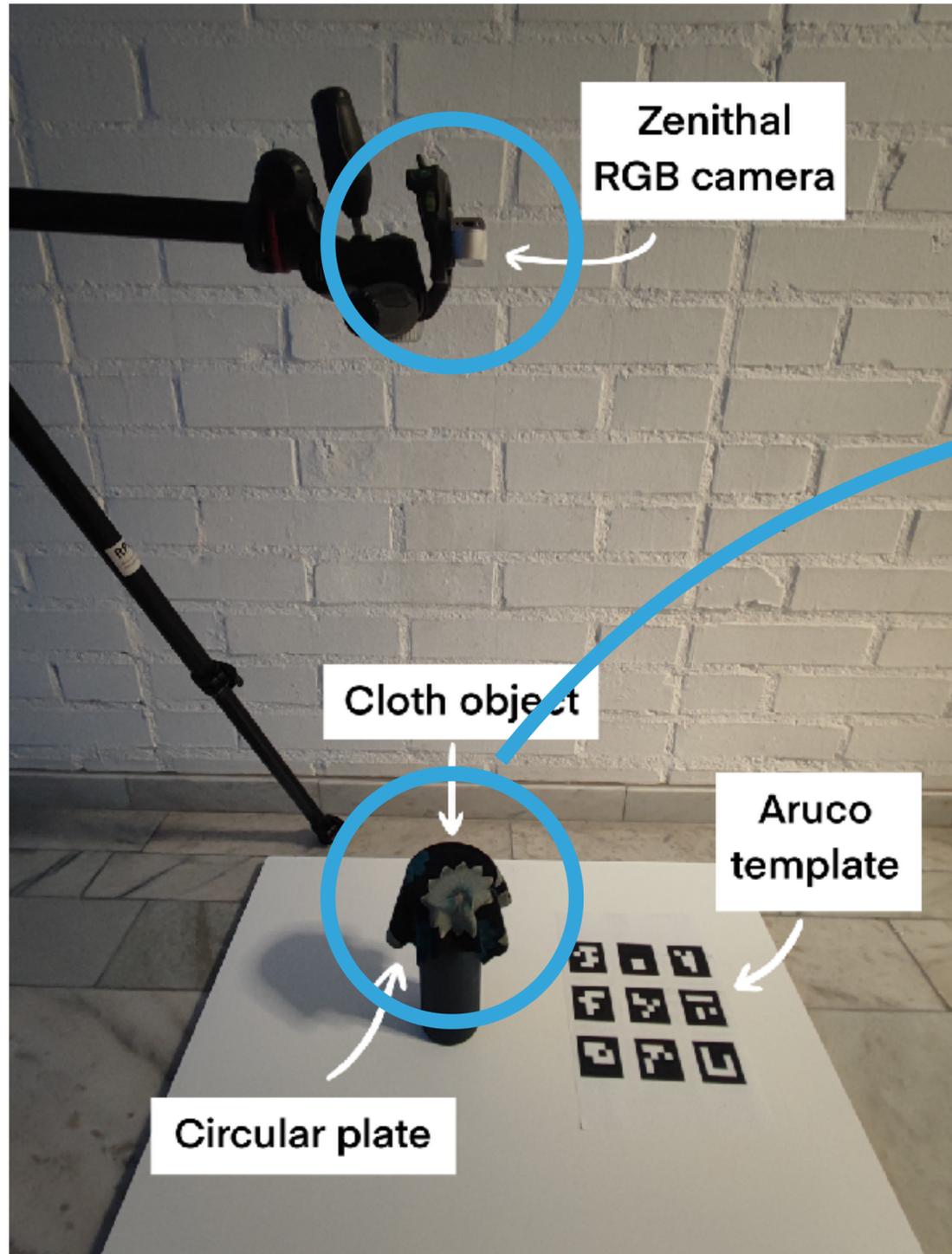
TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

STIFFNESS



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

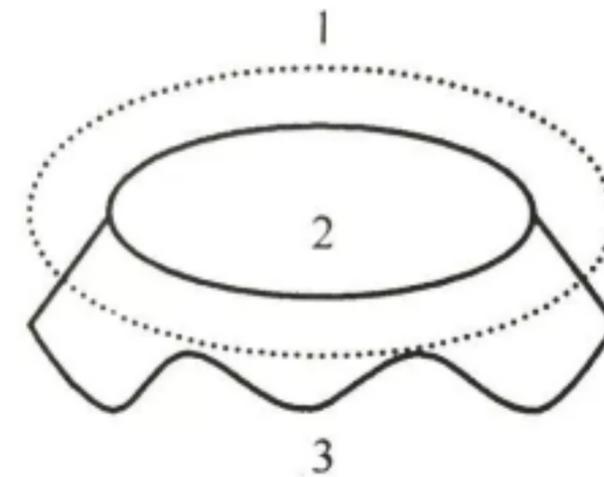
STIFFNESS



GITHUB REPOSITORY

AVAILABLE!

<https://github.com/igarcica/TextileCharacterization>

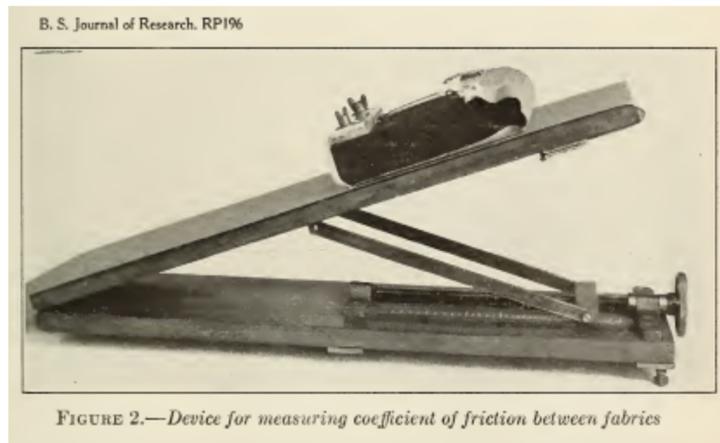


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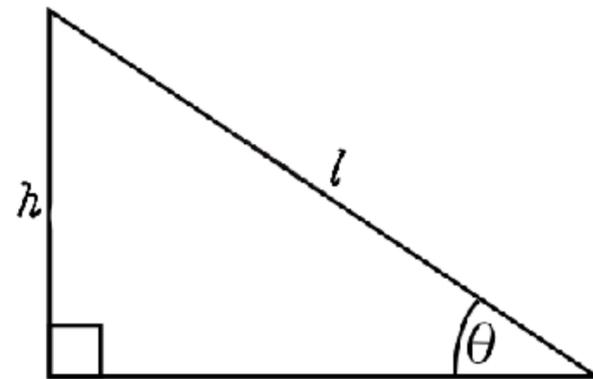
TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

- ▶ Mechanical properties:
 - ▶ Stiffness
 - ▶ Friction
 - ▶ Elasticity

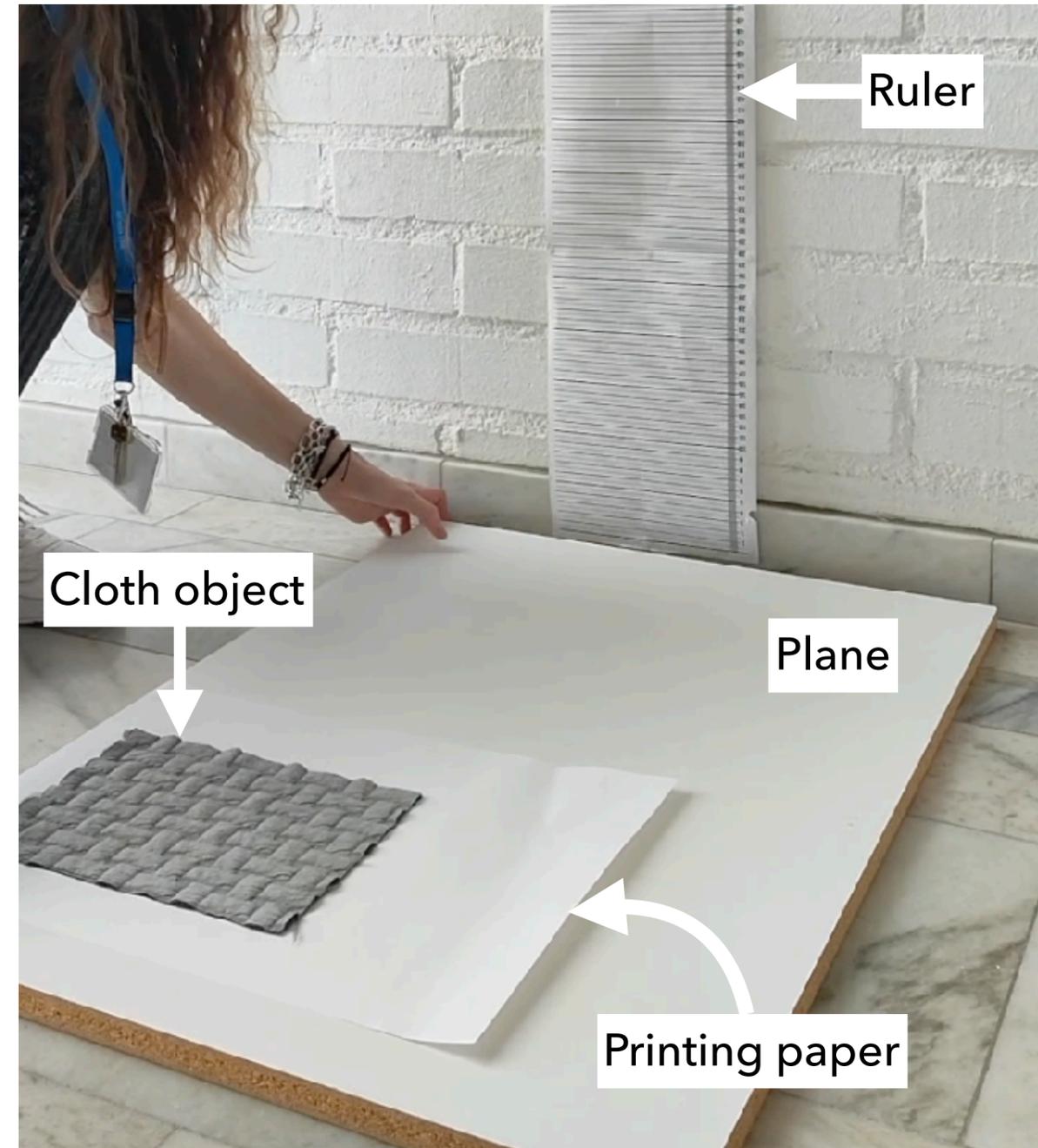
Textile industry



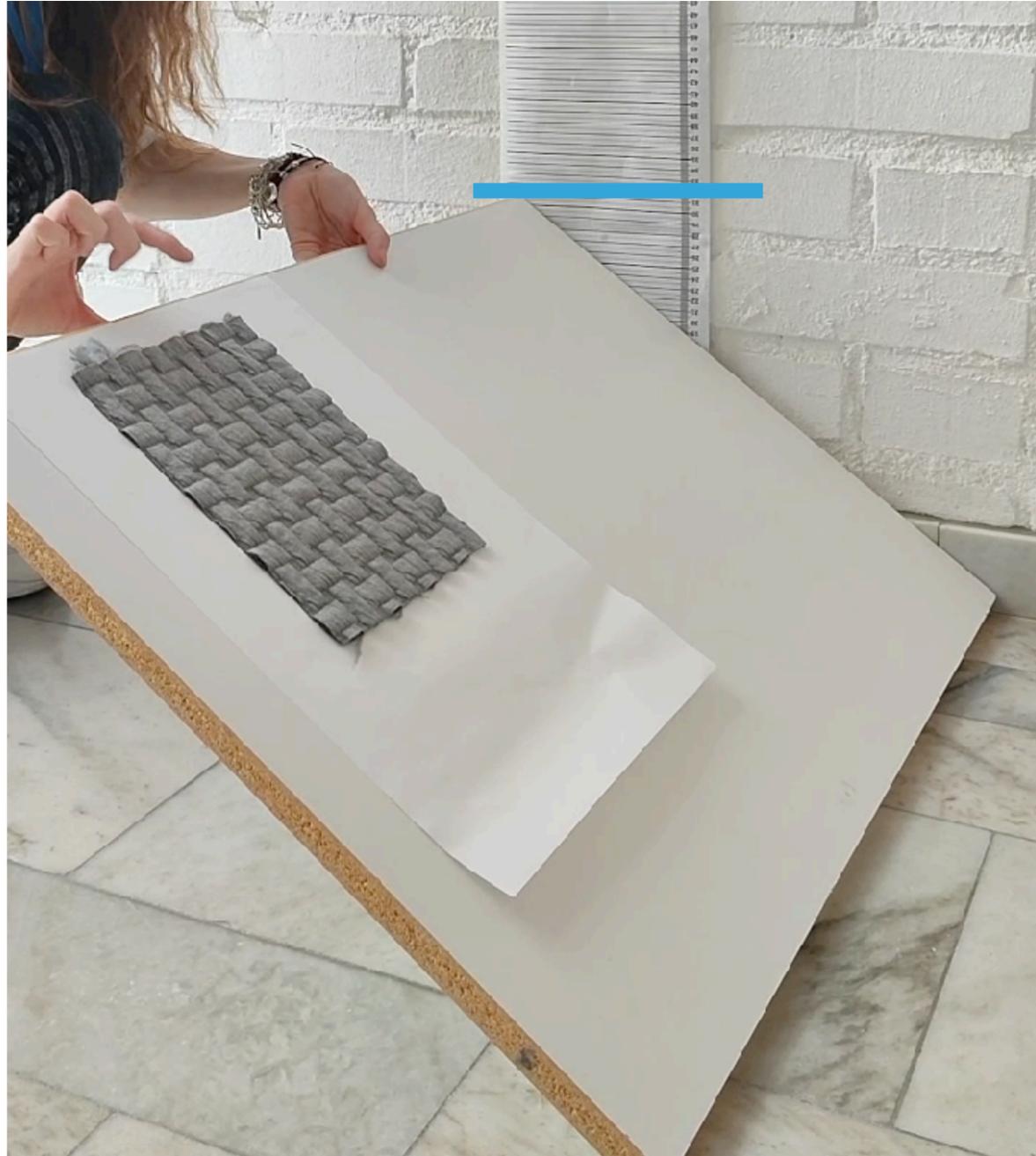
Mercier et. al. 1930



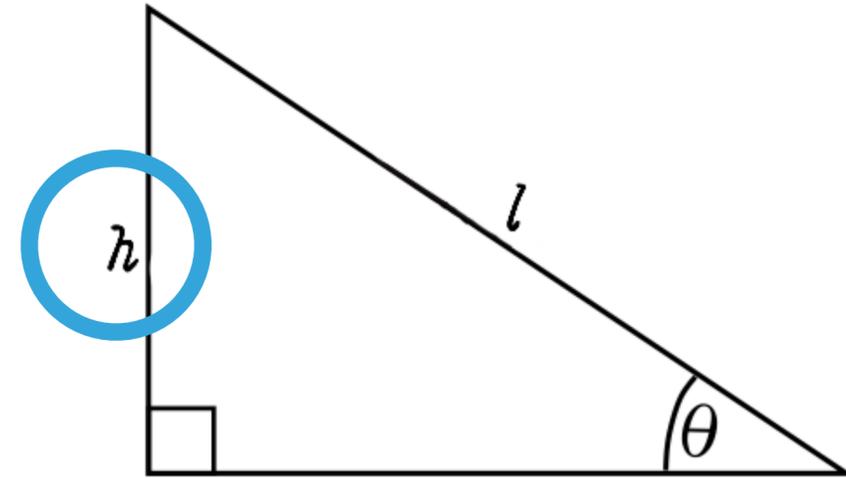
$$\text{friction} = \mu = \tan \left(\sin^{-1} \left(\frac{h}{l} \right) \right)$$



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES



FRICITION



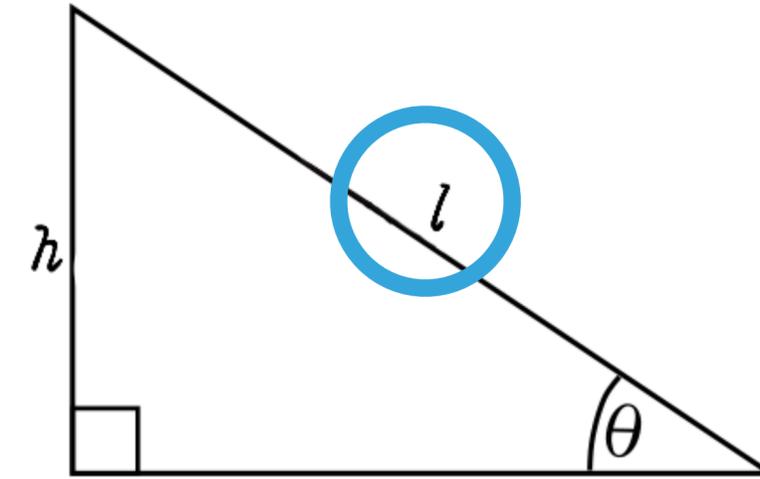
$$\theta = \sin^{-1}\left(\frac{h}{l}\right)$$

$$F_f = F_g$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES



FRICITION

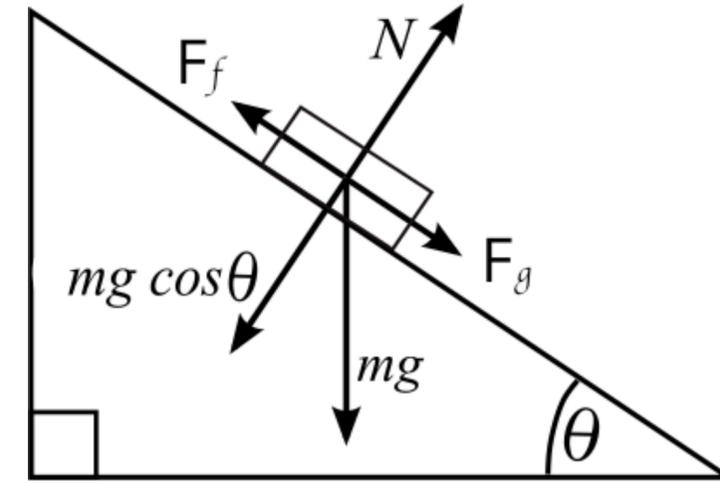


$$\theta = \sin^{-1}\left(\frac{h}{l}\right)$$

$$F_f = F_g$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

FRICITION



$$\theta = \sin^{-1}\left(\frac{h}{l}\right)$$

$$F_f = F_g$$

$$F_f = \mu N = \mu m g \cos(\theta)$$

$$F_g = m g \sin(\theta)$$

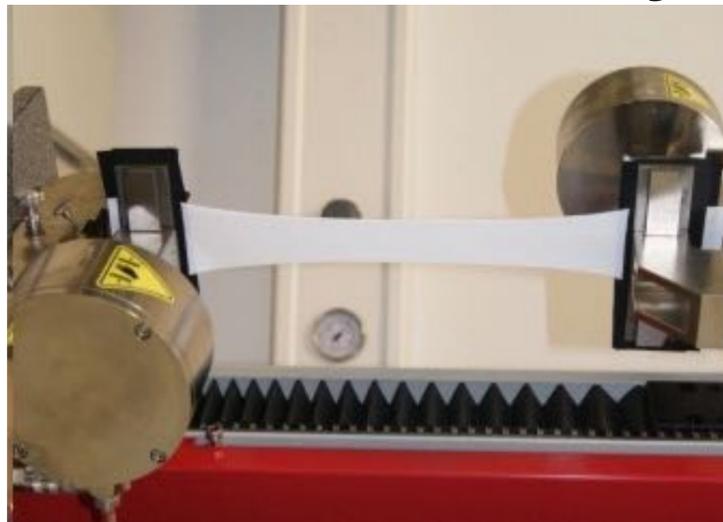
$$\text{friction} = \mu = \tan\left(\sin^{-1}\left(\frac{h}{l}\right)\right)$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

▶ Mechanical properties:

- ▶ Stiffness
- ▶ Friction
- ▶ Elasticity

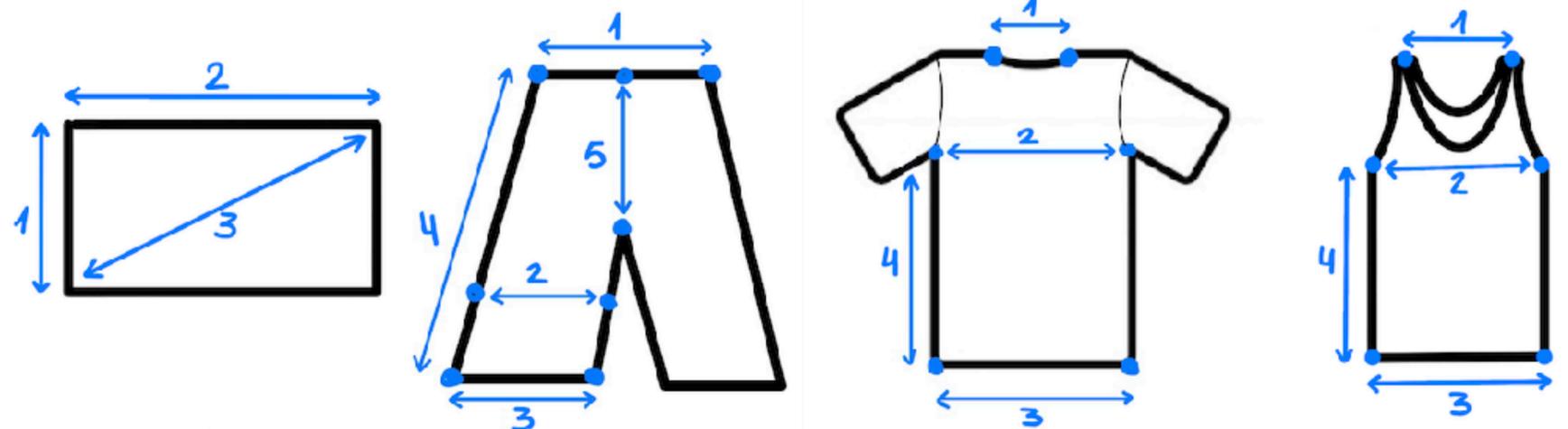
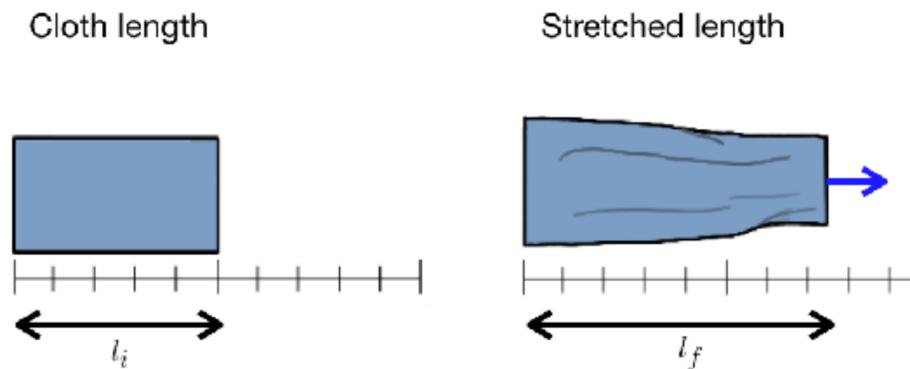
Textile industry



ASTM D76/D76M-21

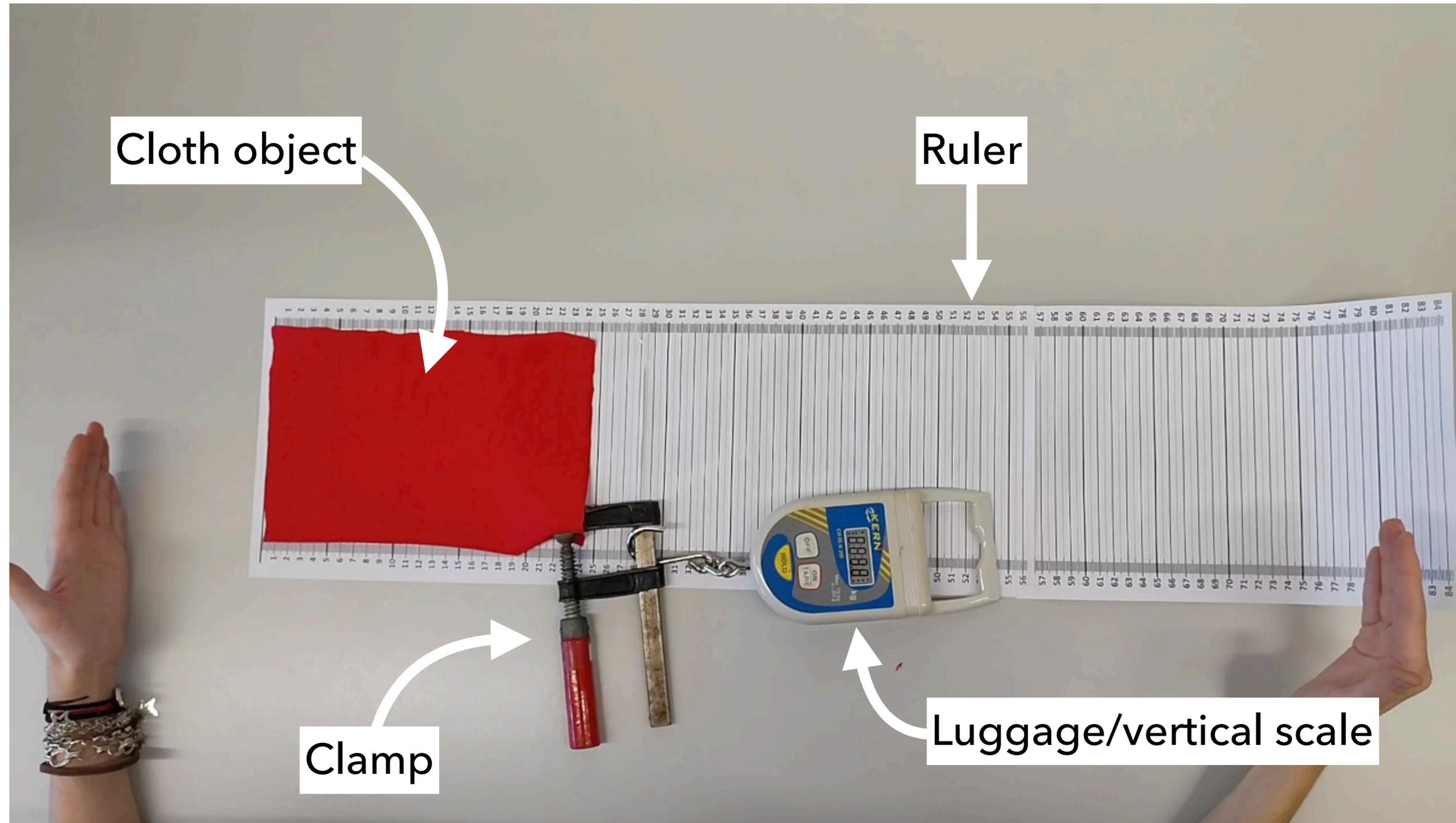
$$elasticity = \frac{l_f - l_i}{l_i}$$

Proposed method



TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

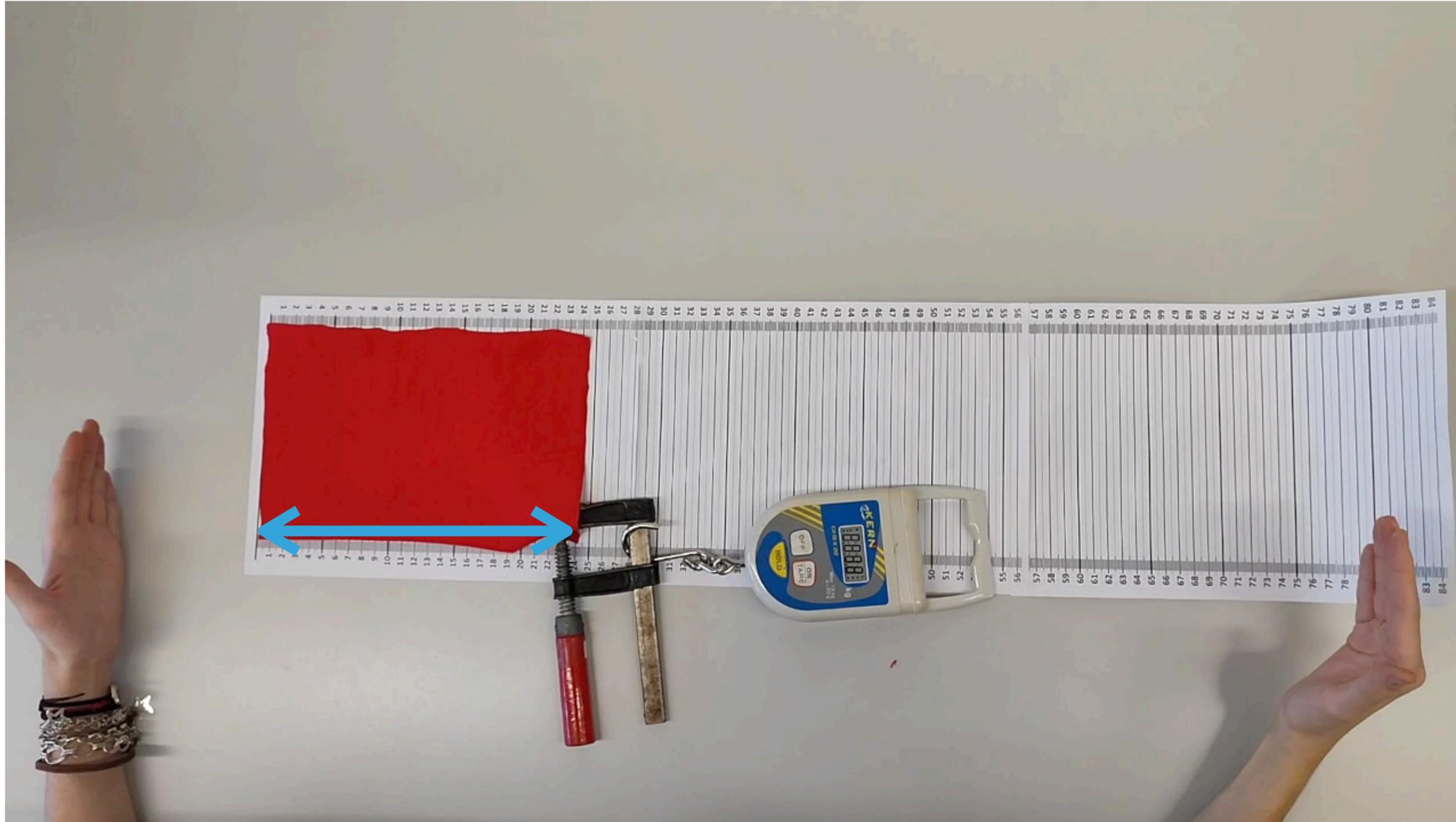
ELASTICITY



$$elasticity = \frac{l_f - l_i}{l_i}$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

ELASTICITY



$$\text{elasticity} = \frac{l_f - l_i}{l_i}$$

TEXTILE CHARACTERIZATION – MECHANICAL PROPERTIES

ELASTICITY



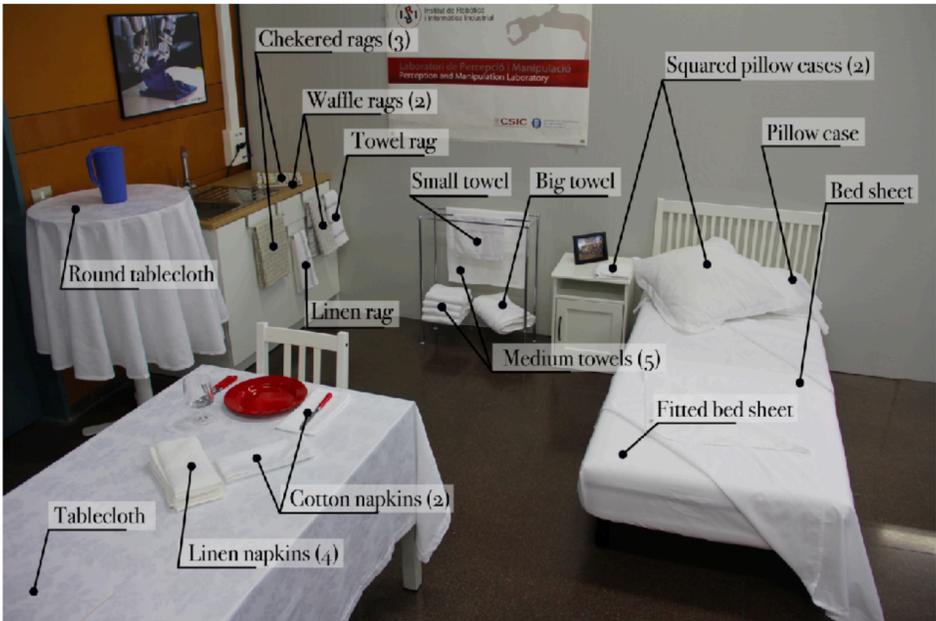
$$\text{elasticity} = \frac{l_f - l_i}{l_i}$$

BENCHMARKING CLOTH SETS

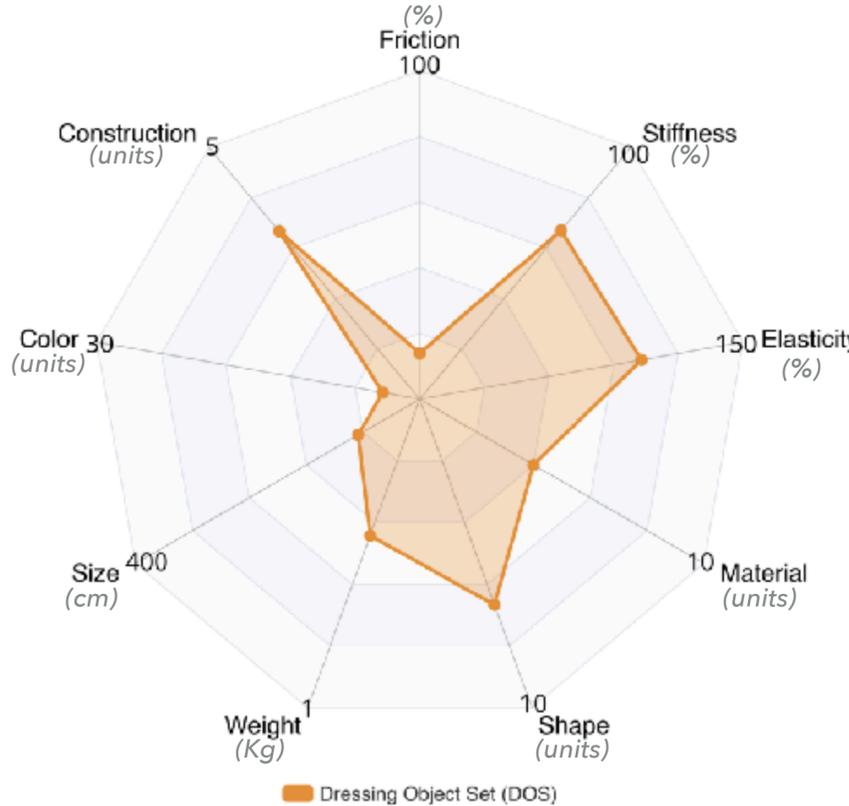
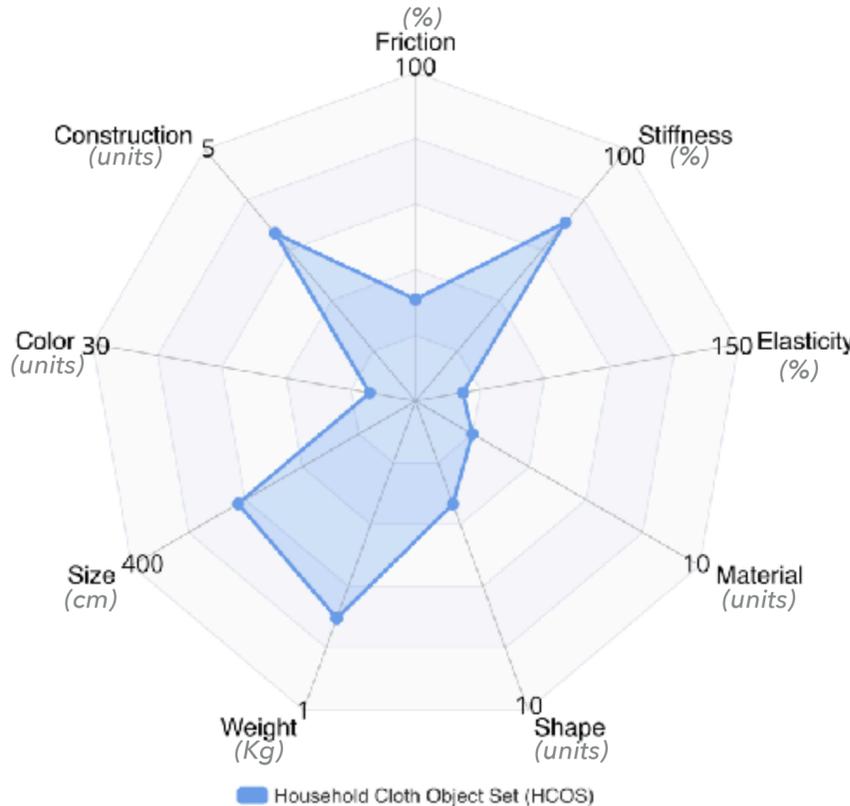
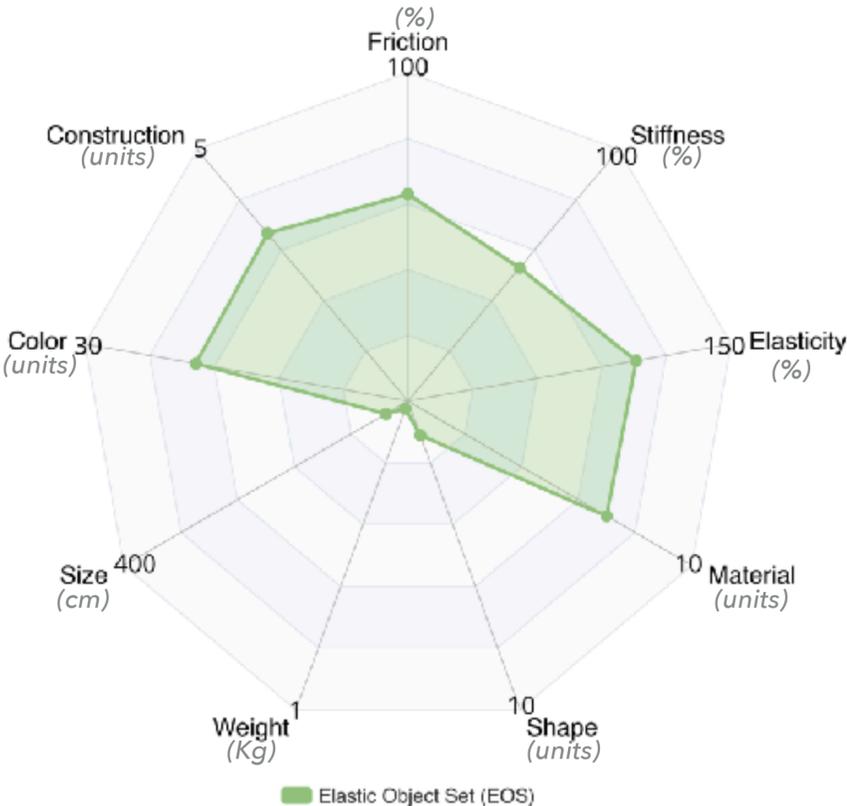
EOS (Longhini et. al. 2023)



HCOS (Garcia-Camacho et. al. 2022)



DOS (Gustavsson et. al. 2022)

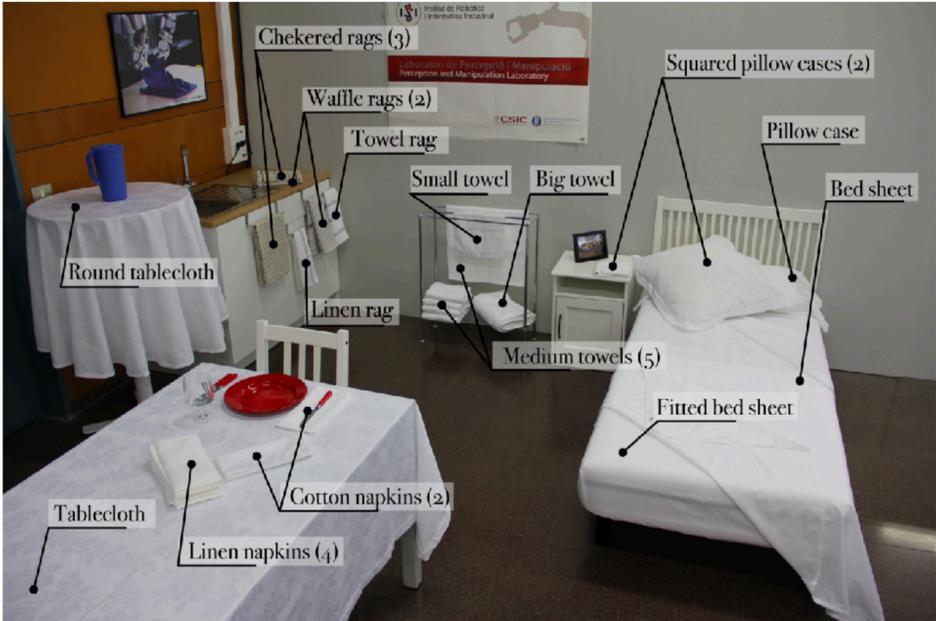


BENCHMARKING CLOTH SETS

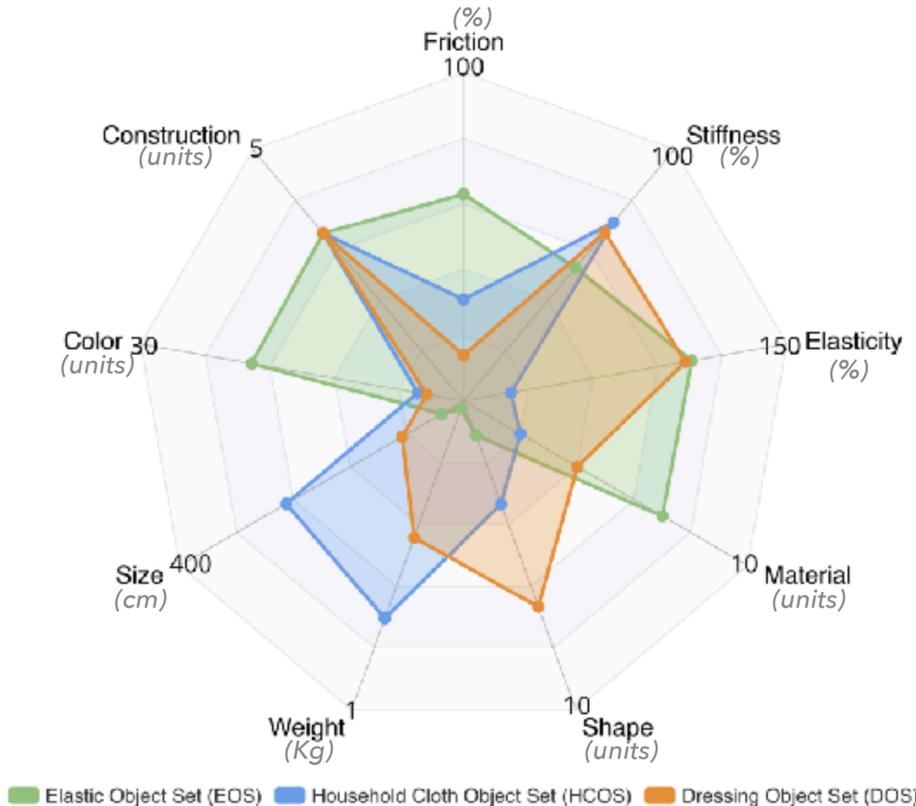
EOS (Longhini et. al. 2023)



HCOS (Garcia-Camacho et. al. 2022)



DOS (Gustavsson et. al. 2022)



RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION



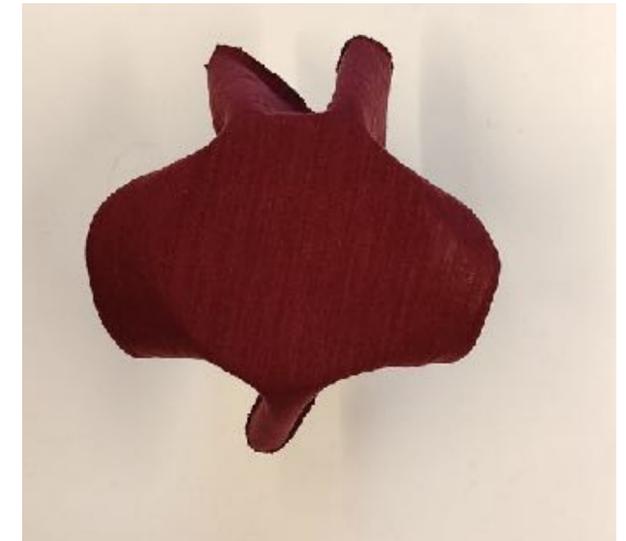
Sample A
Green wool knitted



Sample B
Black polyester woven



Sample C
Red elastane knitted



Sample D
Maroon



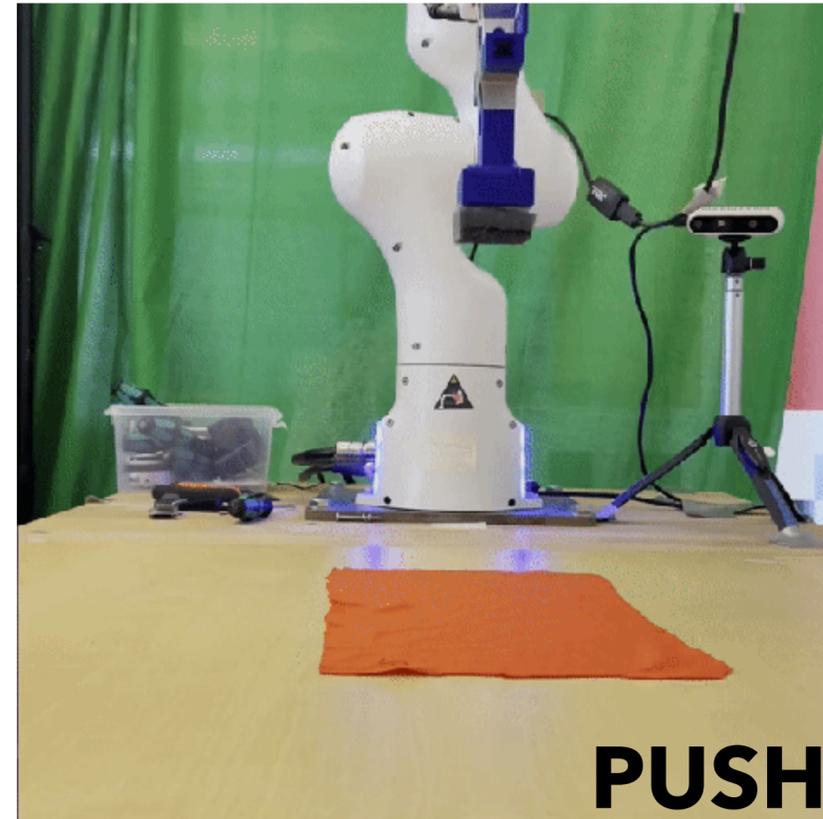
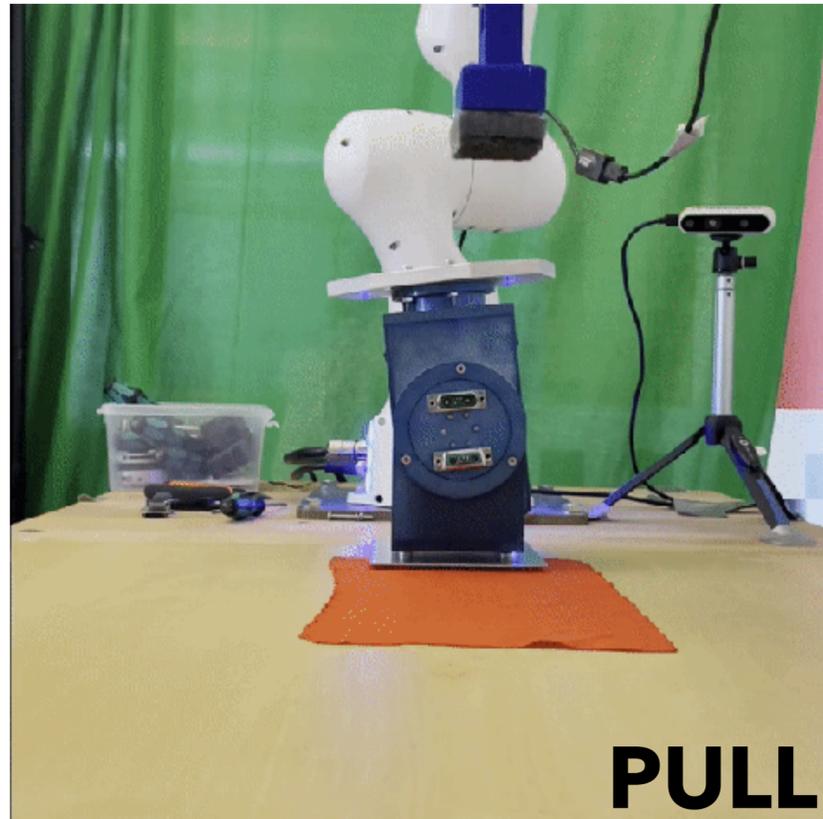
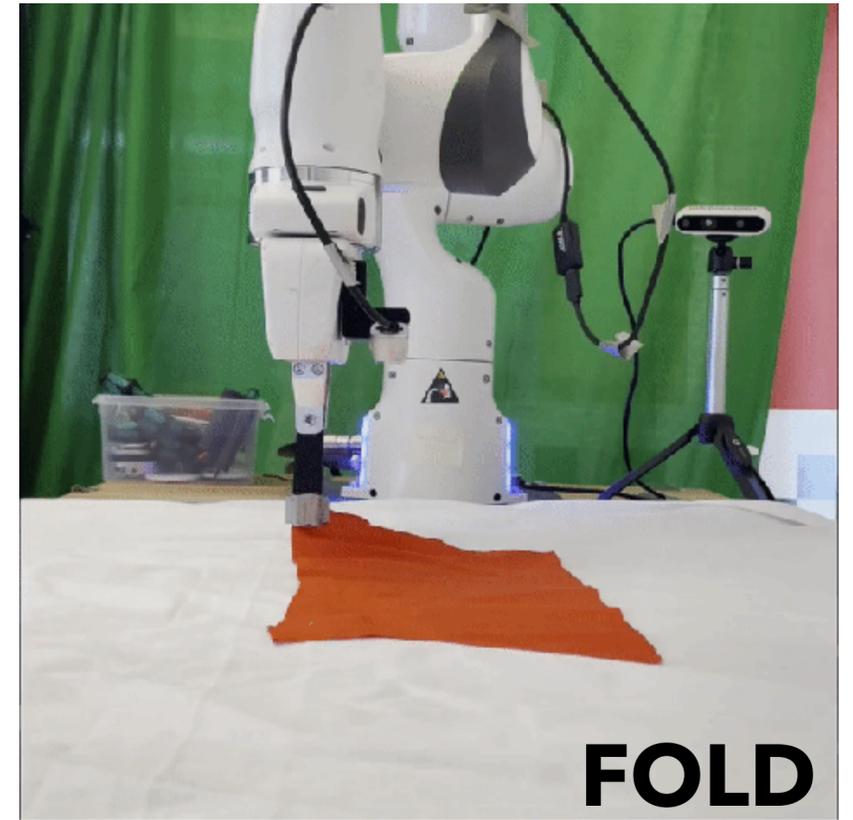
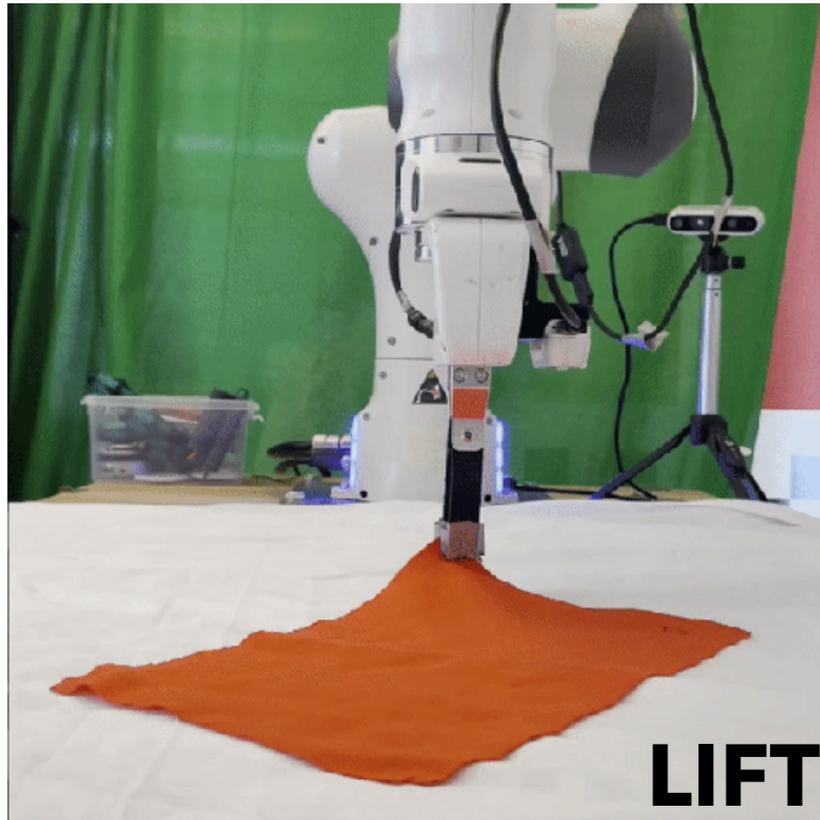
Sample F
Gray elastane woven

Sample	Stiffness	Elasticity	Friction
A	85%	43%	53%
B	34%	7%	45%
C	36%	87%	52%
D	39%	35%	93%
E	59%	100%	60%
F	32%	64%	52%



Sample E
Black&White

RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION



RELEVANCE OF CLOTH PROPERTIES IN ROBOTIC MANIPULATION



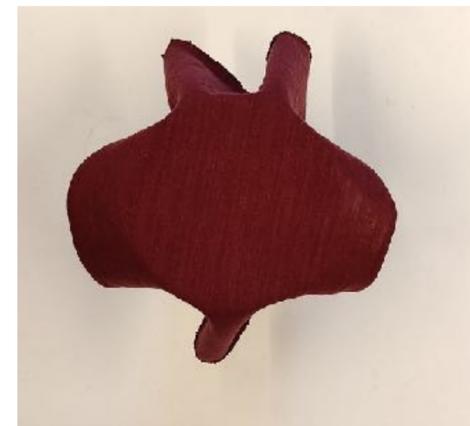
Sample A



Sample B



Sample C



Sample D



Sample E



Sample F

Sample	Stiffness	Elasticity	Friction	Lift	Drag	Fold	Pull	Push
A	85%	43%	53%	0.31 ± 0.01	0.97 ± 0.01	1.00 ± 0.0	0.94 ± 0.02	0.83 ± 0.00
B	34%	7%	45%	0.23 ± 0.00	0.96 ± 0.02	0.63 ± 0.01	0.97 ± 0.00	0.84 ± 0.01
C	36%	87%	52%	0.23 ± 0.02	0.90 ± 0.01	0.63 ± 0.00	0.72 ± 0.07	0.64 ± 0.03
D	39%	35%	93%	0.20 ± 0.00	0.84 ± 0.02	0.63 ± 0.01	0.90 ± 0.03	0.69 ± 0.05
E	59%	100%	60%	0.21 ± 0.01	0.93 ± 0.00	0.60 ± 0.02	0.91 ± 0.01	0.65 ± 0.02
F	32%	64%	52%	0.20 ± 0.00	0.79 ± 0.03	0.60 ± 0.00	0.88 ± 0.02	0.66 ± 0.02

HANDS ON – MINI PROJECT SESSION

Object sets



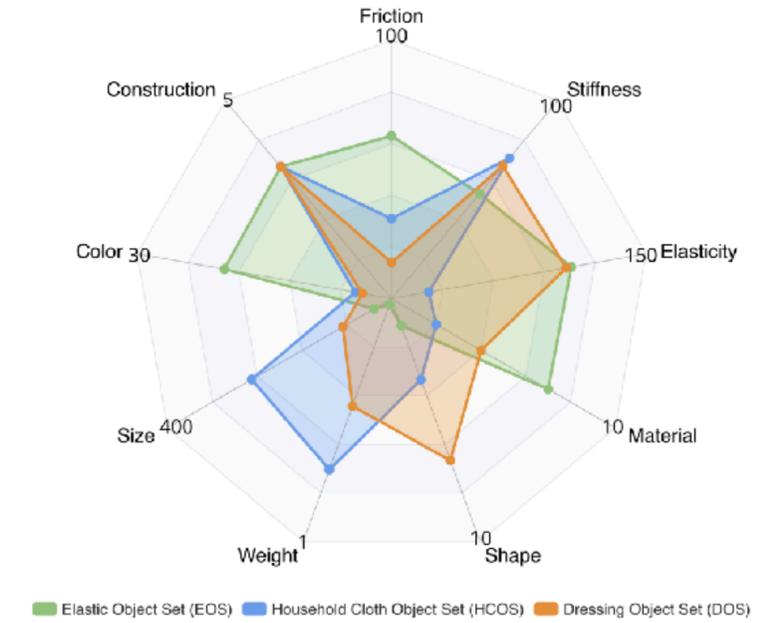
Textile characterization

Objec	Image	# Size sh...	# Size long	Σ Size (di...	Σ Area	# Weight...	Σ Weight...	Shape	Colors	Textures	Material
Black flowers		17	23	29	391	8.4	0.0084	Rectang...	Black White	Texture1	Polyester Elastane
Black		17	30	34	610	6	0.006	Rectang...	Black	Black	Polyester
Denim		17	25	30	426	11.45	0.01145	Rectang...	Blue	Blue	Cotton
Brown		20	22	30	440	18.85	0.01885	Rectang...	Brown	Brown	Wool
Green wool		16	28	32	448	23.1	0.0231	Rectang...	Green	Green	Wool
Black wool		17	31	35	627	16.4	0.0164	Rectang...	Black	Black	Wool
Black & white		18	25	31	450	13.74	0.01374	Rectang...	Black White	Texture2	Acrylic
Brownish		17	32	38	544	17.6	0.0176	Rectang...	White Black	Texture3	Wool
White thin		14.6	31	34	449.6	14.6	0.0146	Rectang...	White	White	Wool
Dark blue thick		14	26	30	364	18.4	0.0184	Rectang...	Blue	Blue	Wool
White thick knit		19	32	37	608	26.5	0.0265	Rectang...	White	White	Acrylic
Dark blue thin		16	24	29	384	15	0.015	Rectang...	Blue	Blue	Wool
Red		17	30	34	610	8.96	0.00896	Rectang...	Red	Red	Elastane Polyester
Flowers gray		18	30	35	540	9.6	0.0096	Rectang...	Black Gray	Texture4	Elastane

NOT EMPTY 37 AVERAGE 17.18 AVERAGE 26.97 MAX 37 AVERAGE 10.82 UNIQUE 1 UNIQUE 10 UNIQUE 23 UNIQUE 7



Radar chart



Study impact in manipulation





ROMANDIC

SCAN ME!



BENCHMARKING CLOTH MANIPULATION: ENABLING COMPARISON THROUGH STANDARDIZATION

IRENE GARCIA-CAMACHO