

Sustainability Robotics



Illustration: Jose Pereja

Prof. Dr. Mirko Kovac
24.11.2025

Introduction to Environmental Science and Engineering



Laboratory of Sustainability Robotics

Robotics innovation global trends



Atlas robot Boston Dynamics

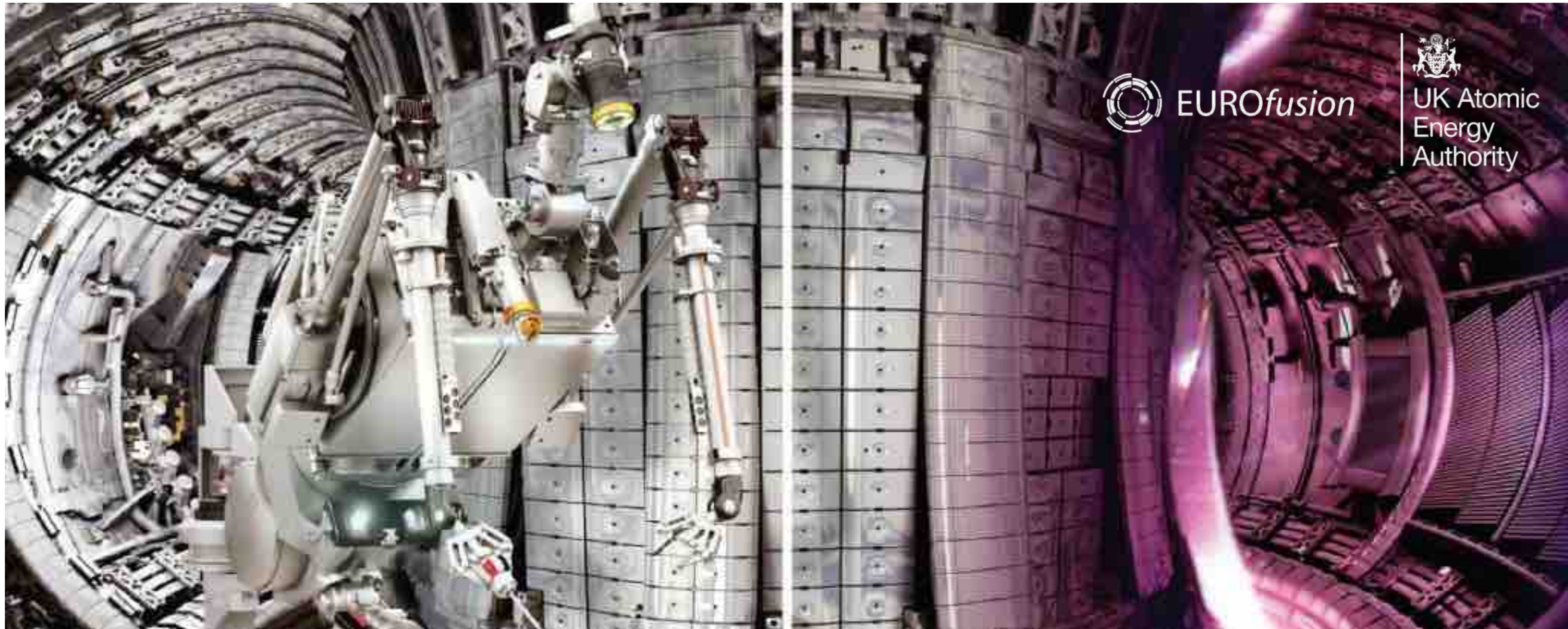
(YouTube: https://www.youtube.com/watch?v=-e1_QhJ1EhQ)

Robotics innovation global trends



Da Vinci robotic surgery system (Intuitive Surgical)

Robotics innovation global trends



Remote Applications in Challenging Environments (RACE) in Culham Oxford

Robotics innovation global trends



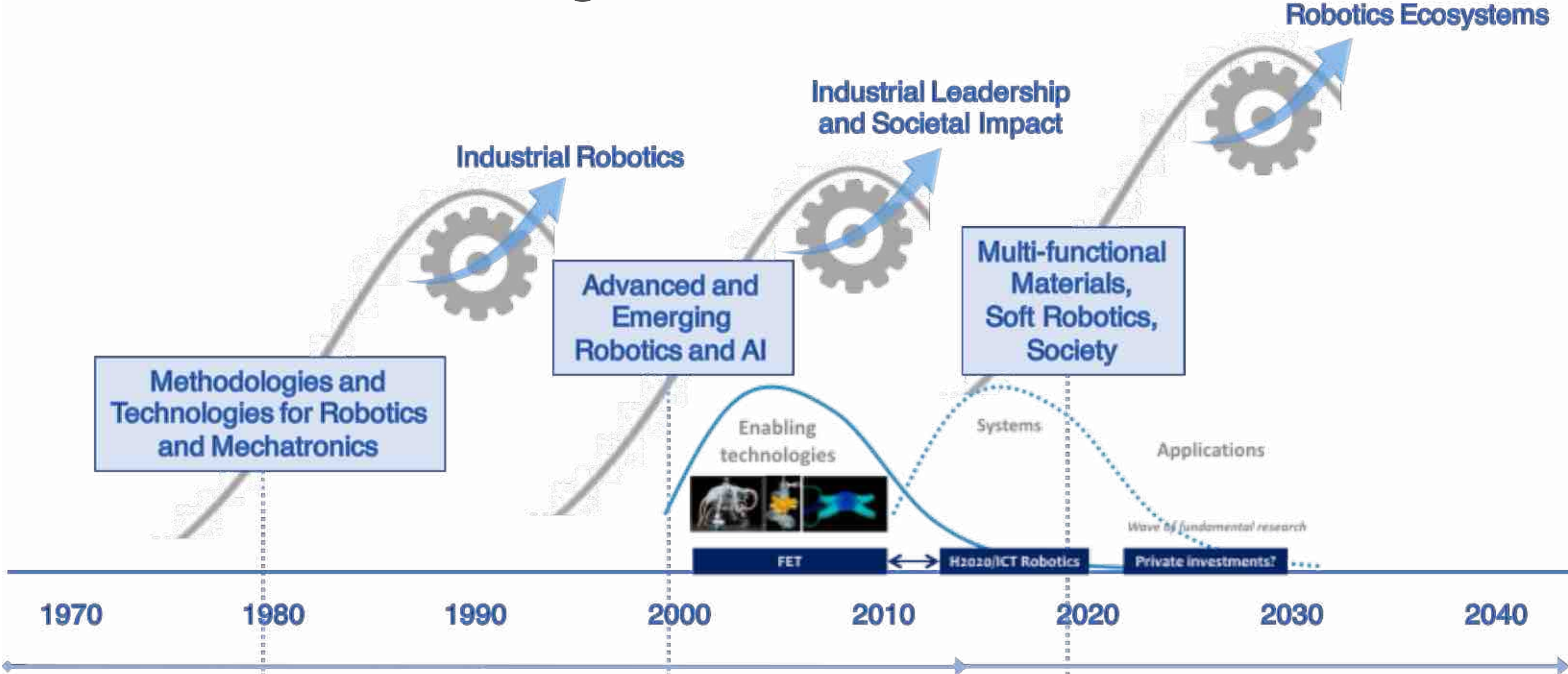
MIT Cheetah robot (Prof. Sang-bae Kim)

Robotics innovation global trends



OceanONE Stanford Robotics Lab (Prof. Ousama Khatib)

Robotics innovation global trends



Body of Knowledge

- Mechanics
- Control
- Computer Engineering



Future Robotics

- Soft Robotics
- Embodied Intelligence
- Robot Companions

Illustration credit: Laura Margheri

Firstpost Home Video Shows World Explainers

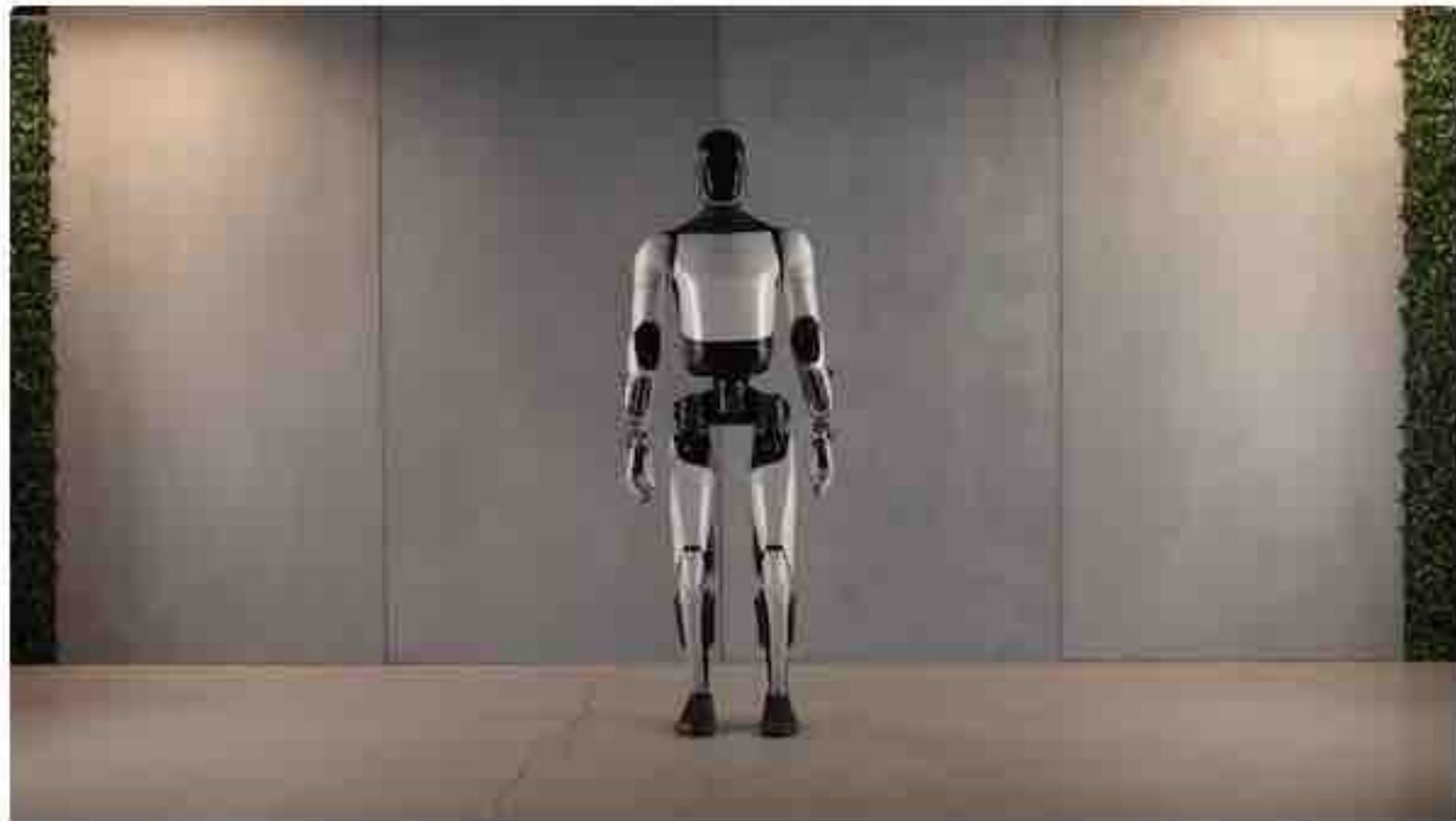
Home / Tech / Tesla goes on a hiring spree as it begins to ramp up production of Optimus hu...

Tesla goes on a hiring spree as it begins to ramp up production of Optimus humanoid robot

FP Staff • February 6, 2025, 18:51:57 IST

WhatsApp Facebook X

The large number of open positions indicates that Tesla is accelerating its efforts to boost manufacturing capacity for Optimus. As the company shifts its focus to high-volume production, it appears poised to move closer to making the Tesla Bot a commercially available product



CES 2025: NVIDIA's Cosmos Just Gave Robots a 'ChatGPT Moment'!

AI ANALYTICS

CES 2025: NVIDIA's Cosmos Just Gave Robots a 'ChatGPT Moment'!

By Nigel Pereira No Comments 5 Mins Read — 02/10/2025

Image: yourtechdiet.com/

HANS PETER BRONDMO THE BIG STORY SEP 18, 2024 6:00 AM

Inside Google's 7-Year Mission to Give AI a Robot Body

WIRED

Boston Dynamics joins forces with its former CEO to speed the learning of its Atlas humanoid robot

Story by Brian Heater • 1w • 3 min read

Forbes

Meta Is Developing Humanoid Robots; This Has Huge Potential For Healthcare

Dr. Sai Balasubramanian, M.D., J.D. Contributor
Sai writes about healthcare, innovation and technology.

Follow

Feb 17, 2025, 08:37am EST

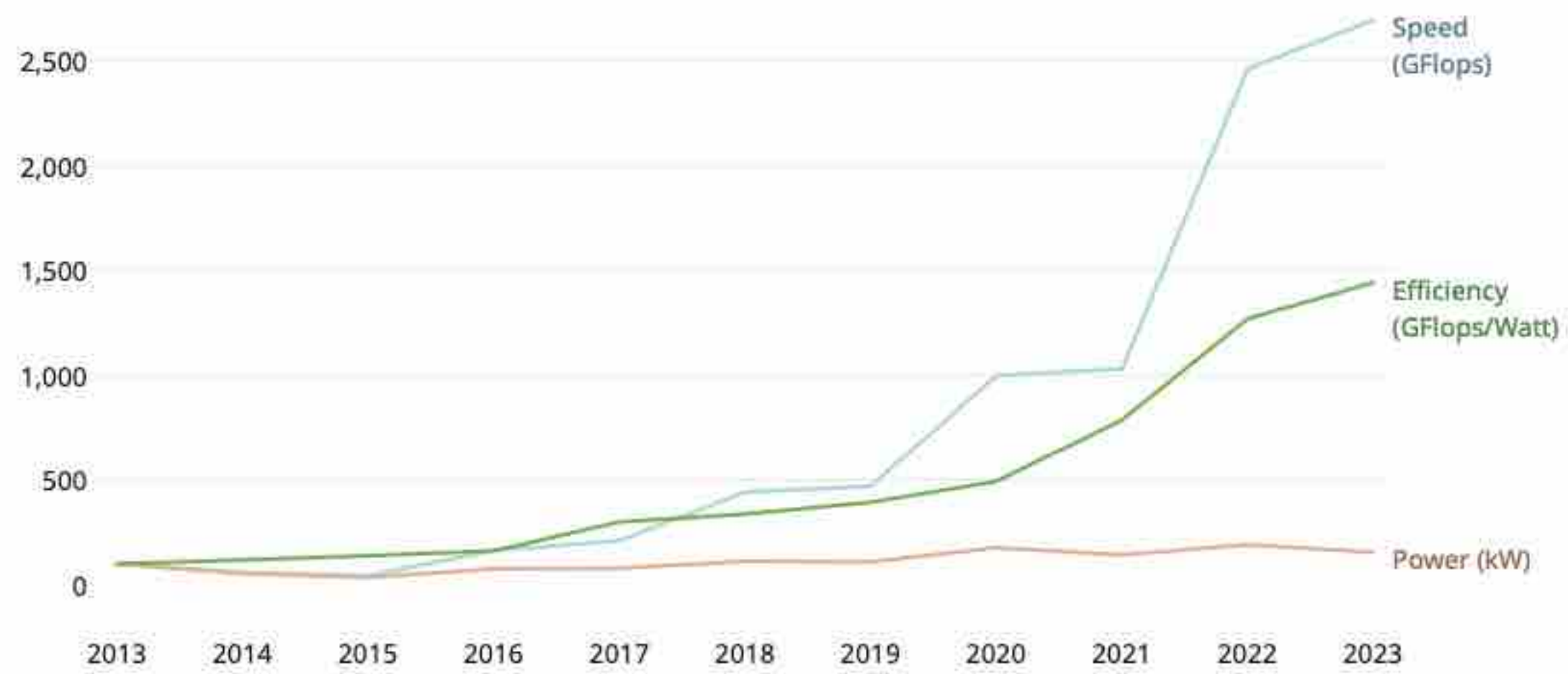
Firstpost Home Video Shows World Explainers

Apple working on building a humanoid robot, to take on Tesla's Optimus

Mehul Reuben Das • February 17, 2025, 15:16:27 IST

WhatsApp Facebook X

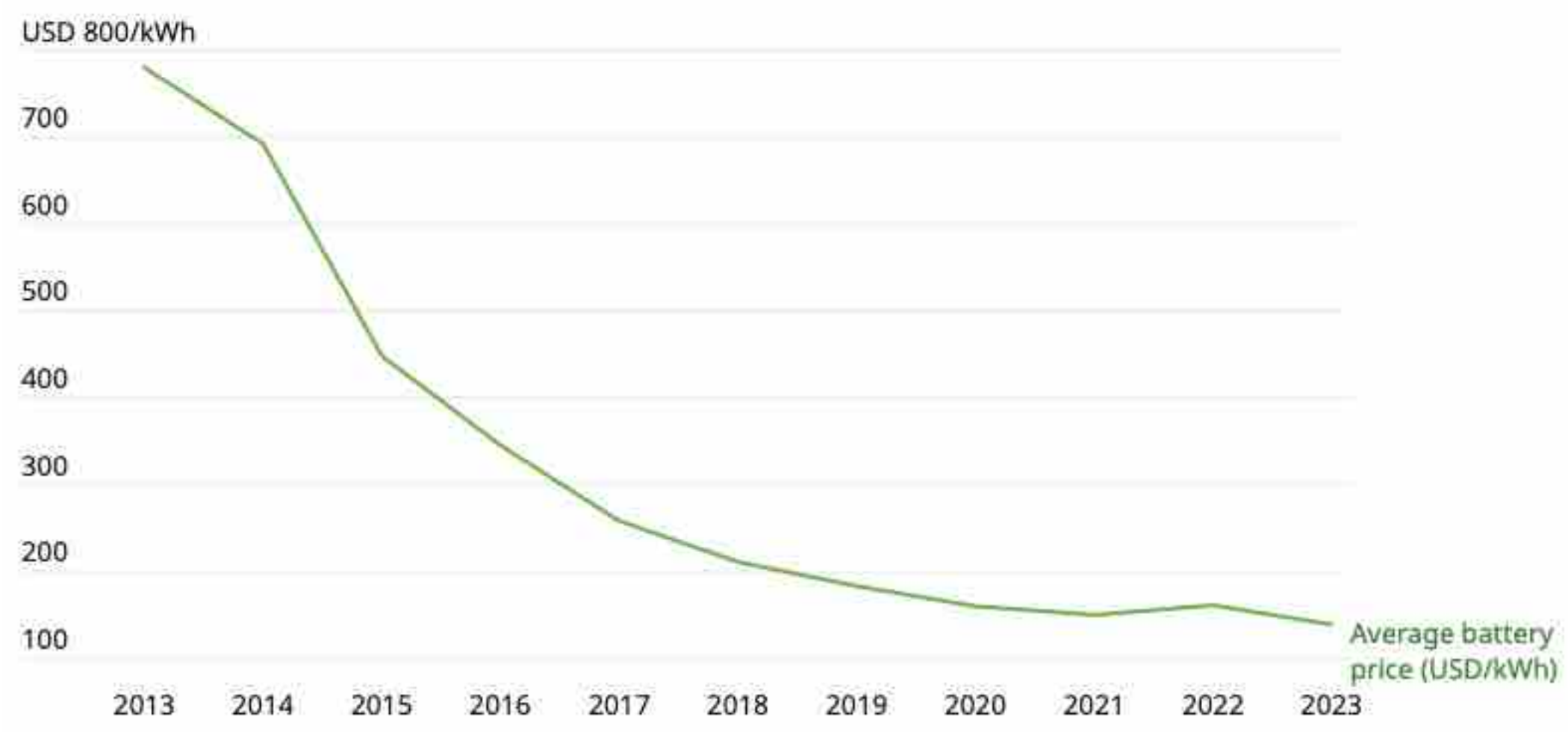
Figure 8 Average speed, power and efficiency of top 50 green supercomputers, 2013–2023



Notes: Average efficiency is calculated as the ratio of average speed to average power for the top 50 green supercomputers. An increase in efficiency can occur even when both speed and power are decreasing. 2013 is the base year and set to 100.

Source: WIPO based on data published by TOP500.

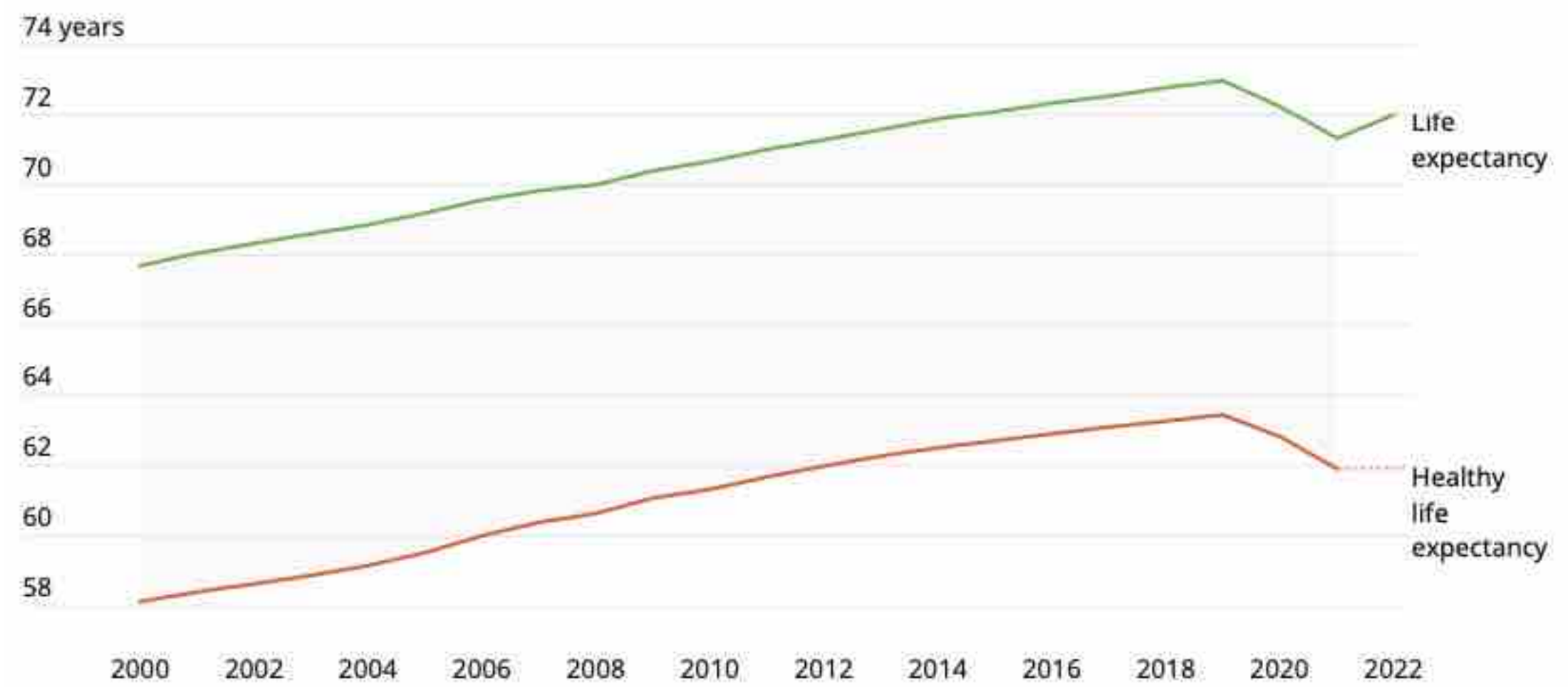
Figure 9 Average lithium-ion battery price, 2013–2023



Note: Prices are shown in real 2023 USD.

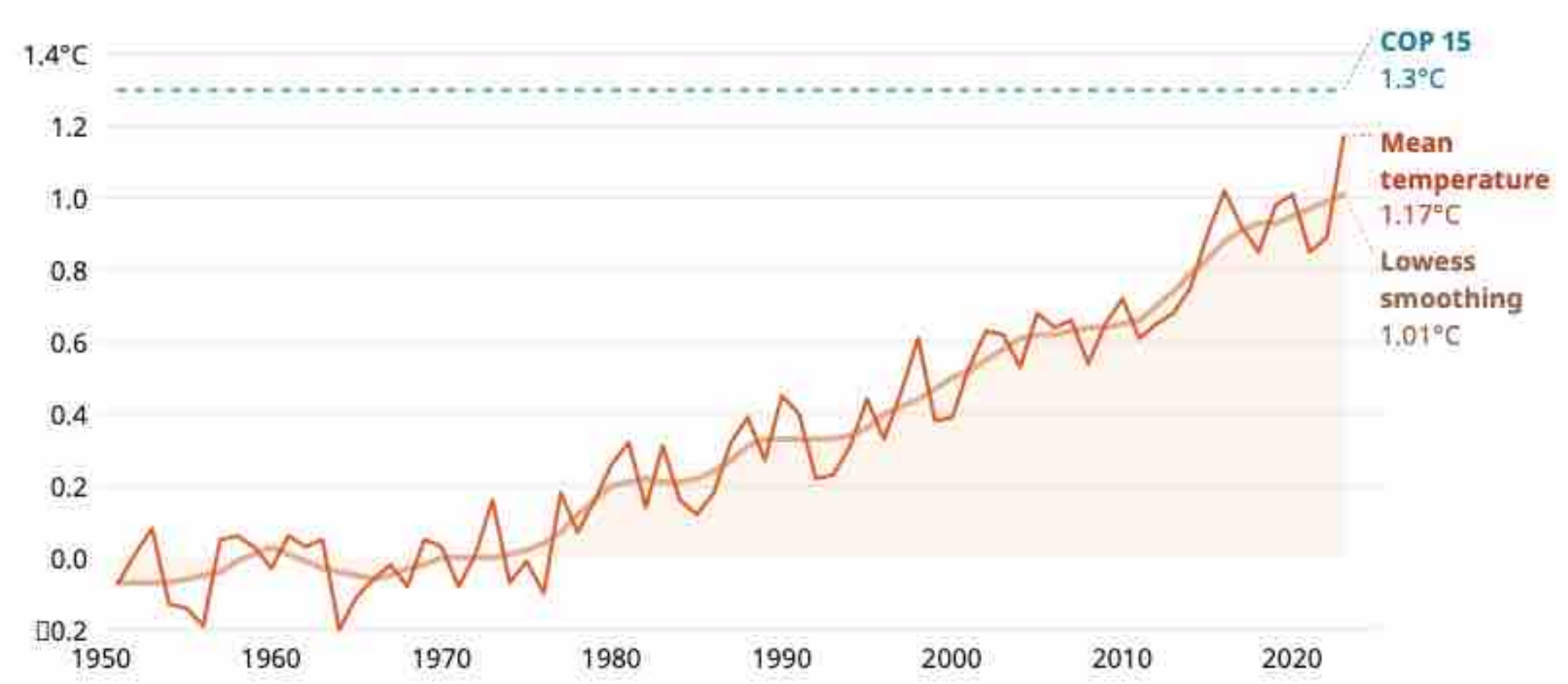
Source: WIPO, based on data published by BloombergNEF.

Figure 13 Life expectancy and healthy life expectancy at birth (years), 2000–2022



Source: WIPO, based on data published by World Bank (LE) and World Health Organization (HALE).

Figure 14 Global temperature anomaly, 1951–2023 land-ocean global mean temperature



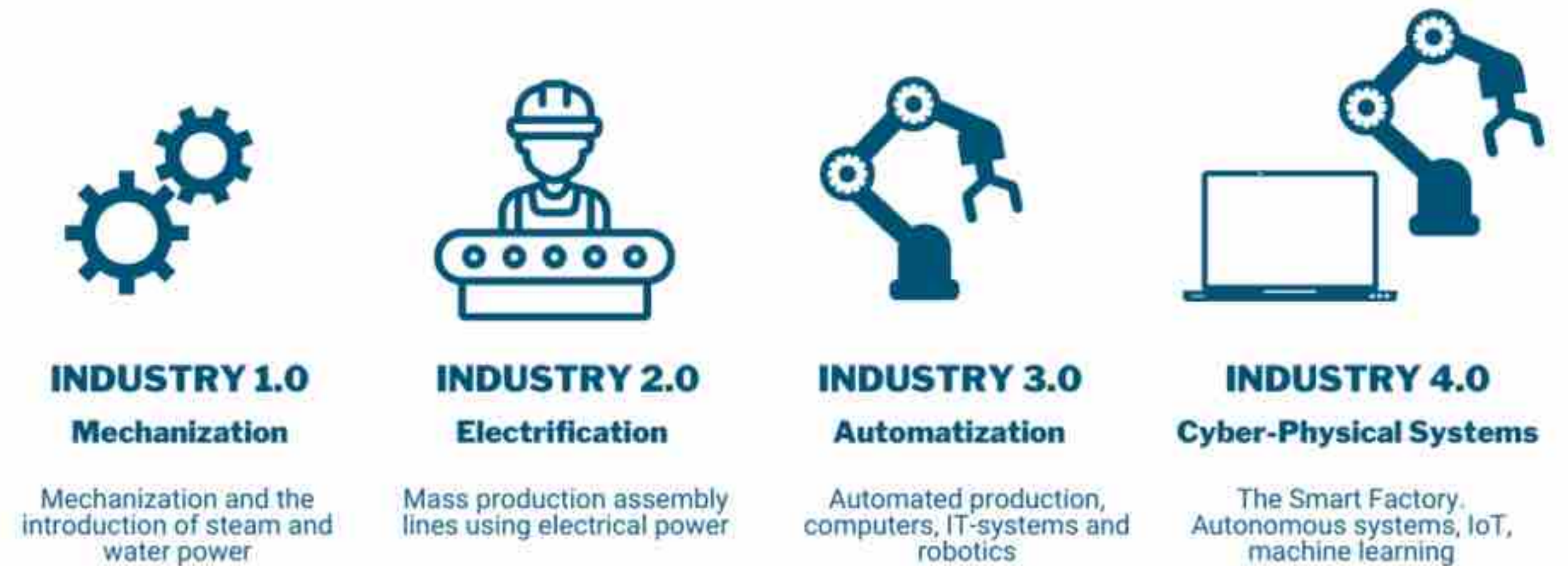
Notes: COP 15 (lower threshold) indicates the lower limit of 1.5°C global warming relative to the pre-industrial temperature. This corresponds to a temperature increase of 1.3°C with respect to the average temperature from 1951 to 1980. Lowess smoothing denotes Locally Weighted Scatterplot Smoothing with a fifth-degree polynomial.

Source: WIPO, based on data published by NASA GISS GISTEM.

What does this mean for you?

- Robotics skills are a must have
 - *All industries becoming more automated / robotic*
 - *“Robotics education [should be] as a mandatory component of other skills training.” (WEF)*
 - *“Industry 4.0 will disrupt nearly every industry in every country, creating new opportunities and challenges for people, places and businesses” (GOV.uk)*
- **Next generation needs knowledge, language, network and track record**

THE FOUR INDUSTRIAL REVOLUTIONS



1. <https://www.weforum.org/stories/2020/10/changes-needed-upskill-workers-robotics-education/>
2. <https://www.gov.uk/government/publications/regulation-for-the-fourth-industrial-revolution/regulation-for-the-fourth-industrial-revolution>
3. <https://www.calsoft.com/what-is-industry-4-0/>



What can drones be used for?

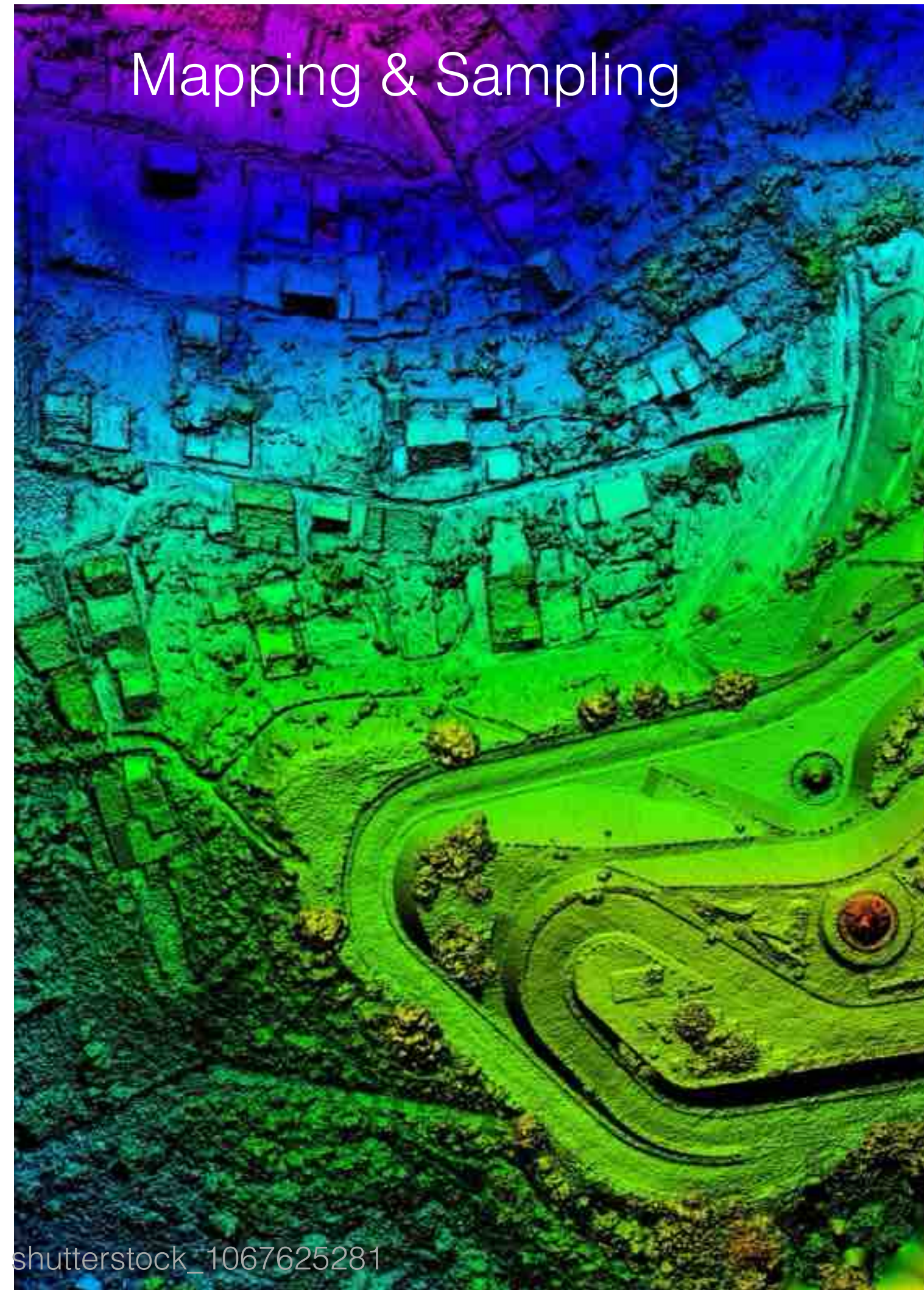
Drone based value chain - today

Imaging & Photography



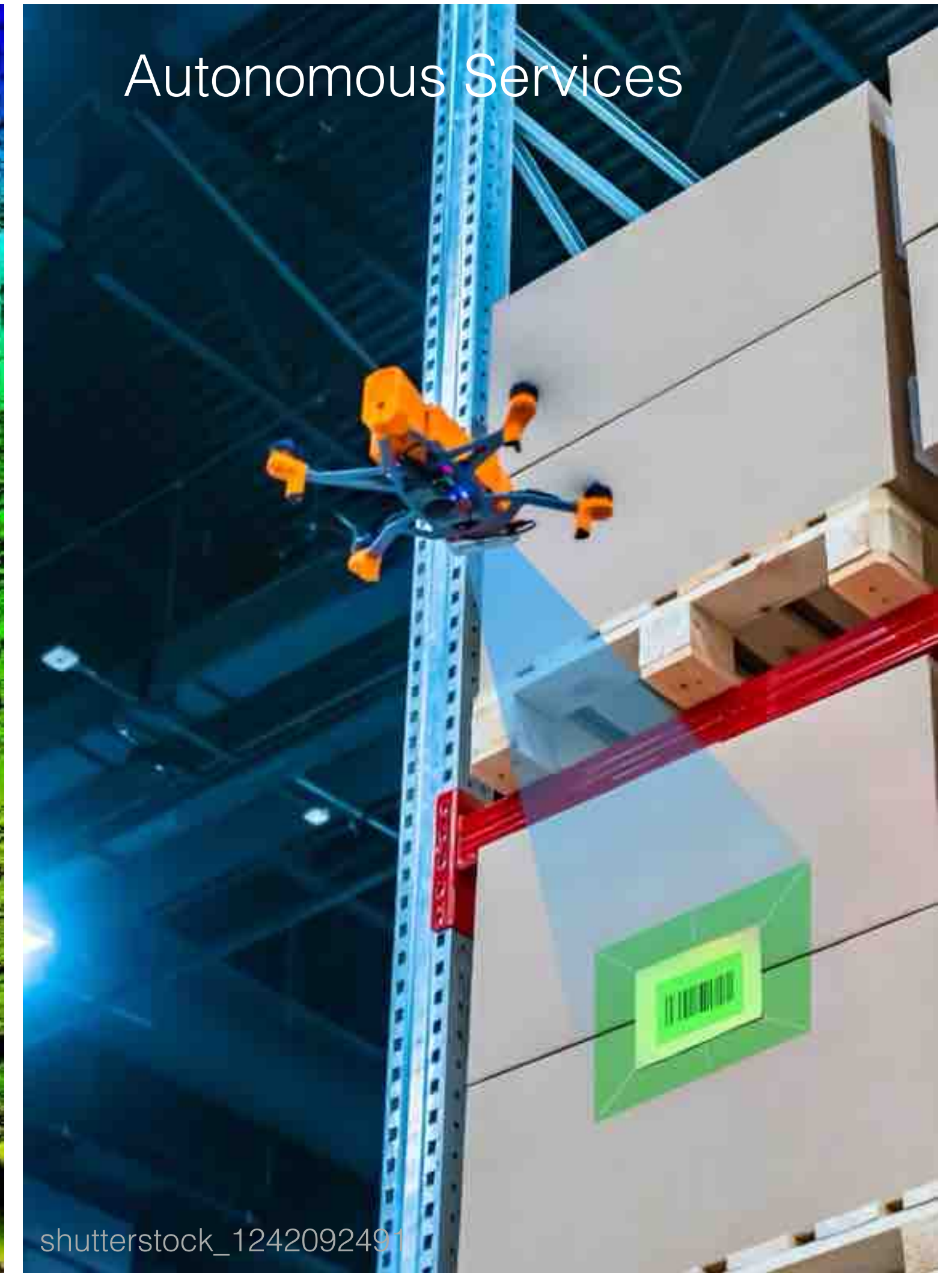
shutterstock_1038791134

Mapping & Sampling



shutterstock_1067625281

Autonomous Services



shutterstock_1242092491

Drones for physical interaction & manipulation



Built environment



Off-shore infrastructure



Environmental health



Construction



Mining/tunnel infrastructure

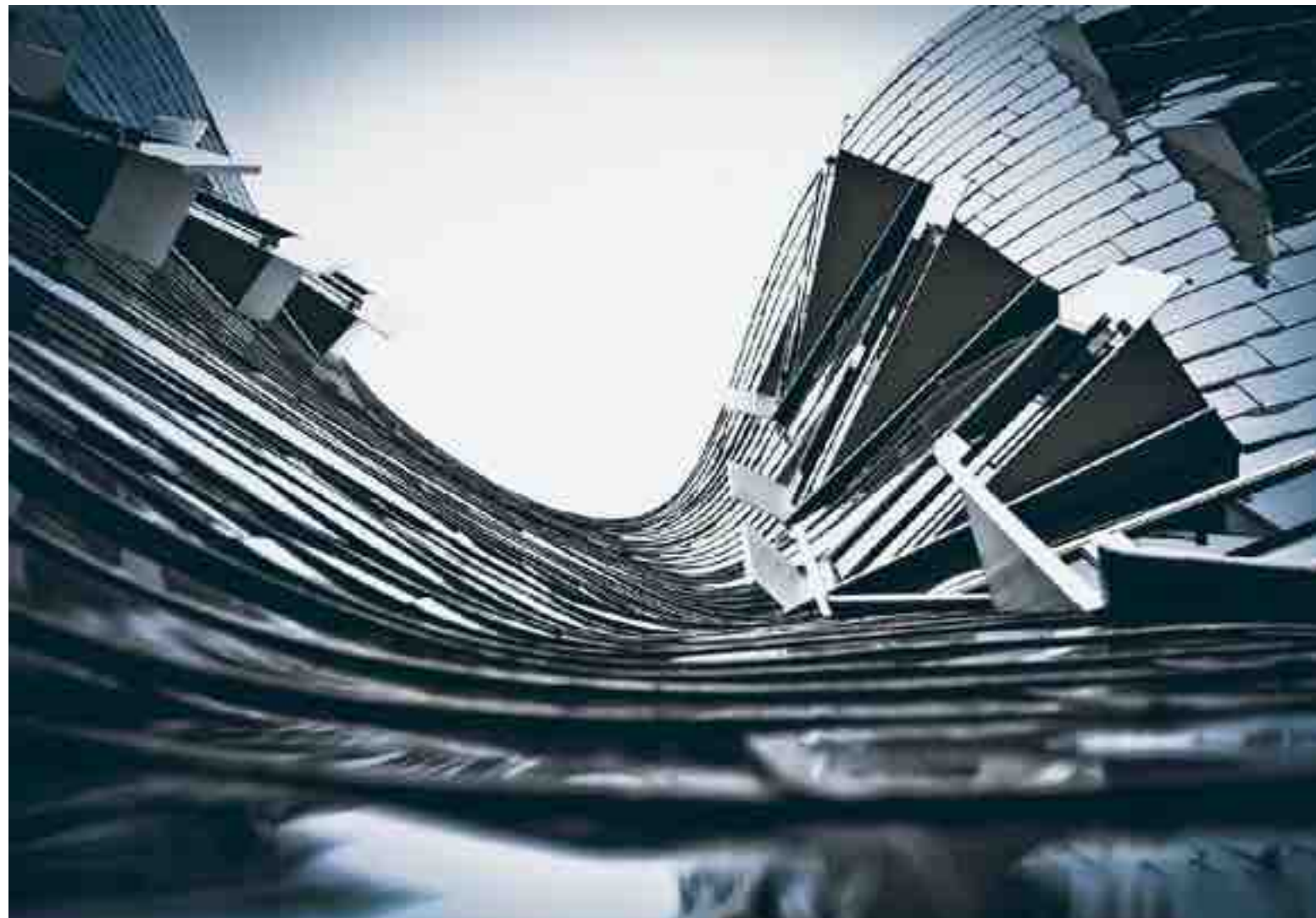


Extreme temperature regions

Drones for physical interaction & manipulation

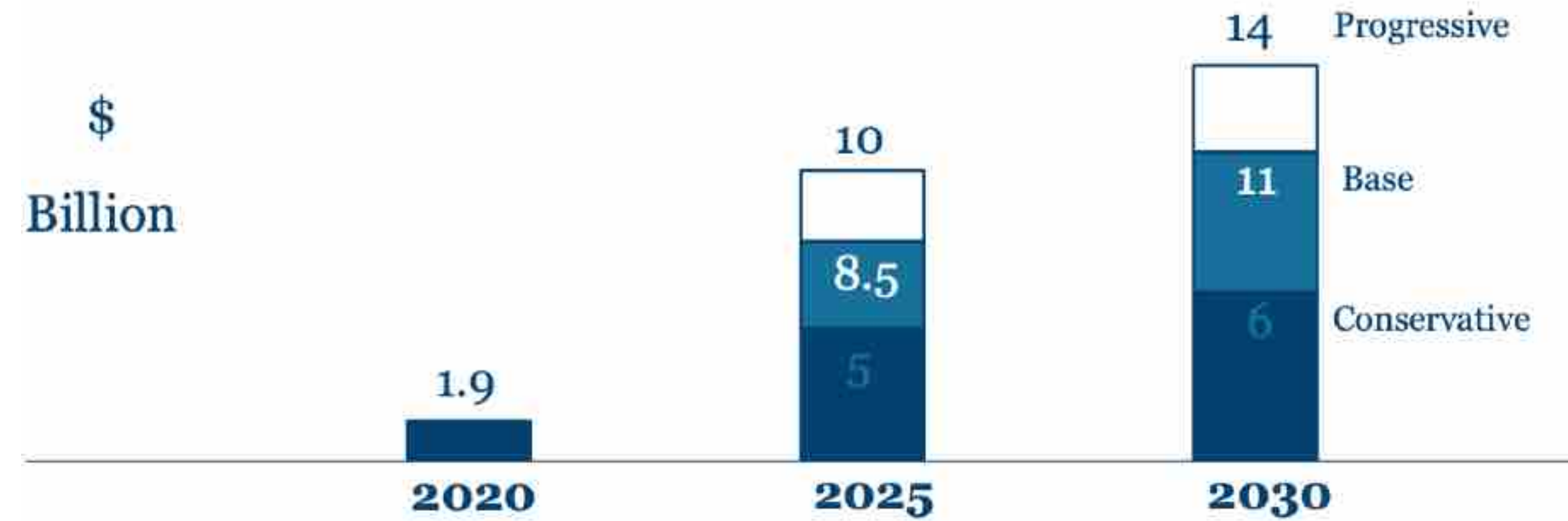


Built environment

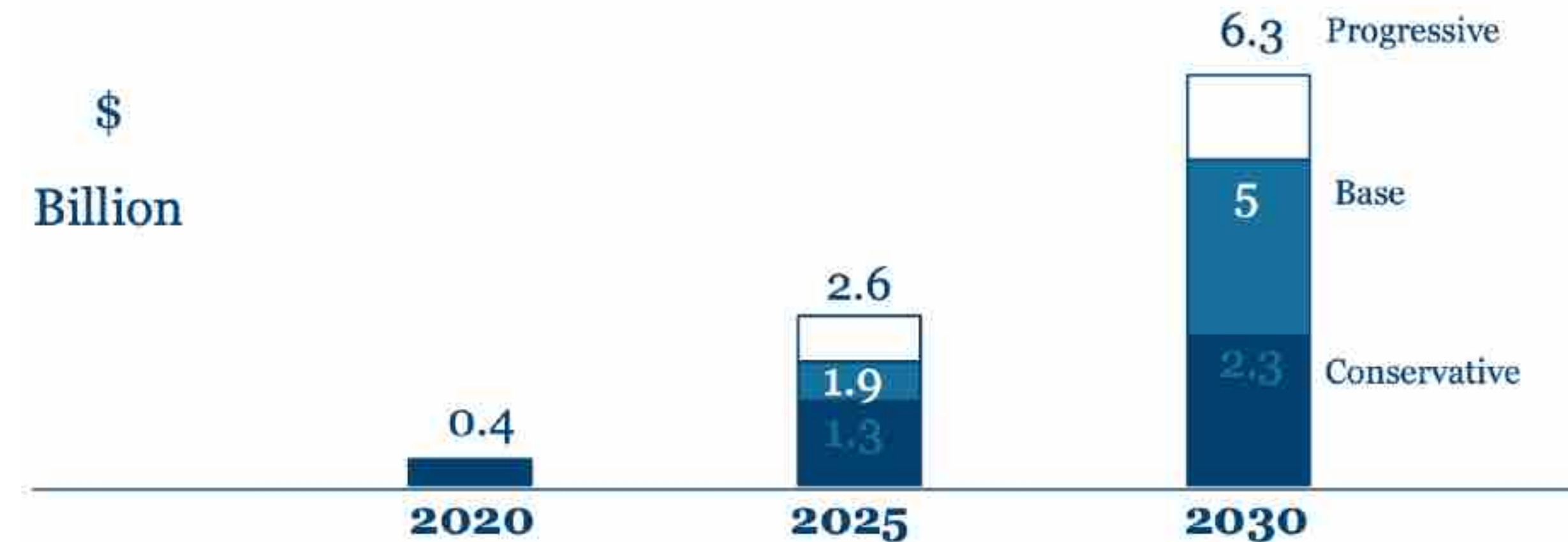


Construction

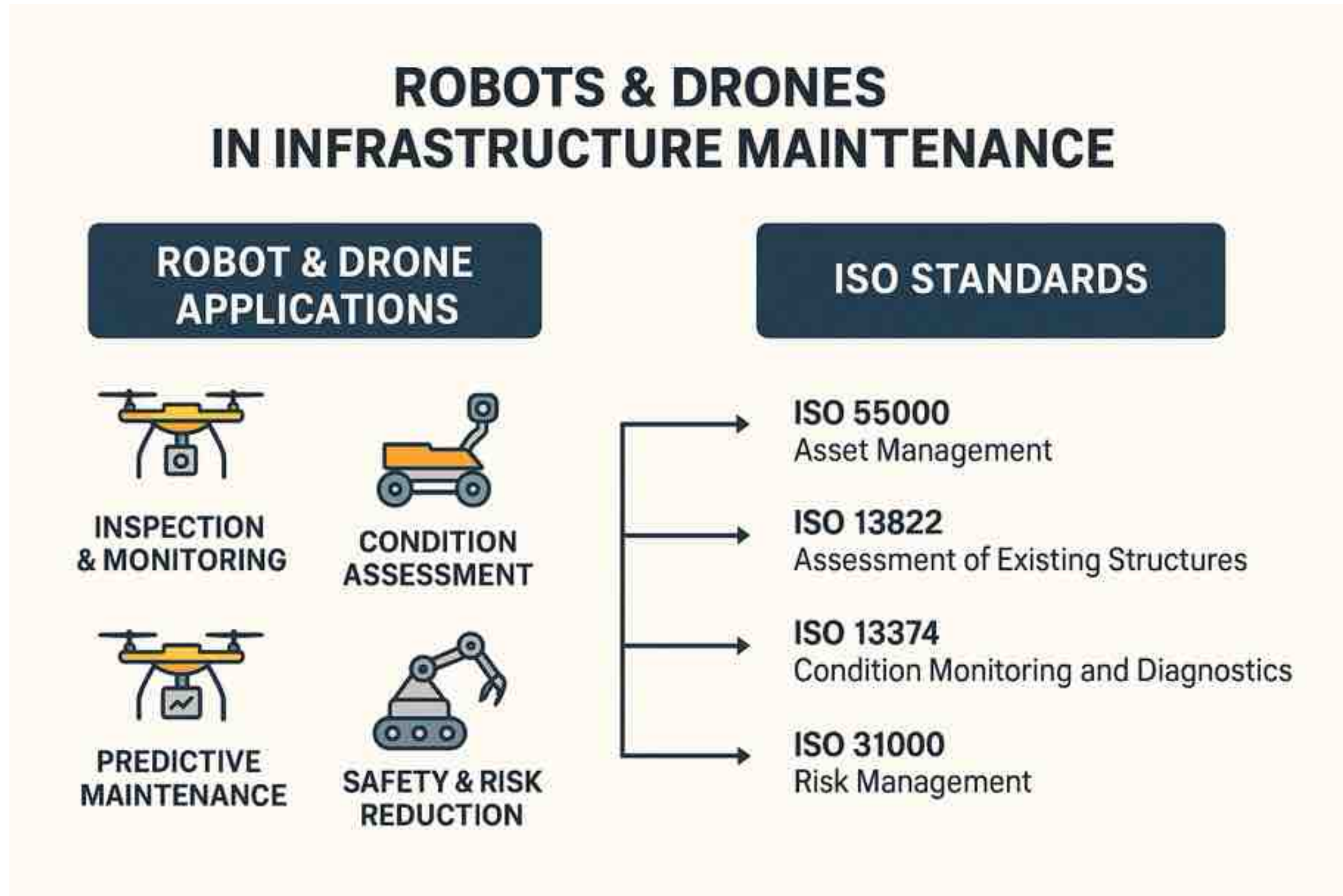
Market Size



Market Size



Robots & Drones in Infrastructure Maintenance



1. Inspection & Monitoring (ISO 55000)
2. Condition Assessment (ISO 13822)
3. Predictive Maintenance & Data Management (ISO 13374)
4. Safety & Risk Reduction (ISO 31000)
5. Sustainability & Lifecycle Optimization (ISO 37101)
6. Digital Twin Integration (ISO 23247)

Cost savings:

Lower labor & safety costs: fewer humans in risky inspections.

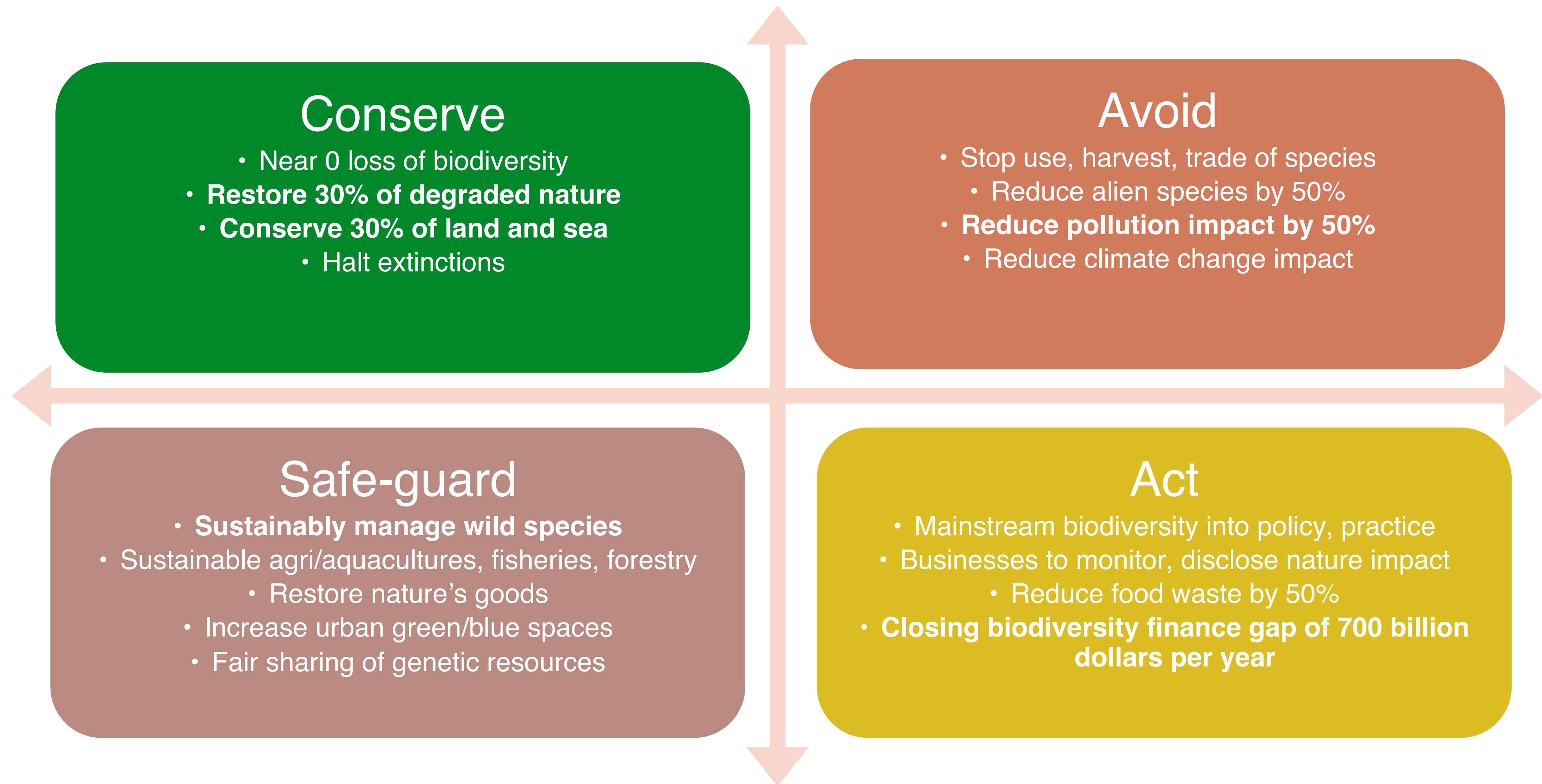
Preventive maintenance: early detection reduces repairs and downtime.

Efficient compliance: automated ISO documentation saves time.



The Paris moment for biodiversity

Kunming Montreal Agreement Framework (COP 2022)



Sustainability Robotics

Est. annual growth rate
11-28%

National & International Framework



Ordinance on
Climate
Disclosures
(since 2024)

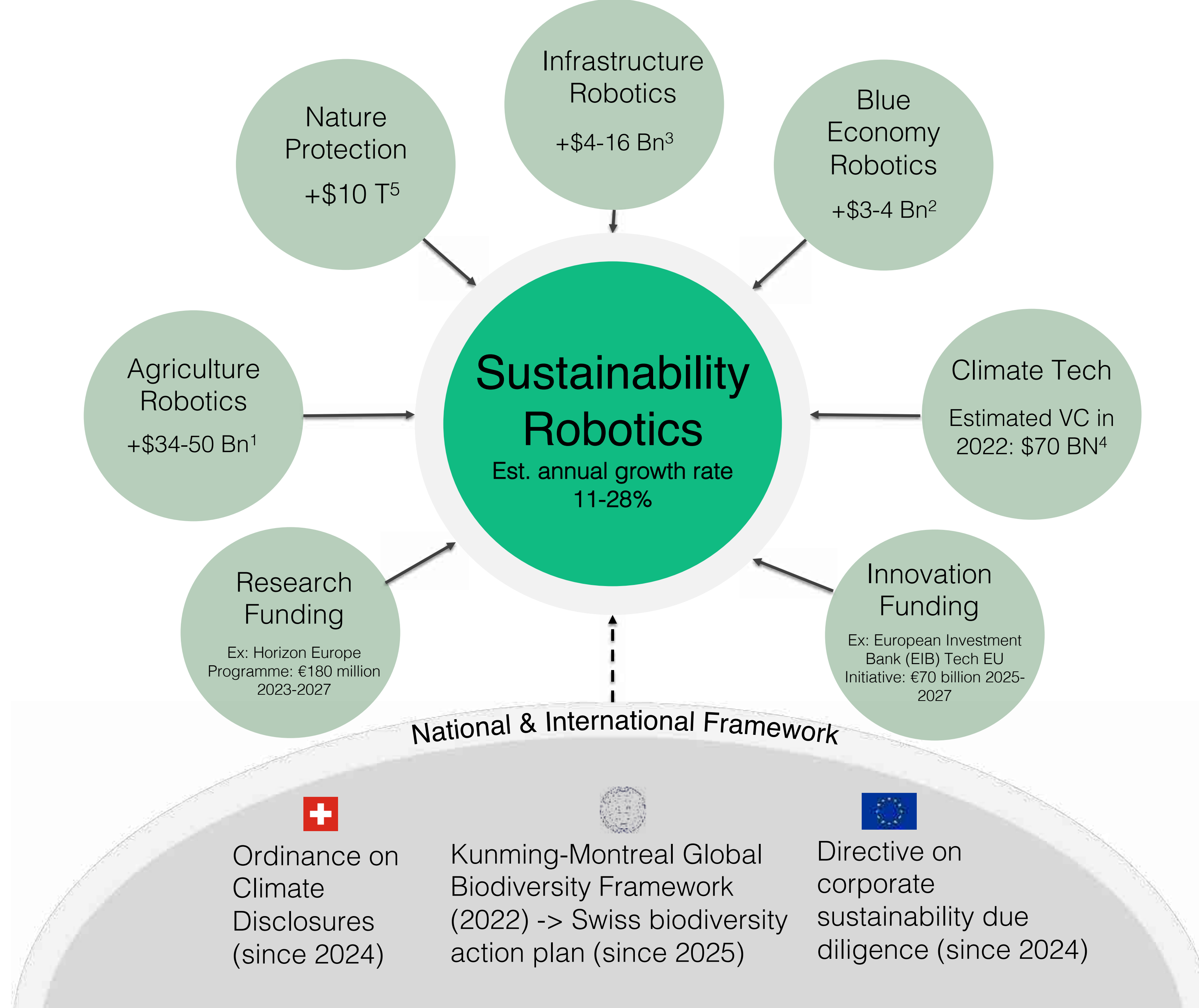


Kunming-Montreal Global
Biodiversity Framework
(2022) -> Swiss biodiversity
action plan (since 2025)



Directive on
corporate
sustainability due
diligence (since 2024)

Source: 1: Agricultural robots market size from Markets and Markets (lower) & Mondor Intelligence (higher) 2: Ocean robots market size from Market.us (lower) & Under water robots market size from Mondor Intelligence (higher) 3: Inspection robots market size from Meticulous research (lower) & Market Research (higher) 4: Climate-tech opportunity, report from Oxford Climate Tech Initiative, 2023 5: The Future Of Nature And Business, New Nature Economy Report II, World Economic Forum, 2020

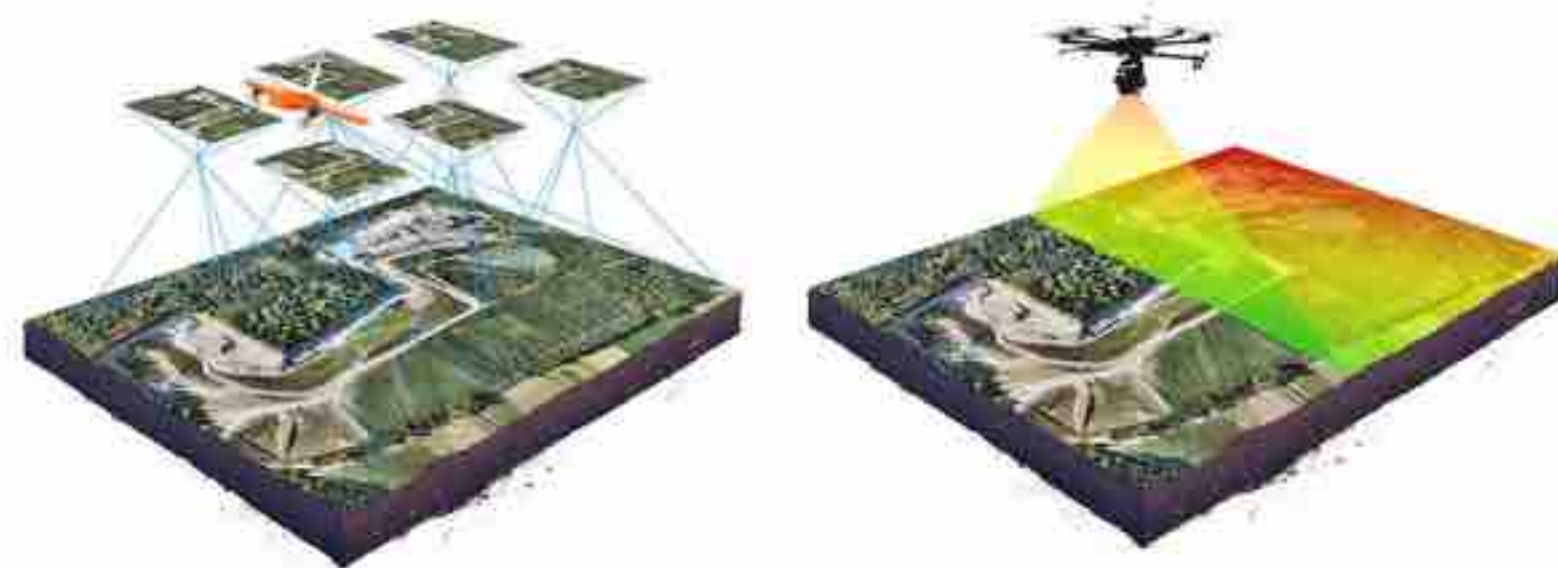


Observation pyramid - technologies today

Air



EPFL Helikite, Tethered Balloon, 2021



Wingtra, Drone Photogrammetry, 2021

Land & Arboreal

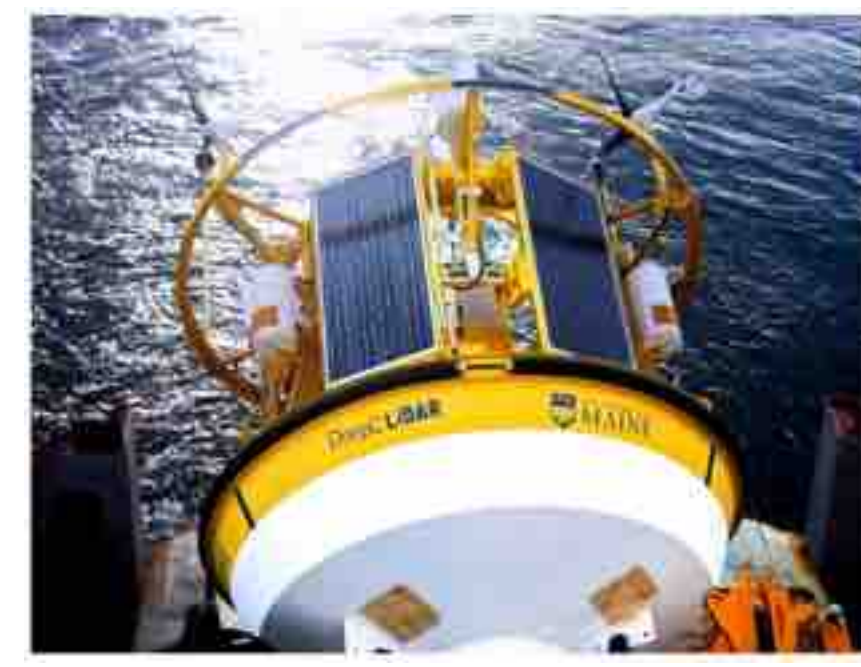


Treetec, Sensor Installation



Hylio, Crop Spraying Drone, 2018

Water



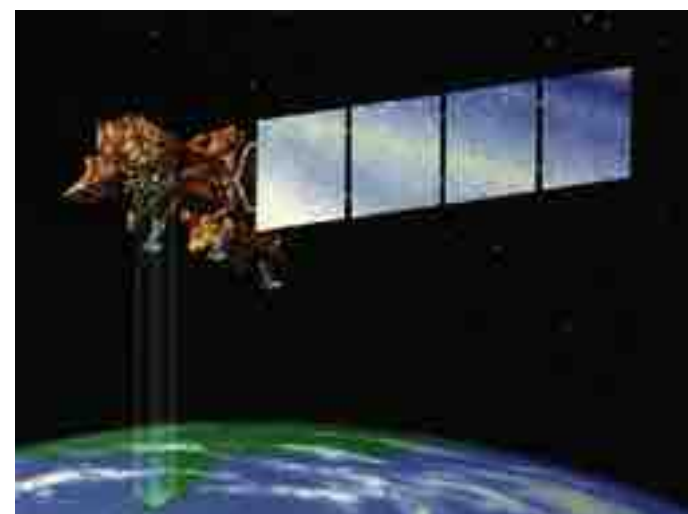
DeepCLiDAR, Floating Buoy, 2016



ASpire, Sailing Platform, 2017



Autonomous surface vehicle: Buscamos-Vigia, 2021

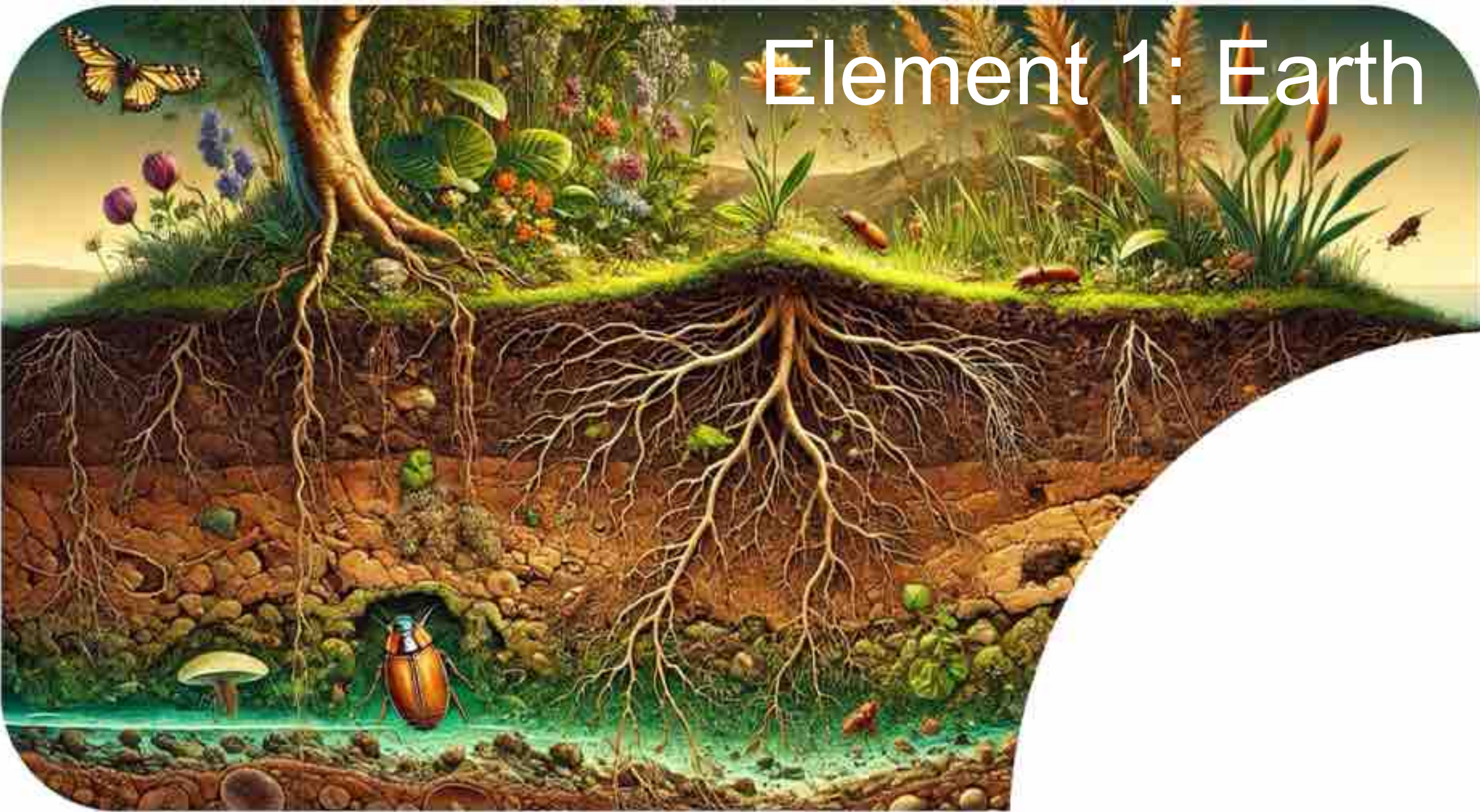


NASA, Land Remote Sensing, 2017



Soil Sampling Robots, Amrita - 2019; Momaro 2017

Element 1: Earth



Element 2: Water



Element 3: Air



Element 4: Fire



Imperial College
London

Aerial Robotics Laboratory (est. 2012)

 **Empa**
Materials Science and Technology

Laboratory of Sustainability Robotics

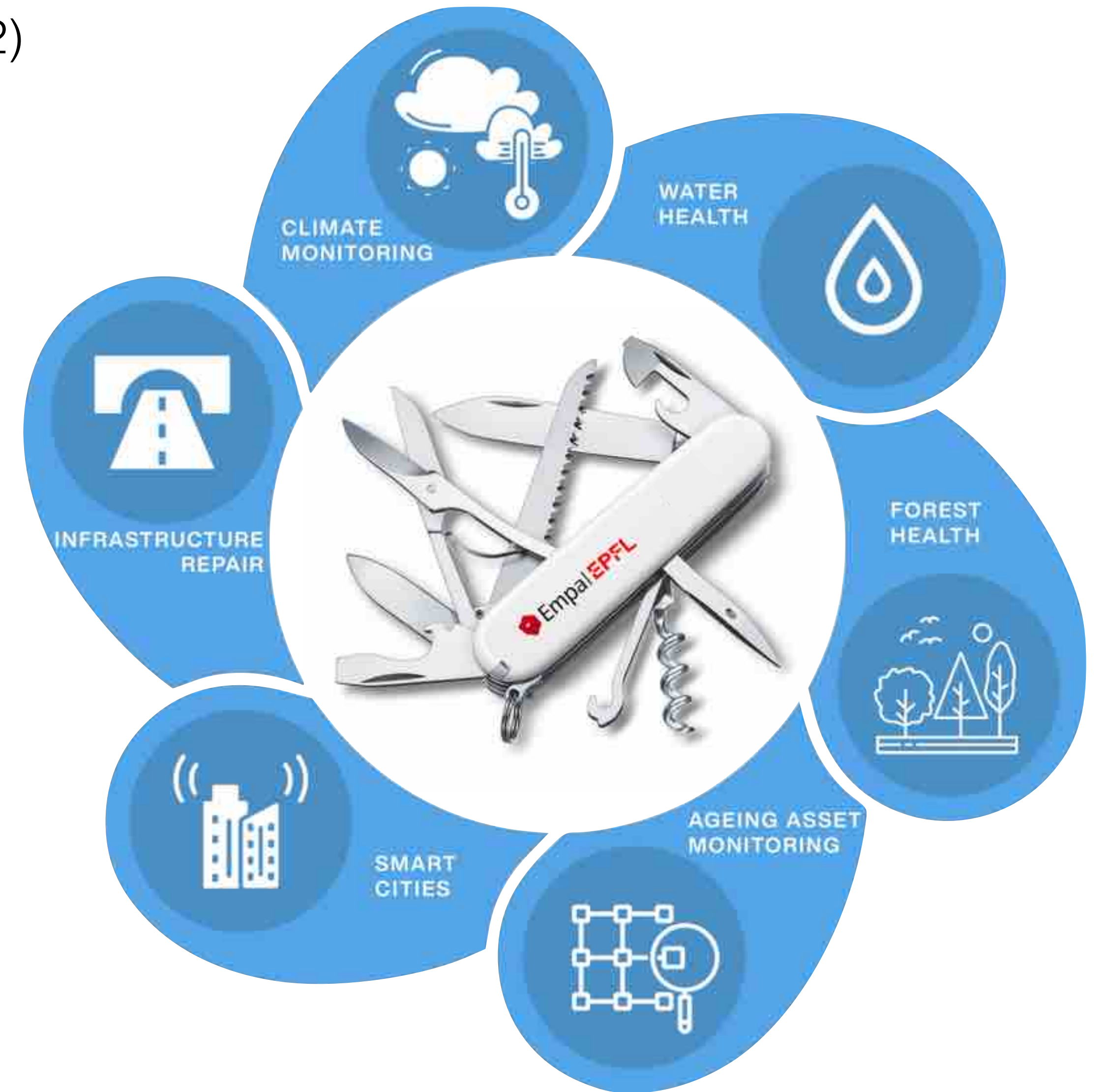
 **ETH DOMAIN**

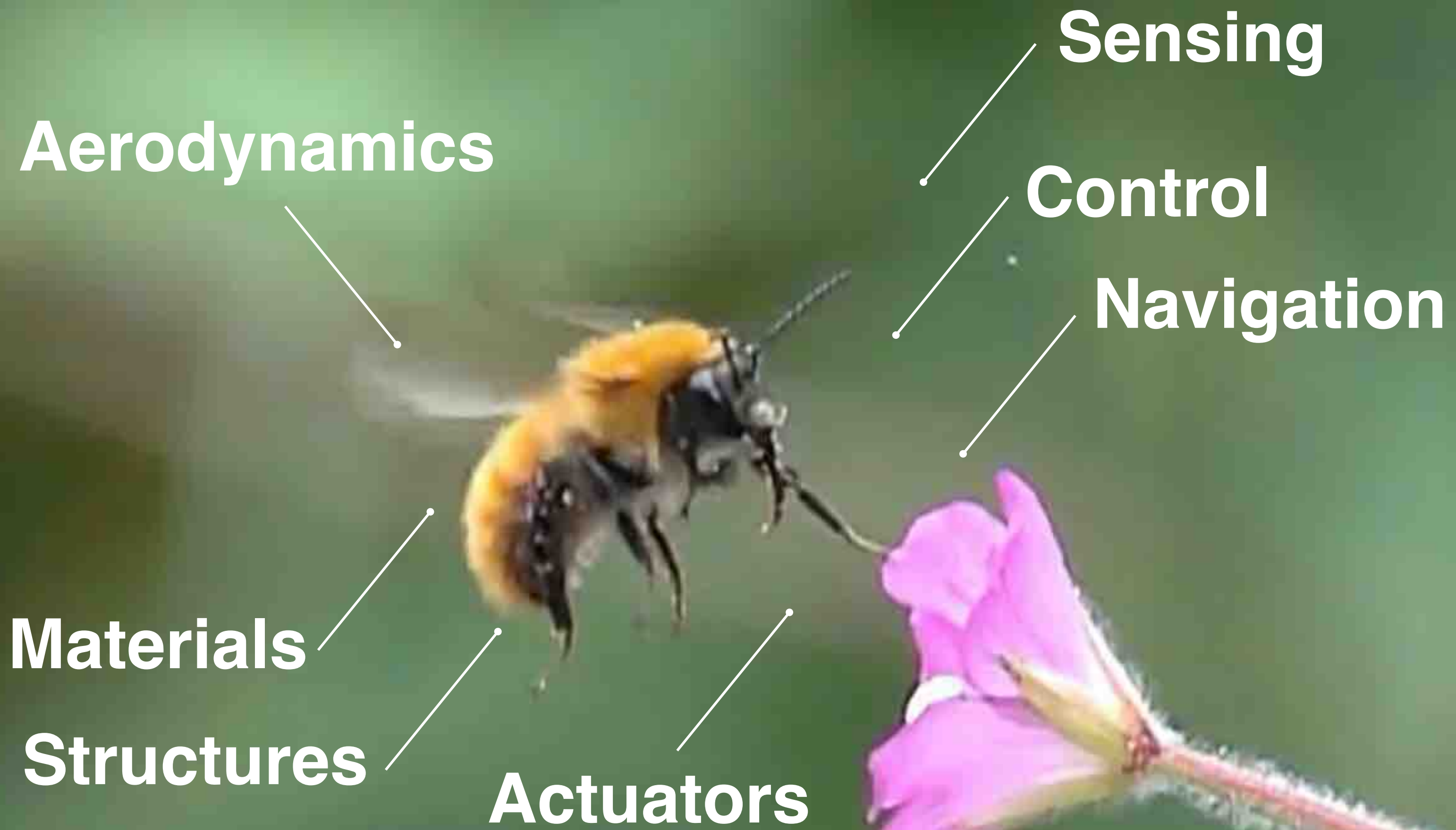
1 Prof. Mirko Kovac
13 Postdocs, Engineers & Scientists
8 PhDs
2 Management
3 Admin and communication

EPFL

Mission statement

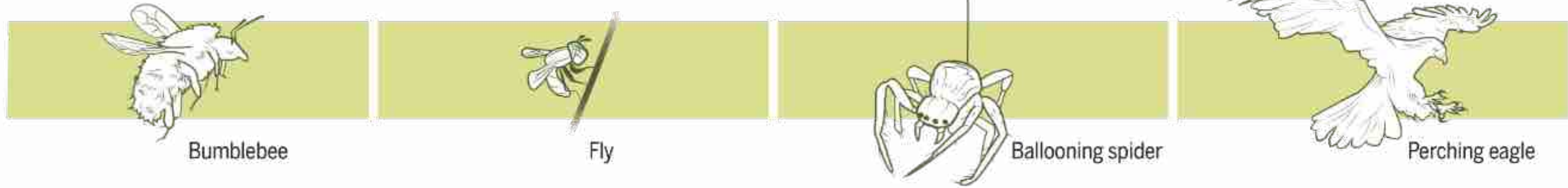
Develop novel Robotics and AI technologies
to measure and modify environments to
deliver sustainable outcomes



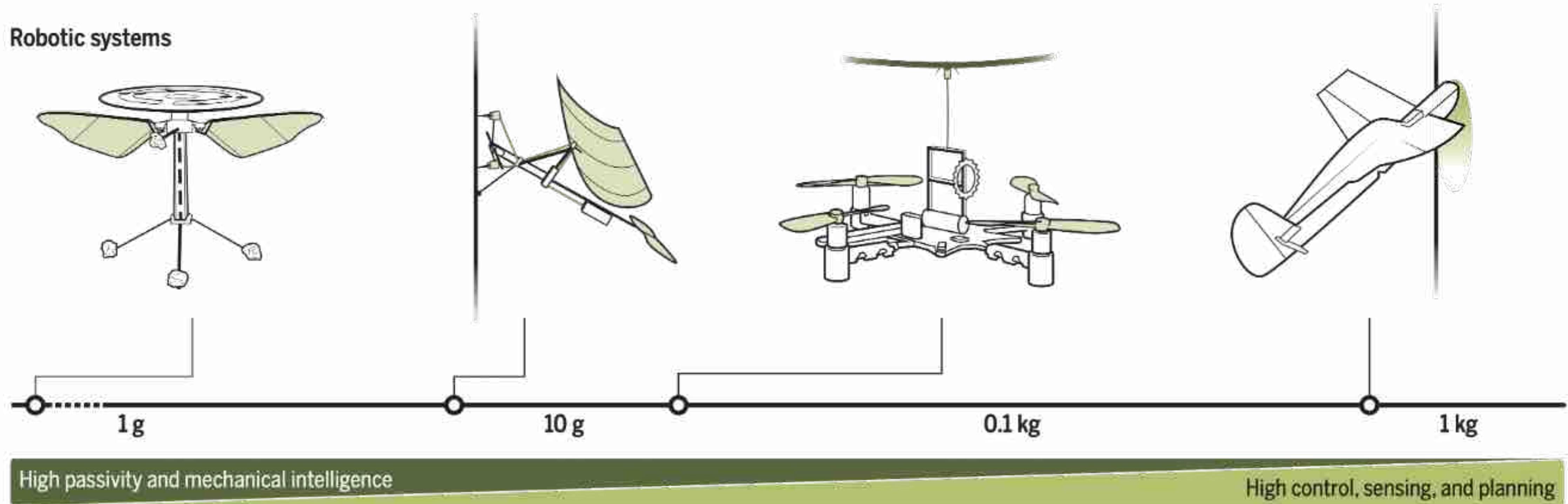


Co-evolve physical and digital intelligence

Comparable biological systems



Robotic systems



Kovac, Learning from nature how to land aerial robots, *Science* (2016)



WATER

Biosystems & Biorobotics

Raphael Zufferey
Robert Siddall
Sophie F. Armanini
Mirko Kovac

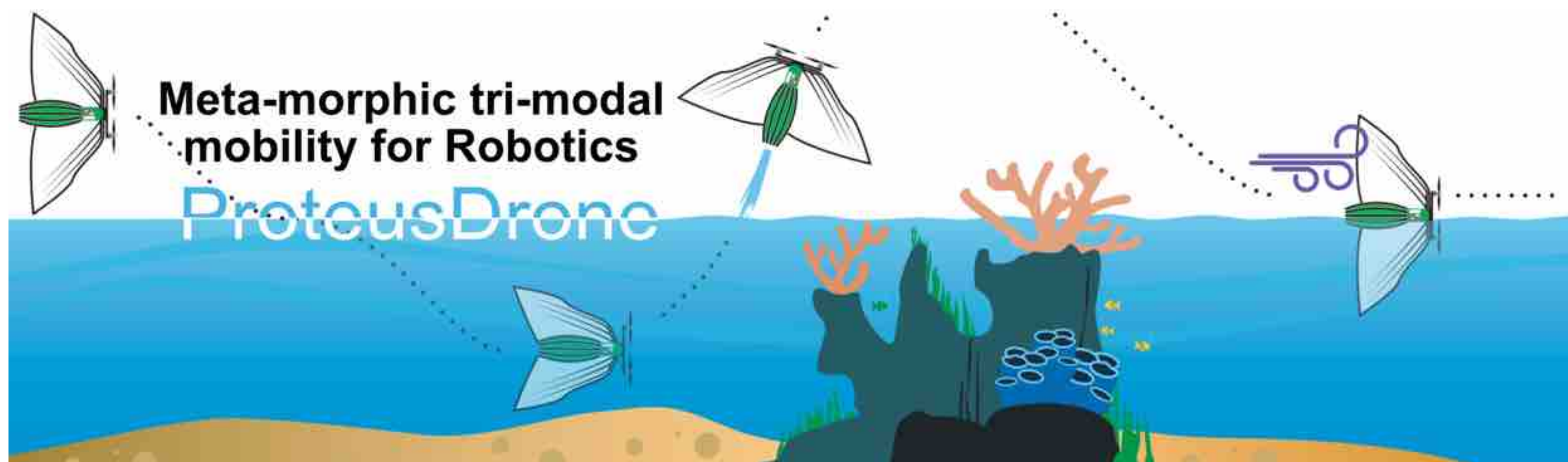
Between Sea and Sky: Aerial Aquatic Locomotion in Miniature Robots

 Springer



European
Research
Council

ProteusDrone
Consolidator grant
(SERI funded) 2023-2027



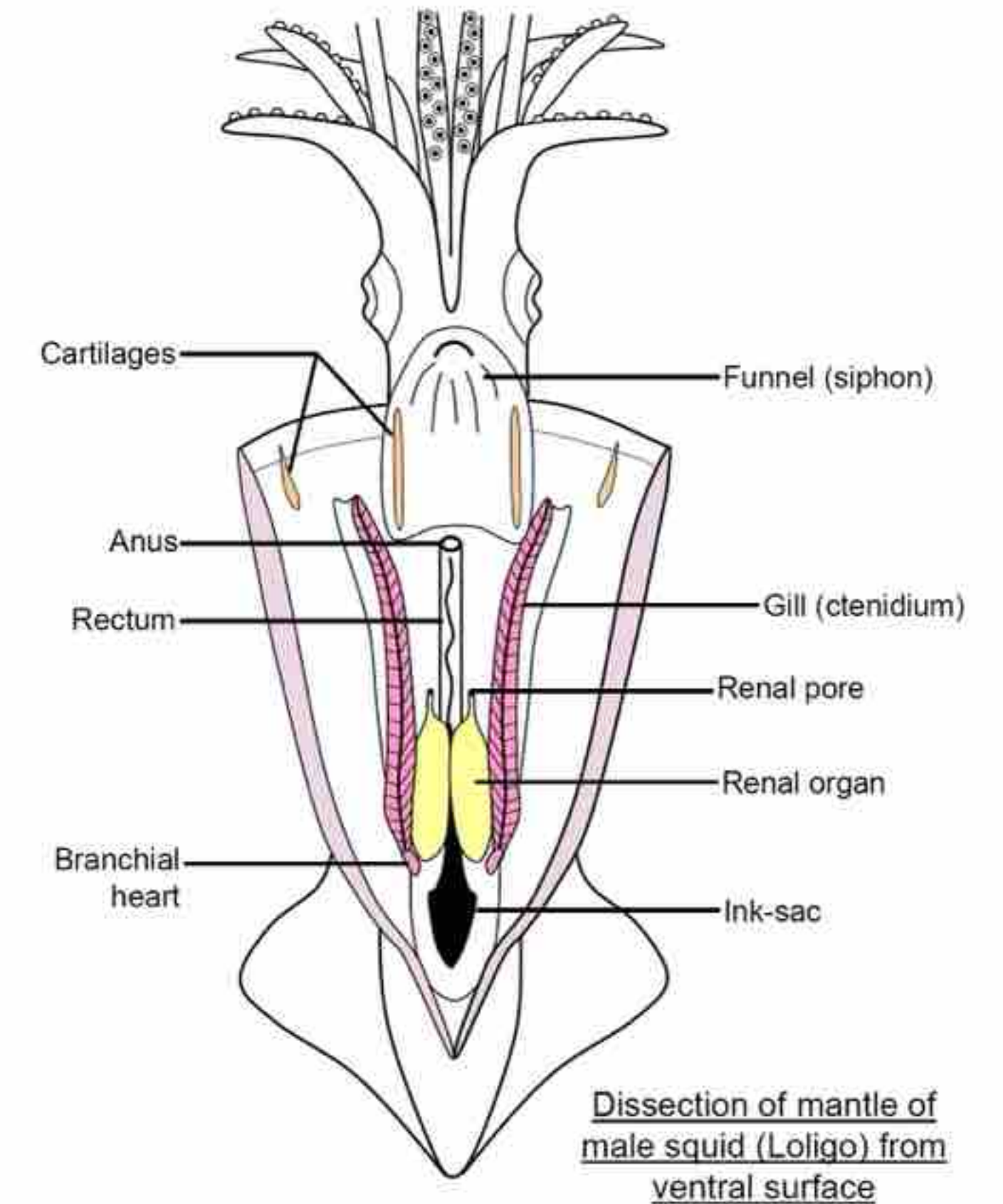
Zufferey, Kovac et al. *Science Robotics*, 2019

Li, Nguyen, Kovac, Wen et al. *Science Robotics*, 2022

Chen, Zufferey, Kovac, Wood, et al. *Science Robotics*, 2017

Flying Squid

HOW IT FLIES JET-POWERED SQUID



Squid classification

Eukaryota
Domain

Animalia
Kingdom

Mollusca
Phylum

Cephalopoda
Class

Myopsida
Oegopsida
Sepiida
Spirulida } Order

Species:



Loligo Pealeii

Source: SEFSC
Pascagoula Laboratory;
Collection of Brandi
Noble,
NOAA/NMFS/SEFSC



**Loligo
Opalescence**

Source: Common market
squid; Monterey Bay
Aquarium, Monterey Bay
Aquarium Foundation



Illex Illecebrosus

Source: Getty images



Architeuthis Dux

Source: Don
Hurlbert/Smithsonian
Institution



**Mesonychoteuthis
Hamiltoni**

Source: Lee Krystek,
unmuseum.org

Squid classification

Species that have been found and photographed / filmed flying

Species:



Loligo Pealeii

Source: SEFSC
Pascagoula Laboratory;
Collection of Brandi
Noble,
NOAA/NMFS/SEFSC



Sthenoteuthis
pteropus

(Orangeback squid)
Source: Common market
squid; Monterey Bay
Aquarium, Monterey Bay
Aquarium Foundation



Dodosicus Gigas
(Humbolt squid)

Source: NOAA/MBARI 2006



Architeuthis Dux

Source: Don
Hurlbert/Smithsonian
Institution



Mesonychoteuthis
Hamiltoni

Source: Lee Krystek,
unmuseum.org

Flight

Lift induced drag
 $0.5 C_{Di} \rho_{air} v^2 A$
Dominant when slow
 $C_{Di} \propto Lift^2$

Profile drag
 $0.5 C_F \rho_{air} v^2 A_{front}$

Lift
 $0.5 C_L \rho_{air} v^2 A$

$Re \approx 10^5$

Propulsion
 F

Weight
 mg

Skin friction drag
 $0.5 C_D \rho_{air} v^2 A_{skin}$
Dominant when fast

Forces are indicated in blue

- C coefficient
- ρ density
- v velocity
- A area
- V volume
- Q torque
- ω angular speed
- k gear ratio
- η efficiency

Flight

Powered propeller case

$$T_a = \frac{\eta_{prop,a}}{v_a} \cdot Q_a \cdot \omega_a$$

Plunge

Surface tension
 $L_{waterline} \cdot \gamma \cdot \cos(\theta)$

typ: $\theta \approx 70^\circ$

$Re \approx 10^0$

Exit

Surface tension
 $L_{waterline} \cdot \gamma \cdot \cos(\theta)$

High power jet
 $\dot{m} v_{jet}$

Buoyancy
 $\rho_{H2O} \cdot g \cdot V$

$Re \approx 10^5$

Gearbox and propeller

$$T_w = \frac{\eta_{prop,w}}{v_w} \cdot Q_w \cdot \omega_w$$

$$Q_w = Q_a \cdot k$$

$$\omega_w = \frac{\omega_a}{k}$$

Profile drag
 $0.5 C_F \rho_{H2O} v^2 A_{front}$

Skin friction drag
 $0.5 C_D \rho_{H2O} v^2 A_{wet}$
Dominant drag

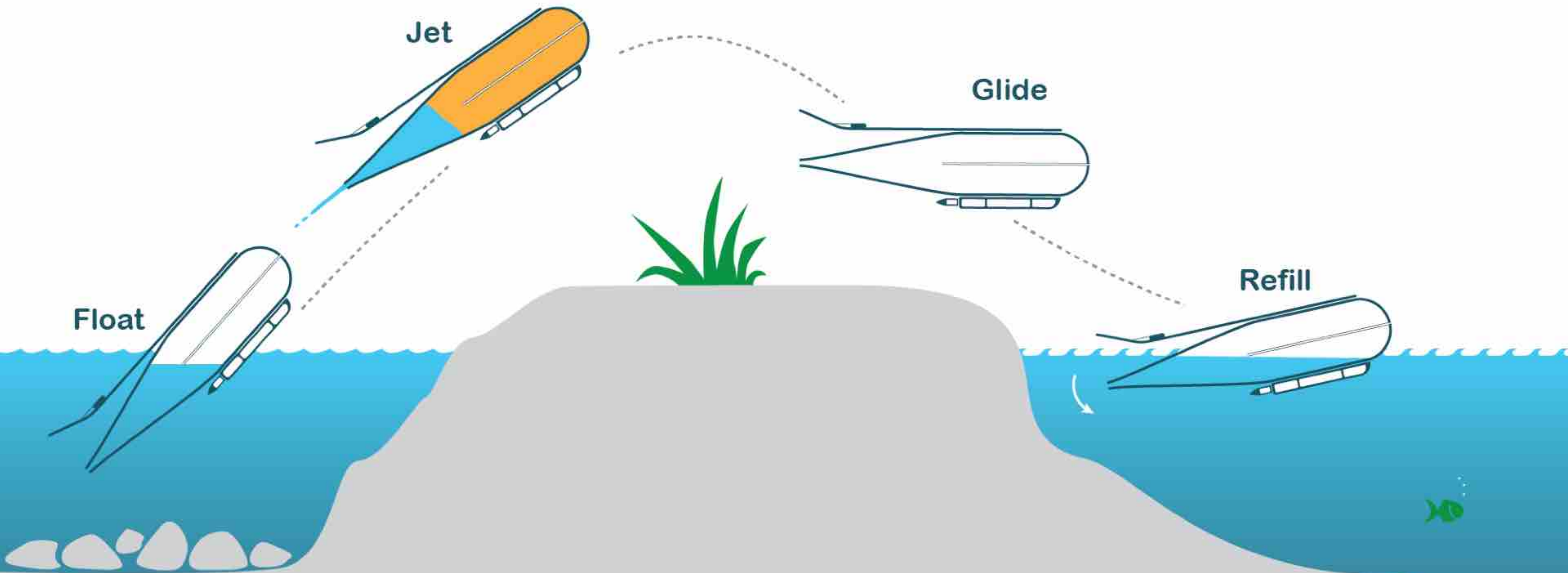
Weight
 mg

Basset force : negligible

Added mass = $\alpha \cdot m_{added}$
 $m_{added} \approx \frac{1}{2} \rho_w V$

Dive

Mission Cycle



Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmam, R. V., Kennedy, G., Kovac, M.,

Science Robotics (2010)

Aquatic Jump gliding with water reactive fuel

32



Flying Squid



Flying Fish

Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmam, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)

Image Credits (from left): 'Oceanic Squid do Fly', Muramatsu et al., Oceans 2013; US NOAA

Propulsion System

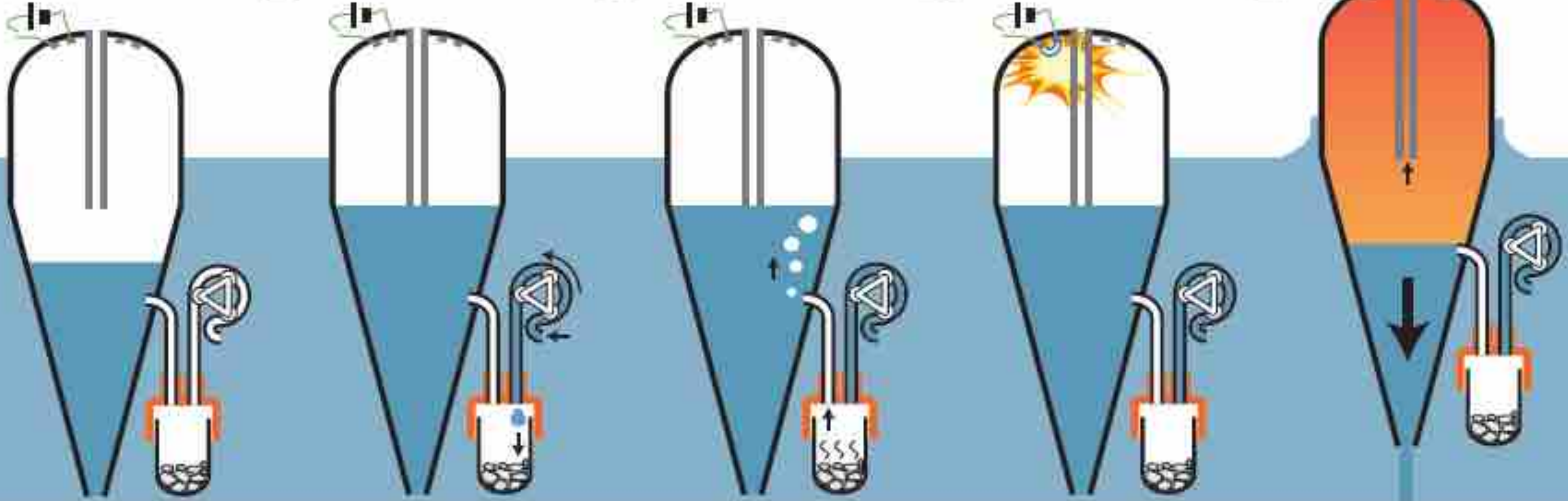
Filling

Water
pumping

Acetylene
production

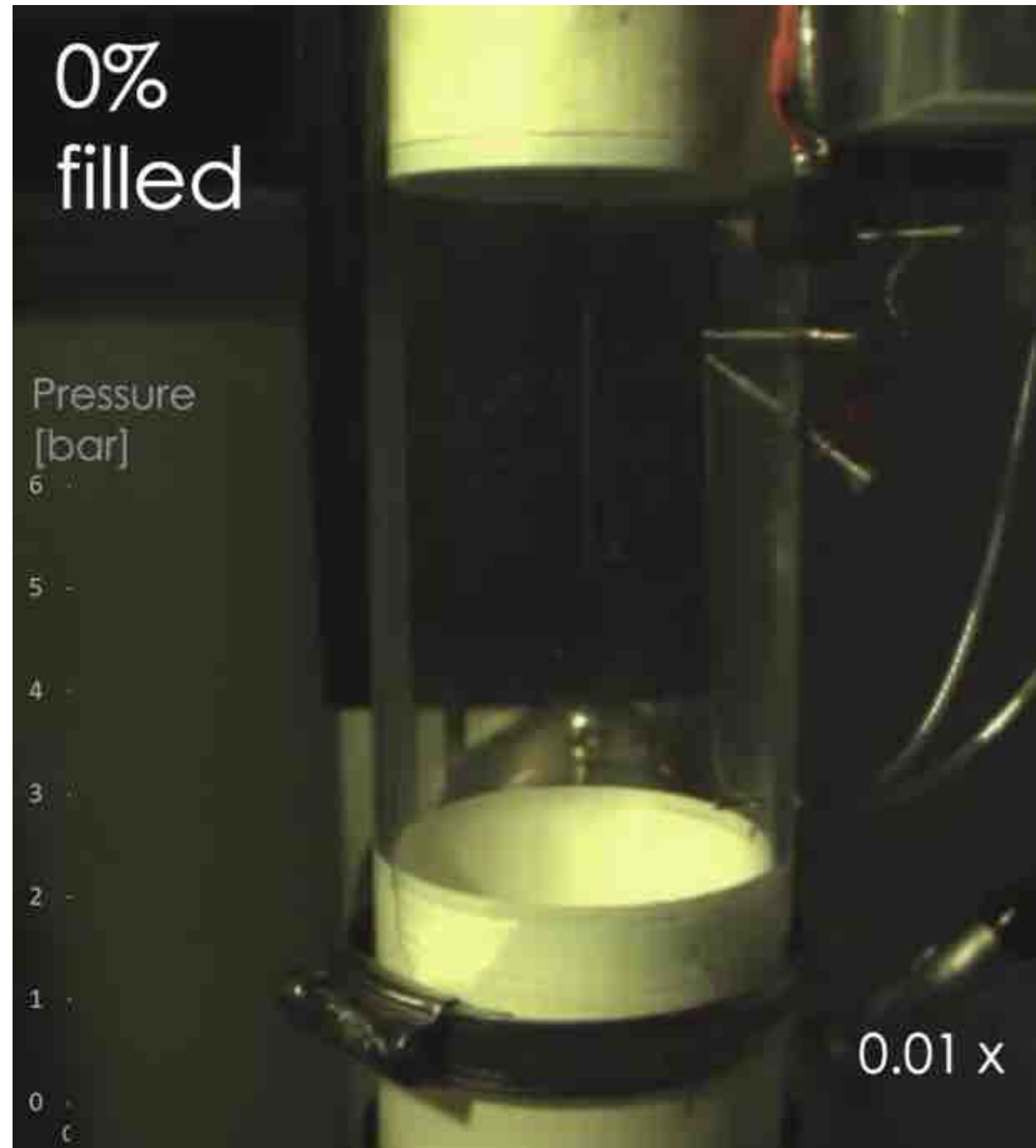
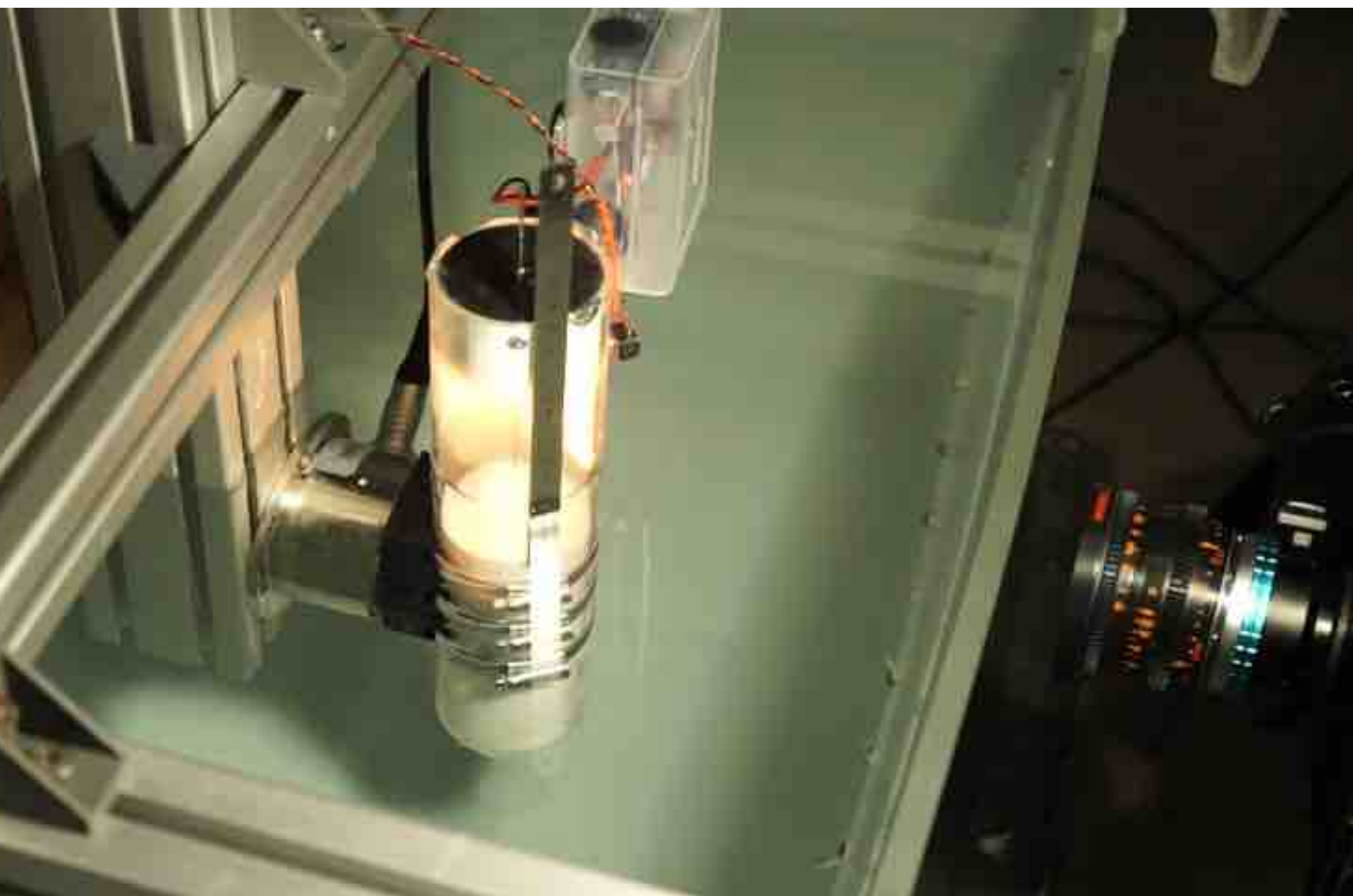
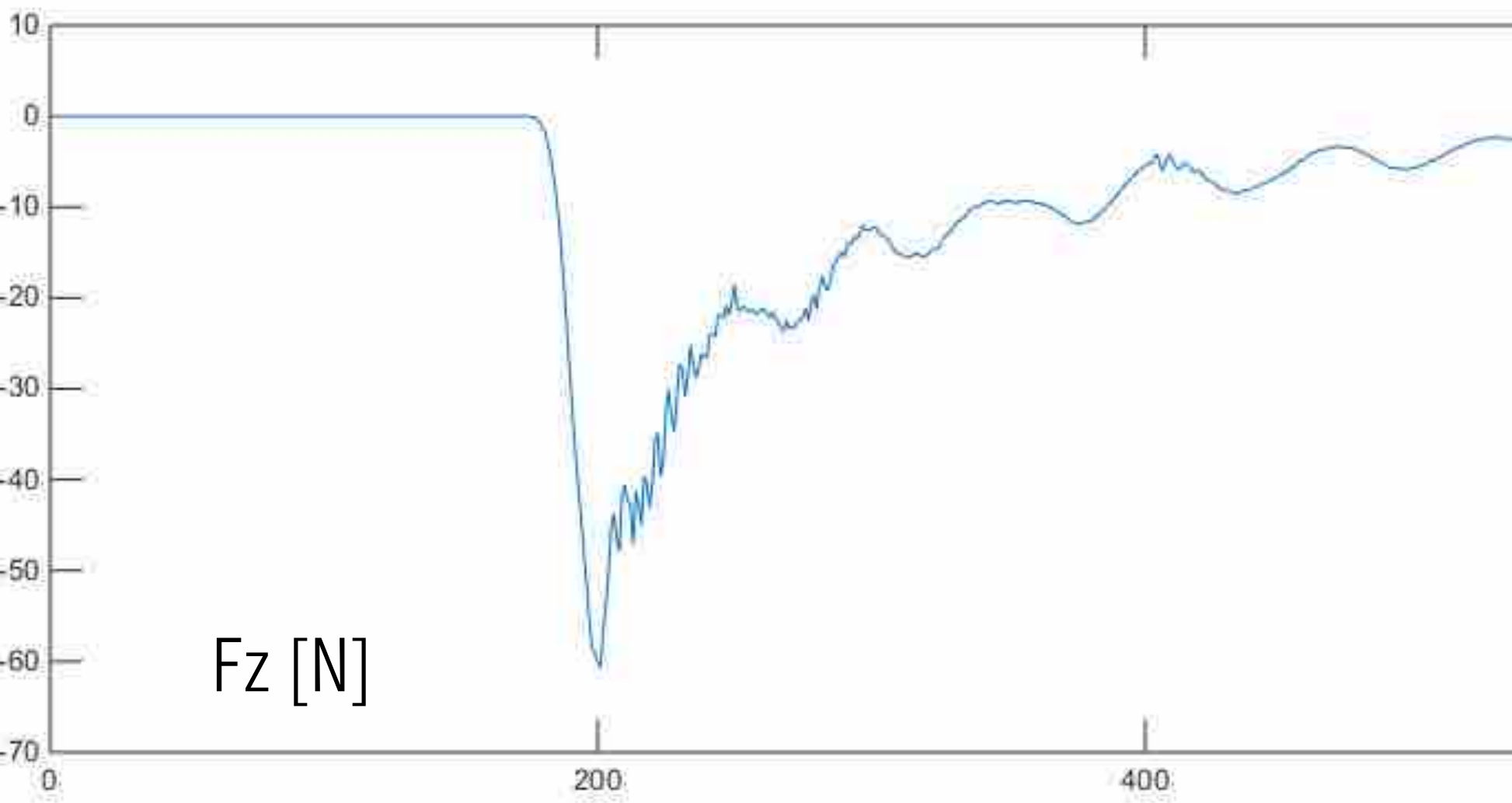
Ignition

Thrust

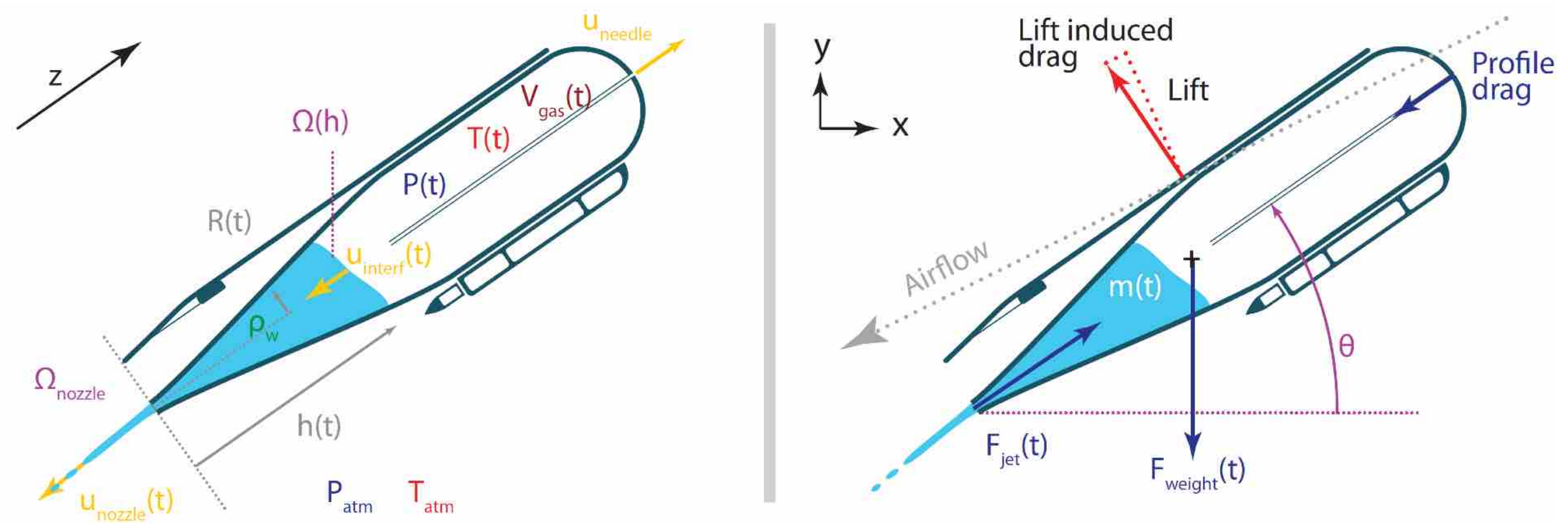


Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmam, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)

Static Tests

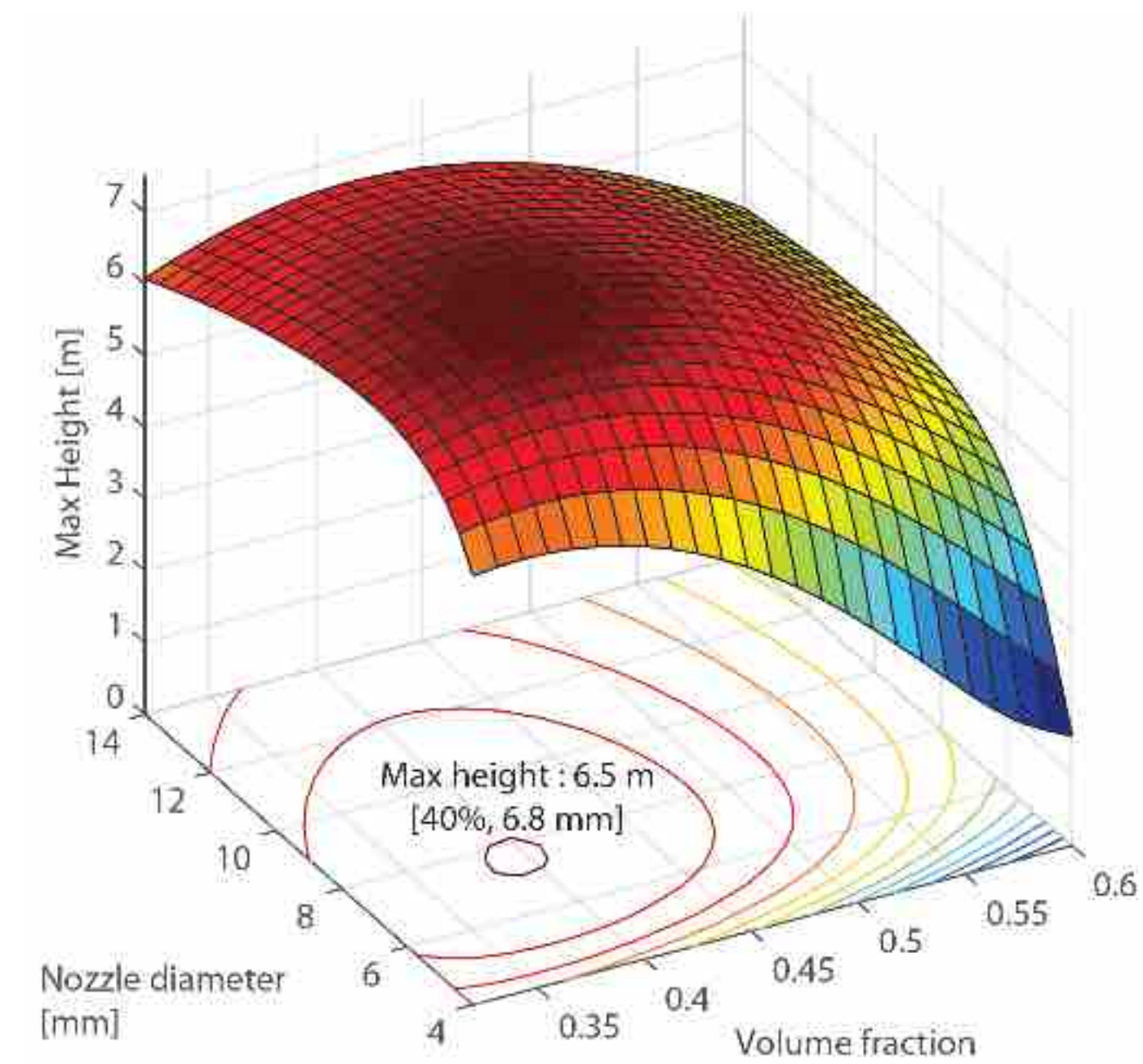
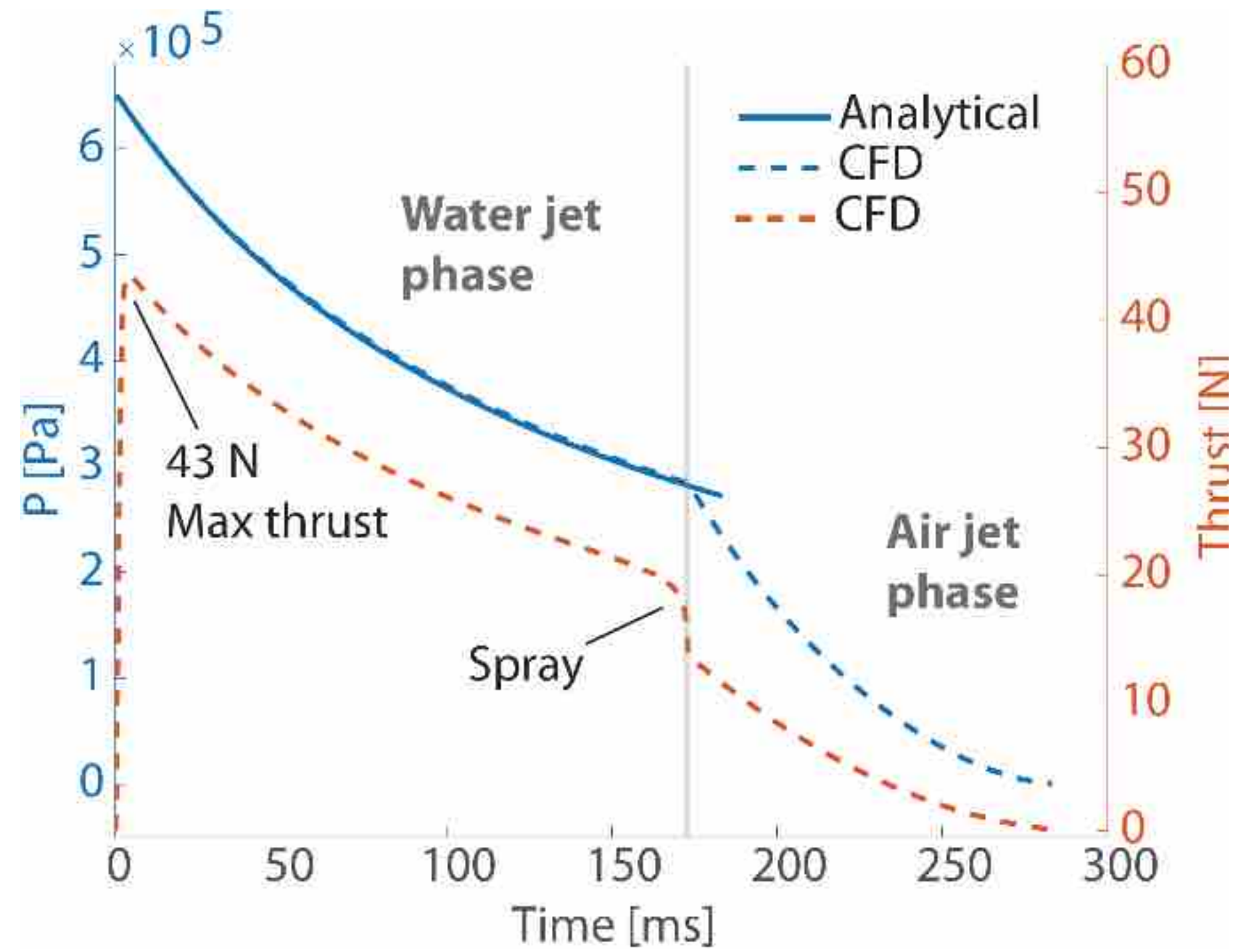
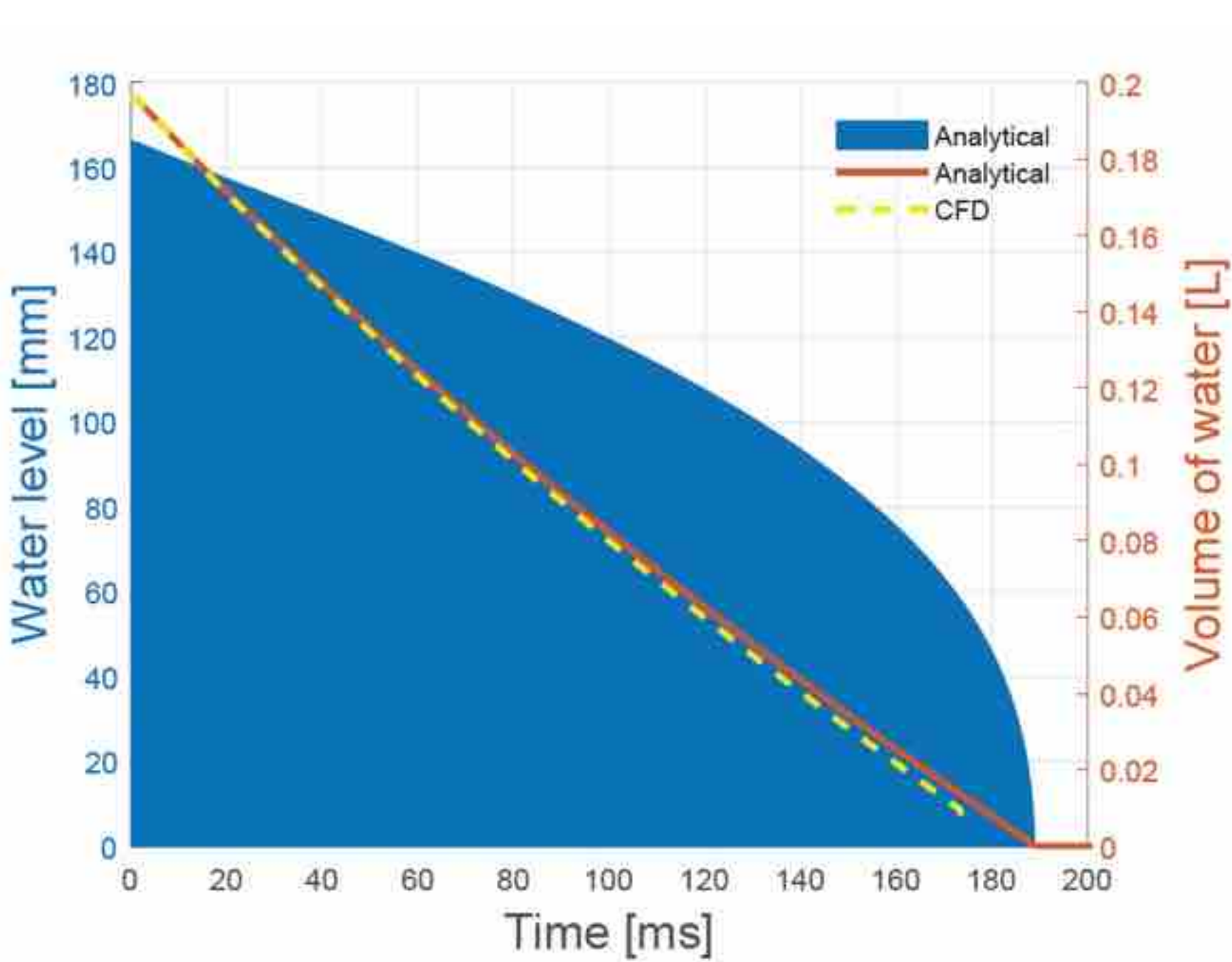


Physics-based development



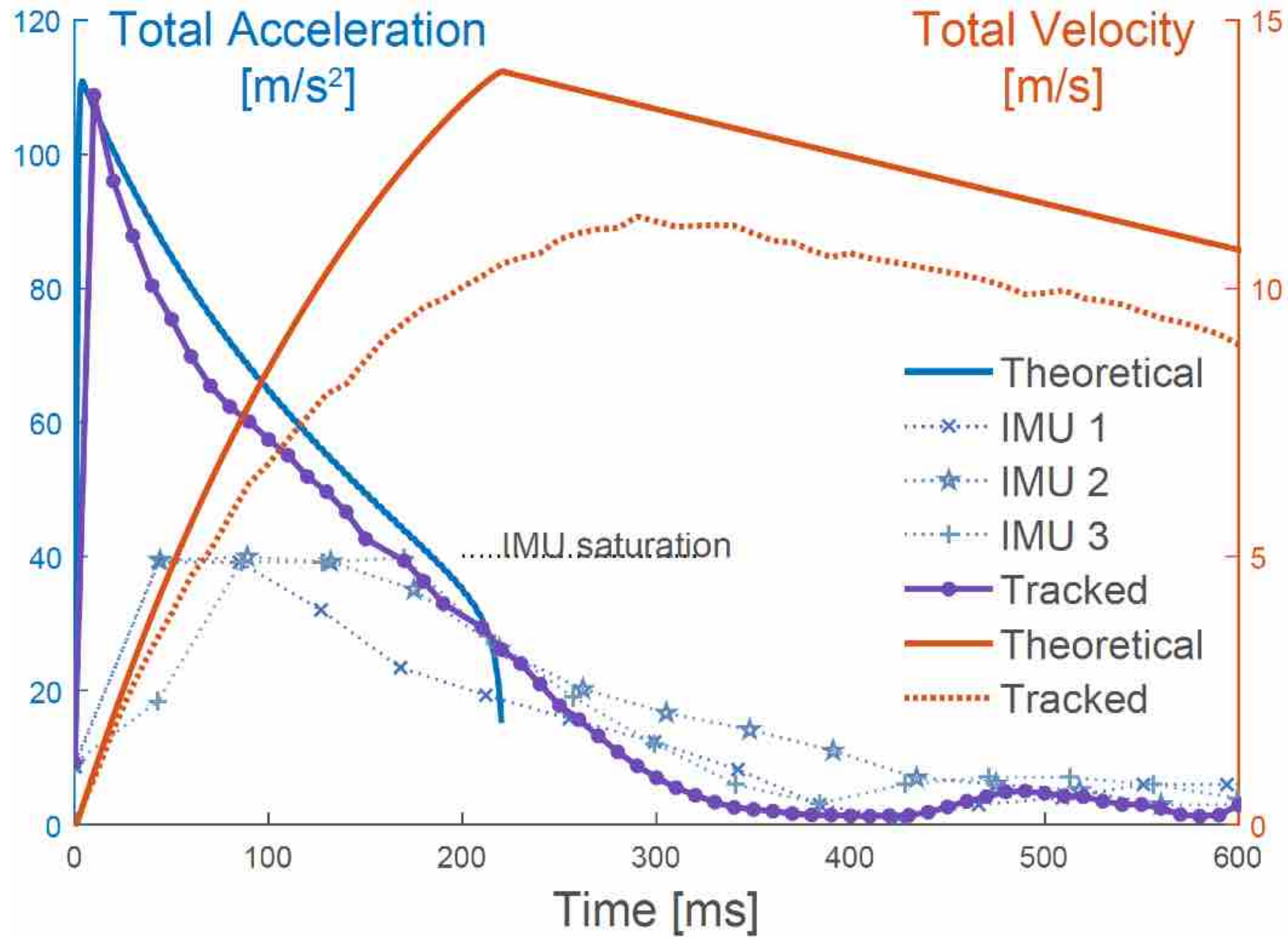
Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmhal, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)

CFD and model analysis



Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmam, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)

Experimental Comparison



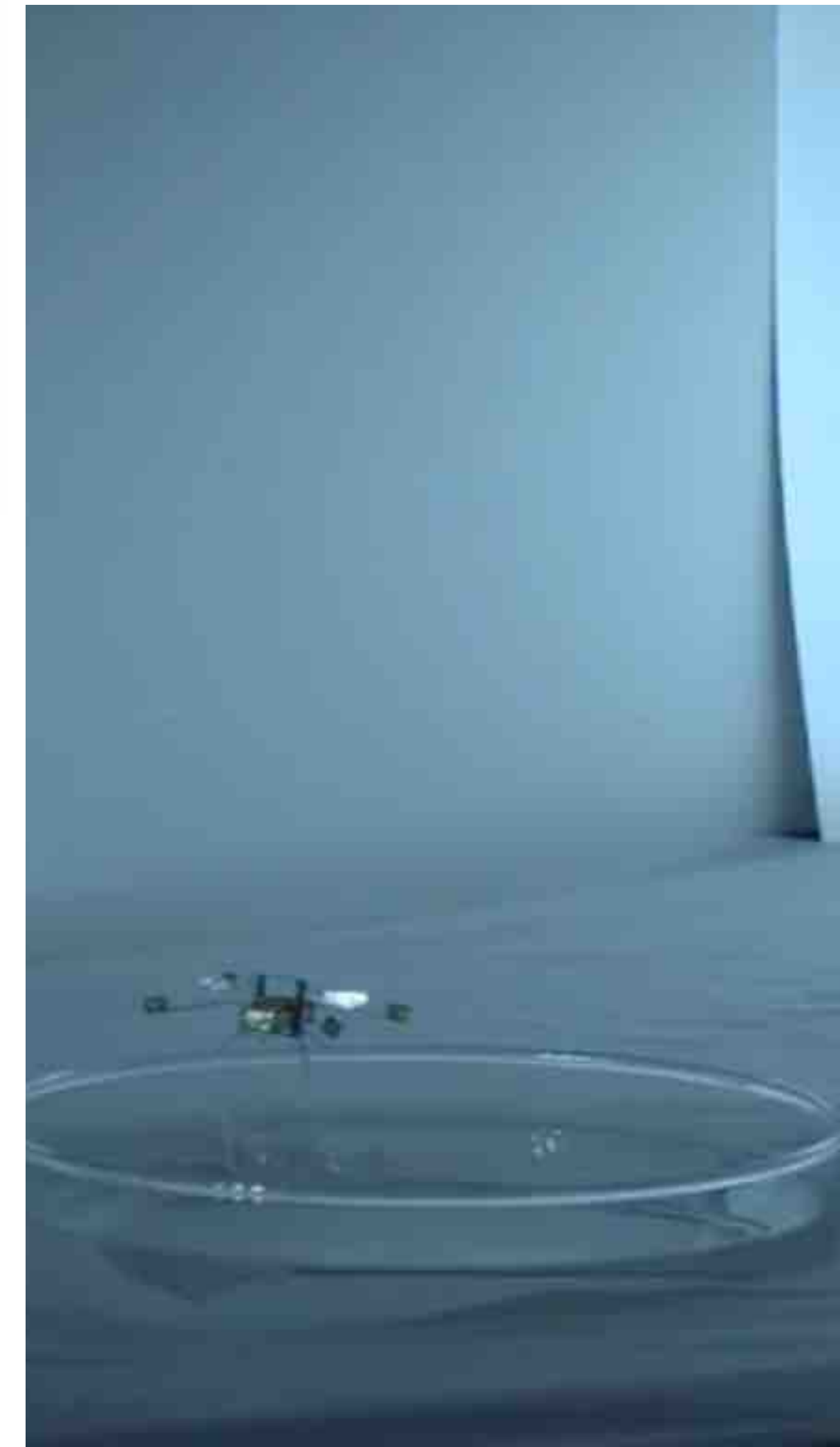
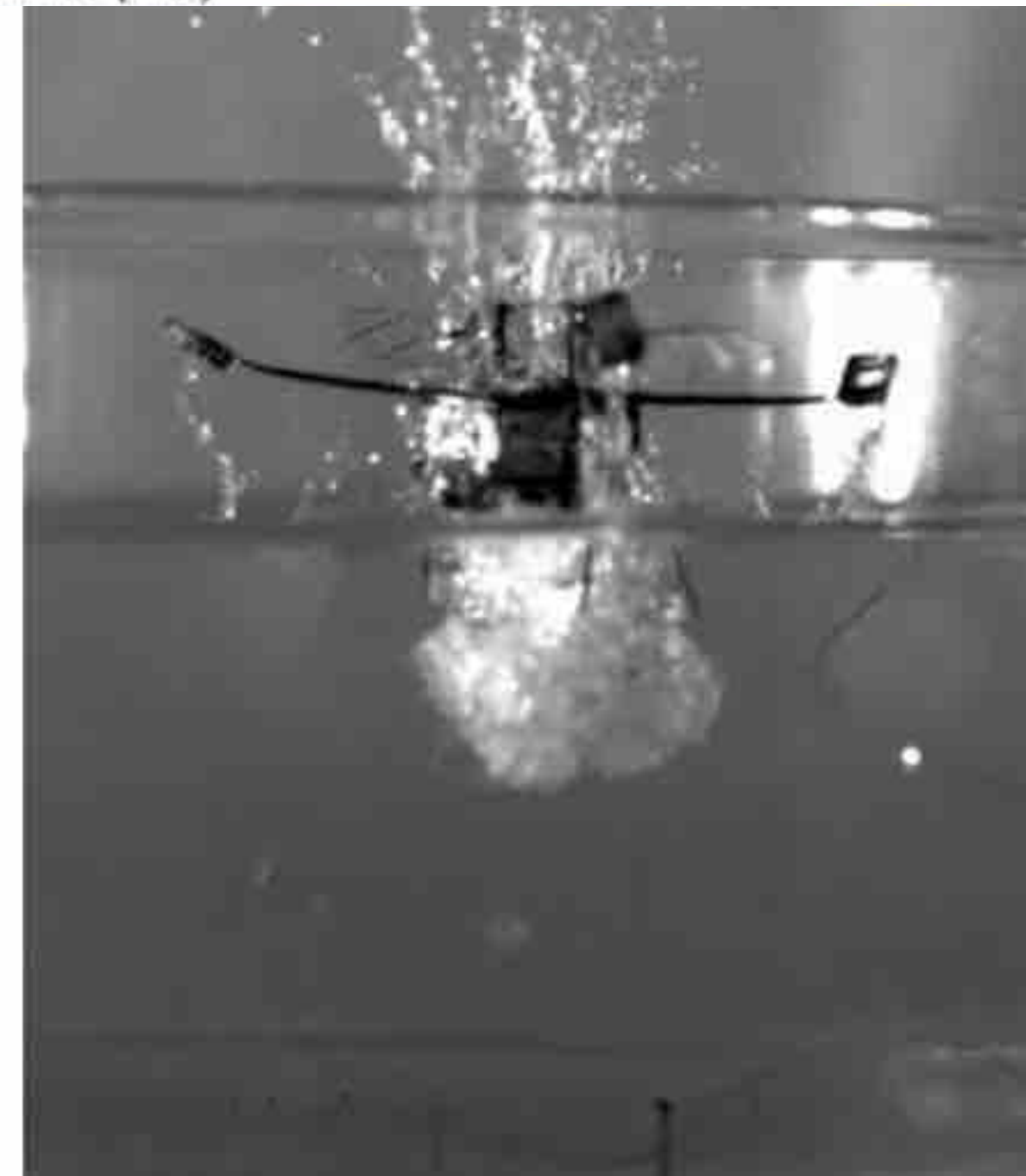
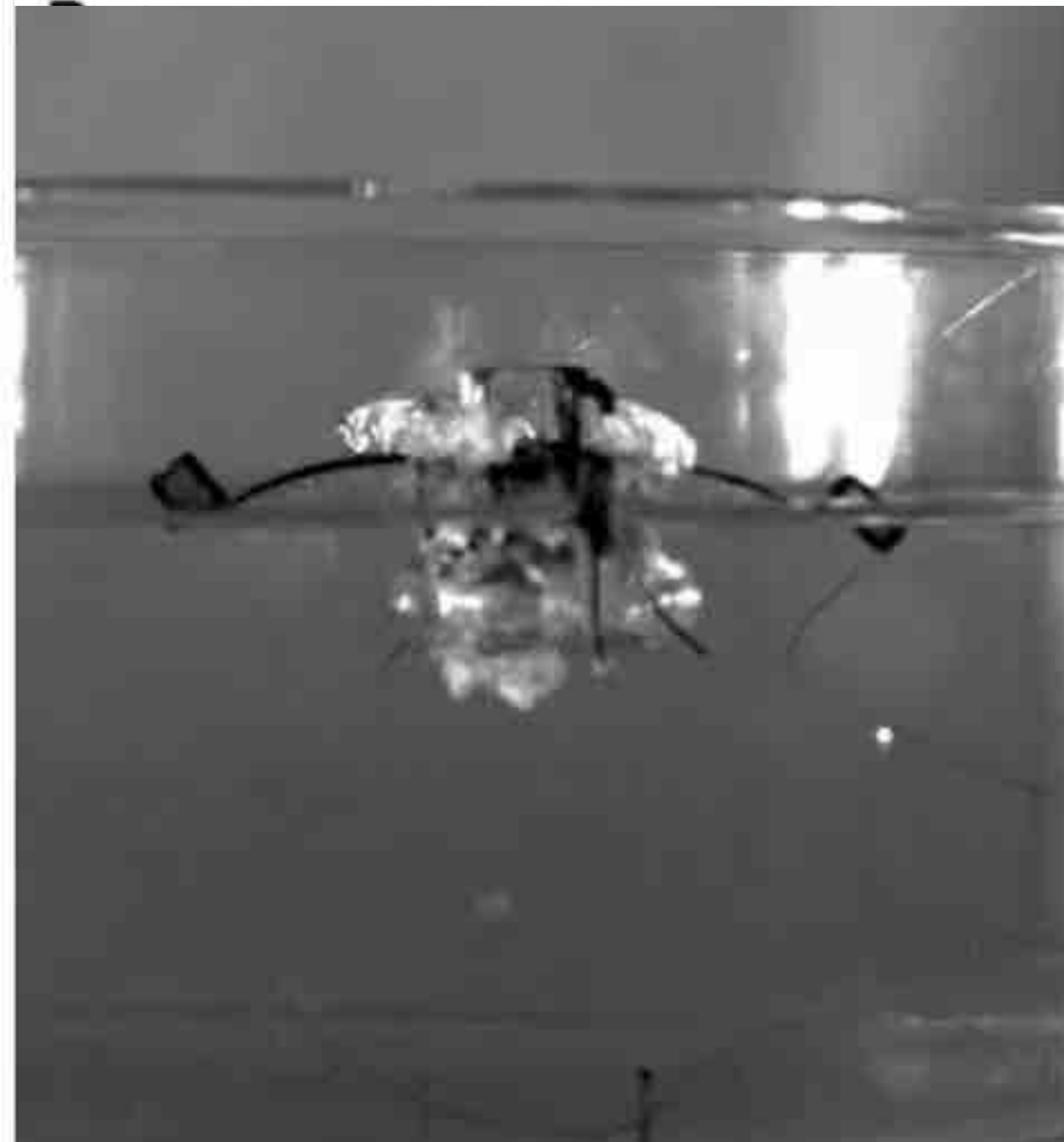
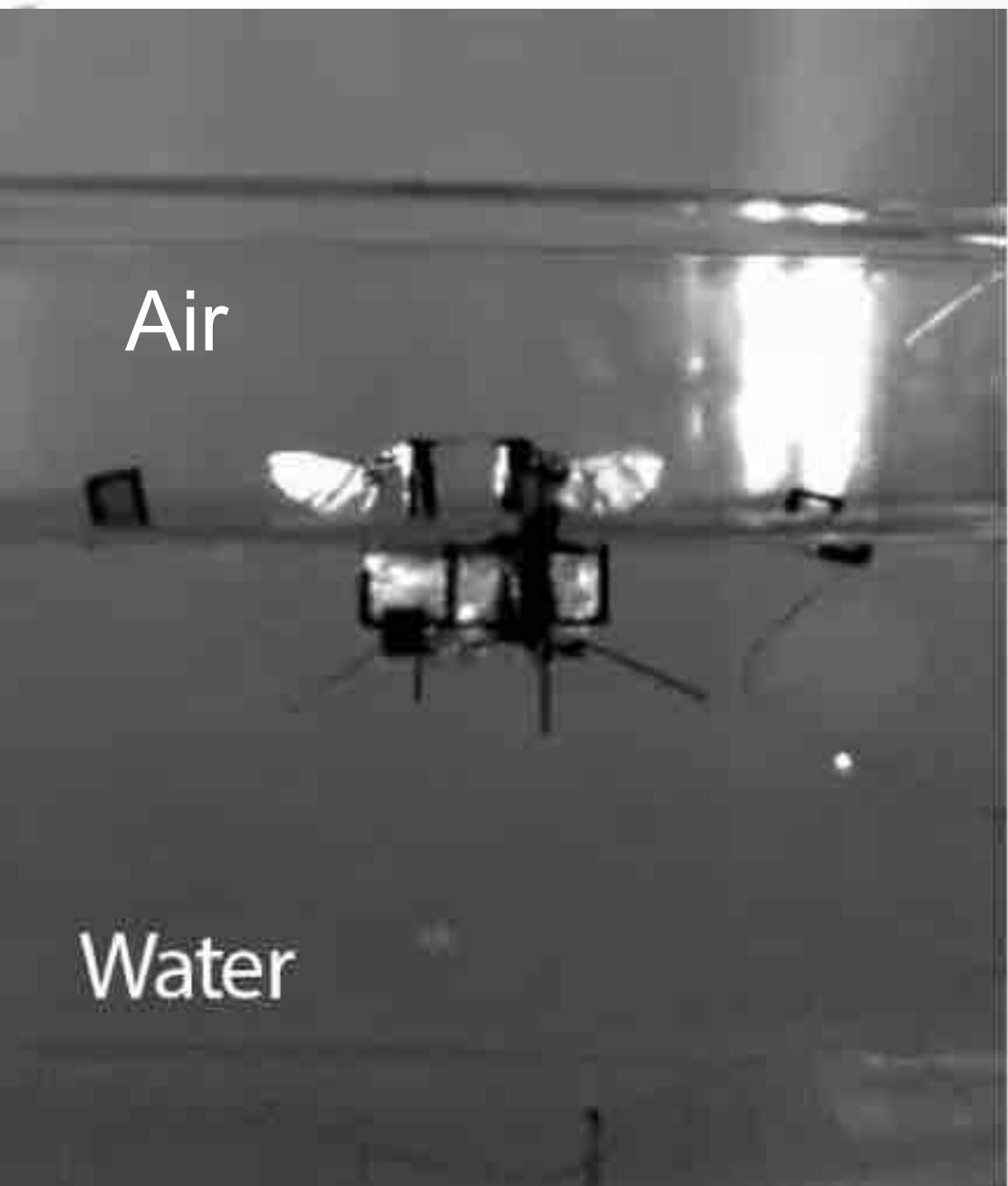
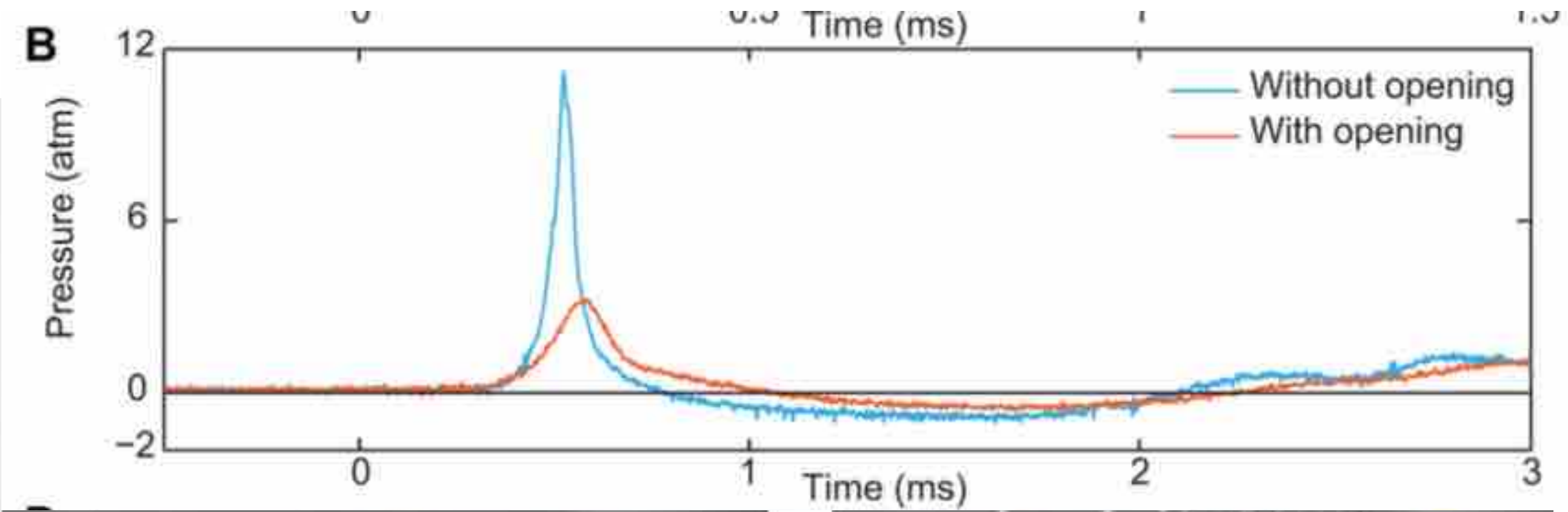
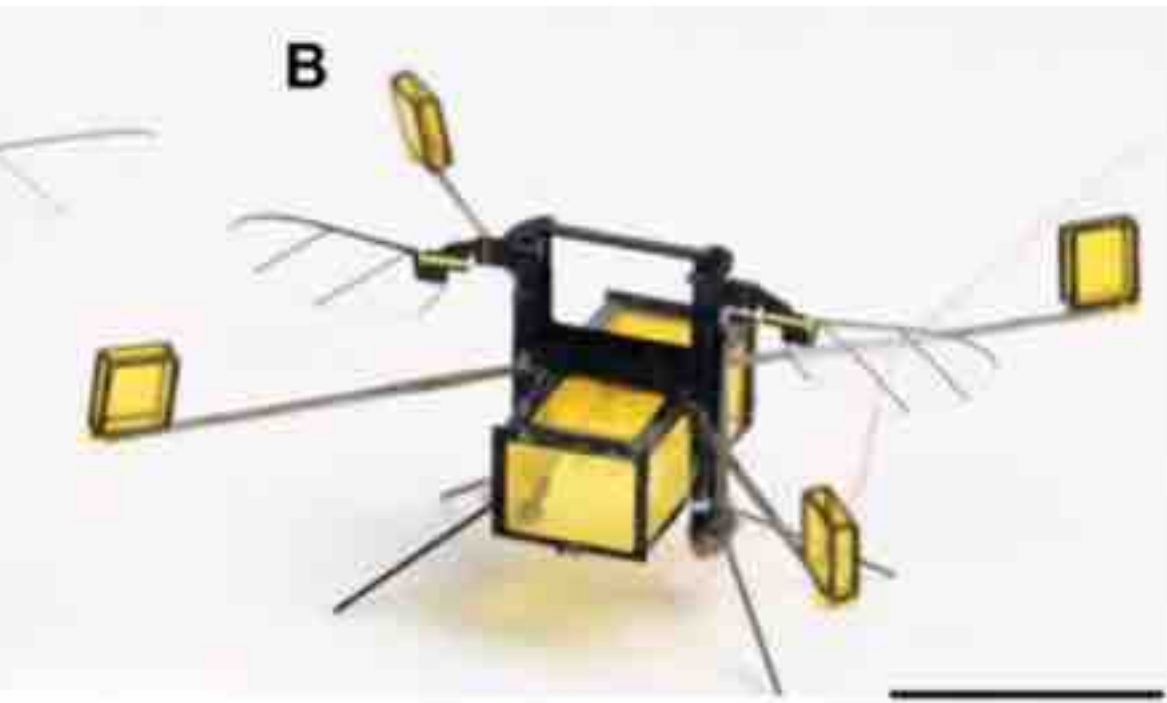
Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmam, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)



Launch

0.03 x

Aerial-aquatic RoboBee



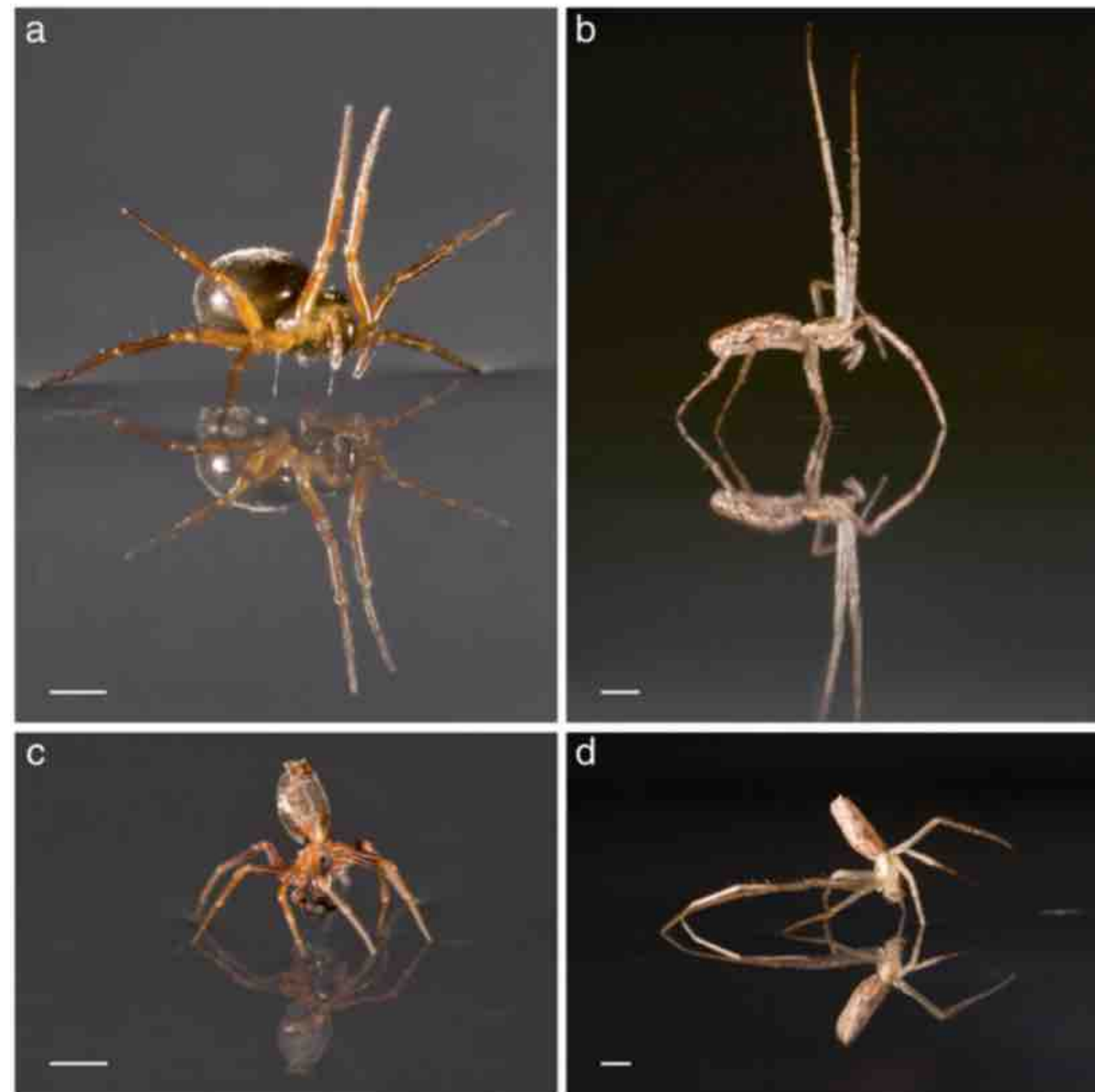
Chen, K., Zufferey, R., Kovac, M., Wood, R. et al.
Science Robotics (2017)

Li, L., Nguyen, P., Kovac, M., Wen, L. et al.
Science Robotics (2022)

Nature (Remora Fish)

Robot

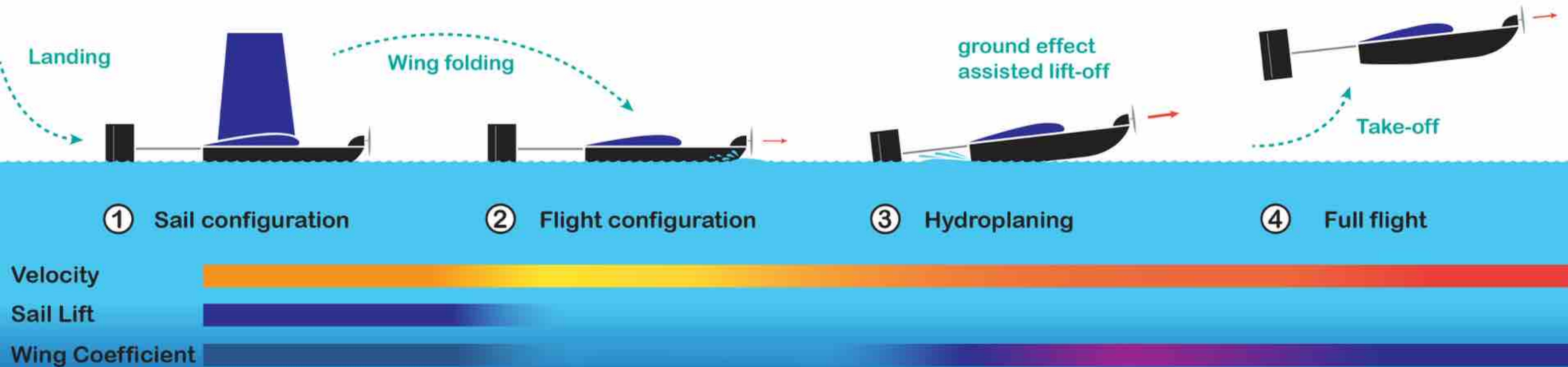
Sailing : Energy efficient locomotion



- Terenius. Windsurfing in Mute Swans (*Cygnus olor*). *The Wilson Journal of Ornithology*, (2016)
- Hayashi, Morito, et al. "Sail or sink: novel behavioural adaptations on water in aerially dispersing species." *BMC evolutionary biology* (2015)

Sailing Micro Aerial Vehicles

Motivation:
Marine Research
Climate change Research
Innaccessible area Exploration





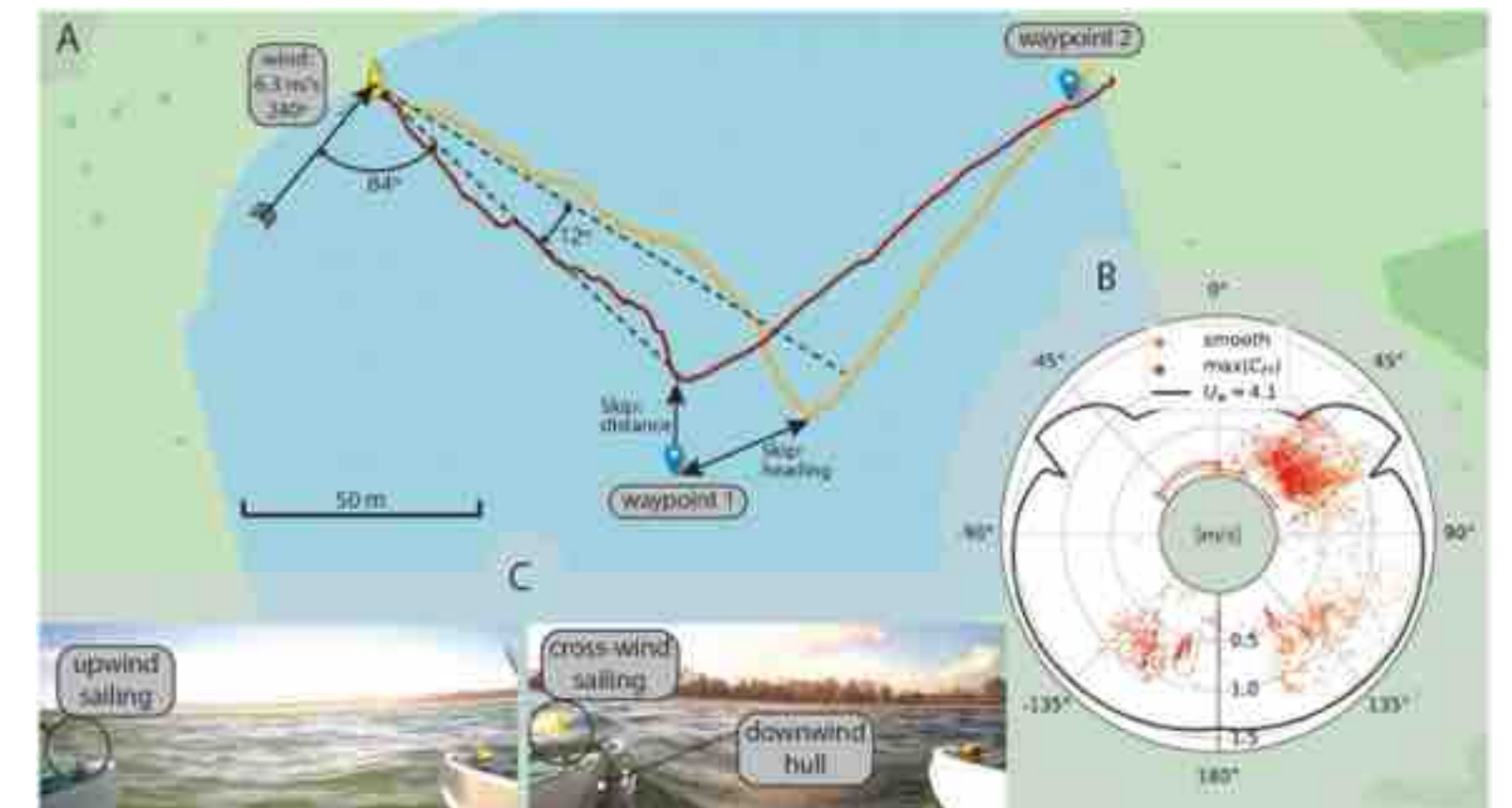
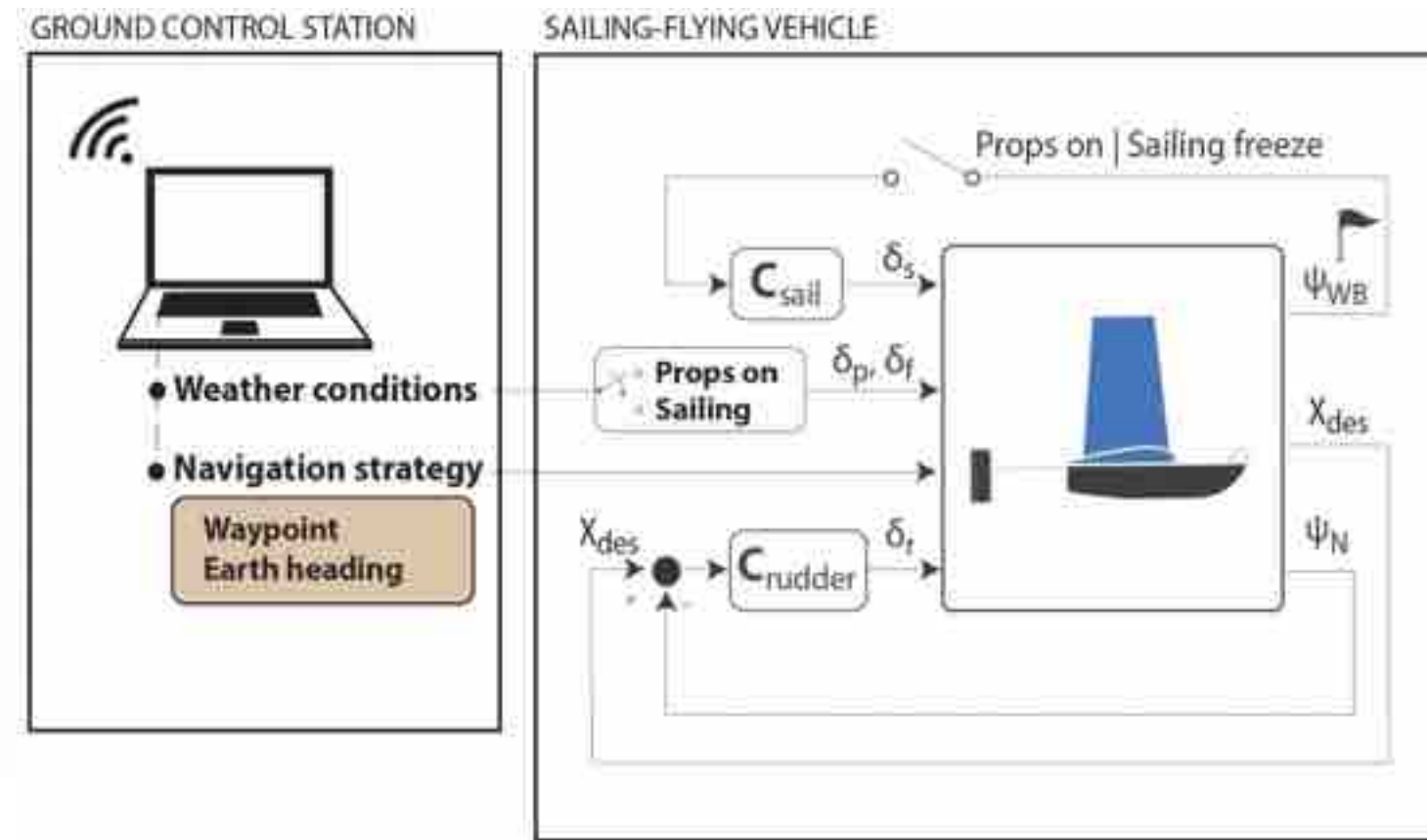
Wing morphology changes

Autonomously navigating and mapping Lake Vrana

Wind direction **sensor**

Autonomous **control** algorithm

Testing & Mapping

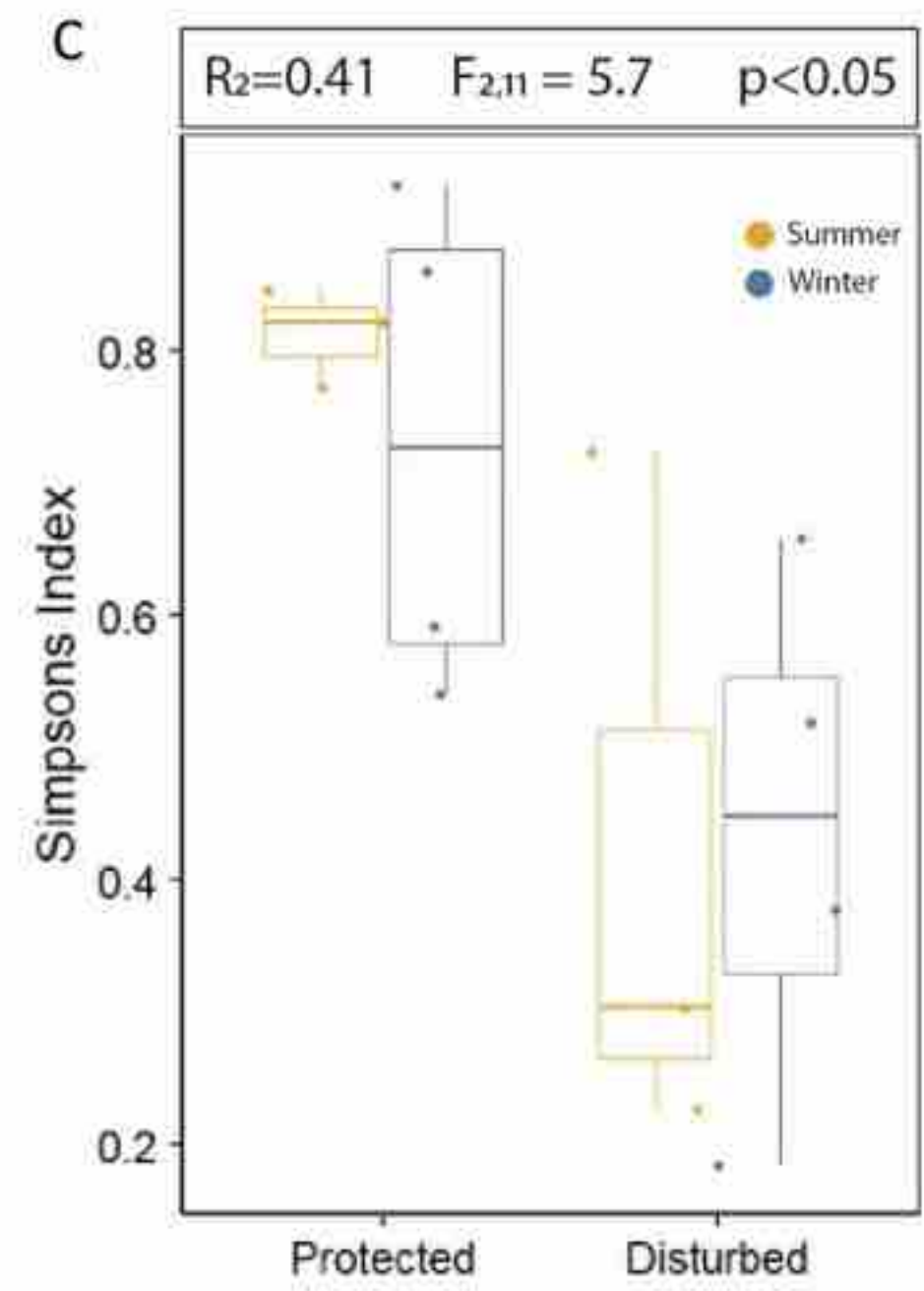
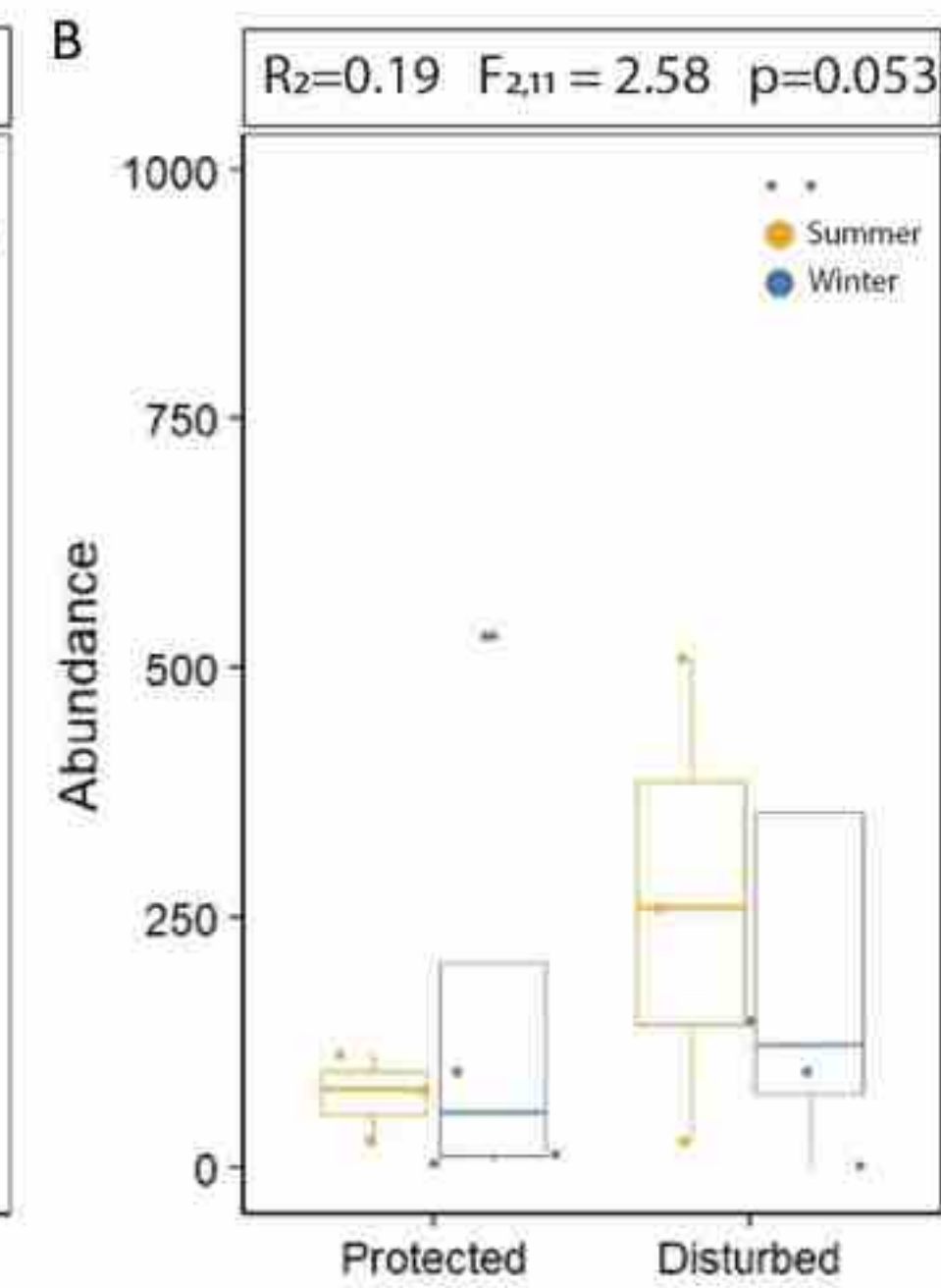
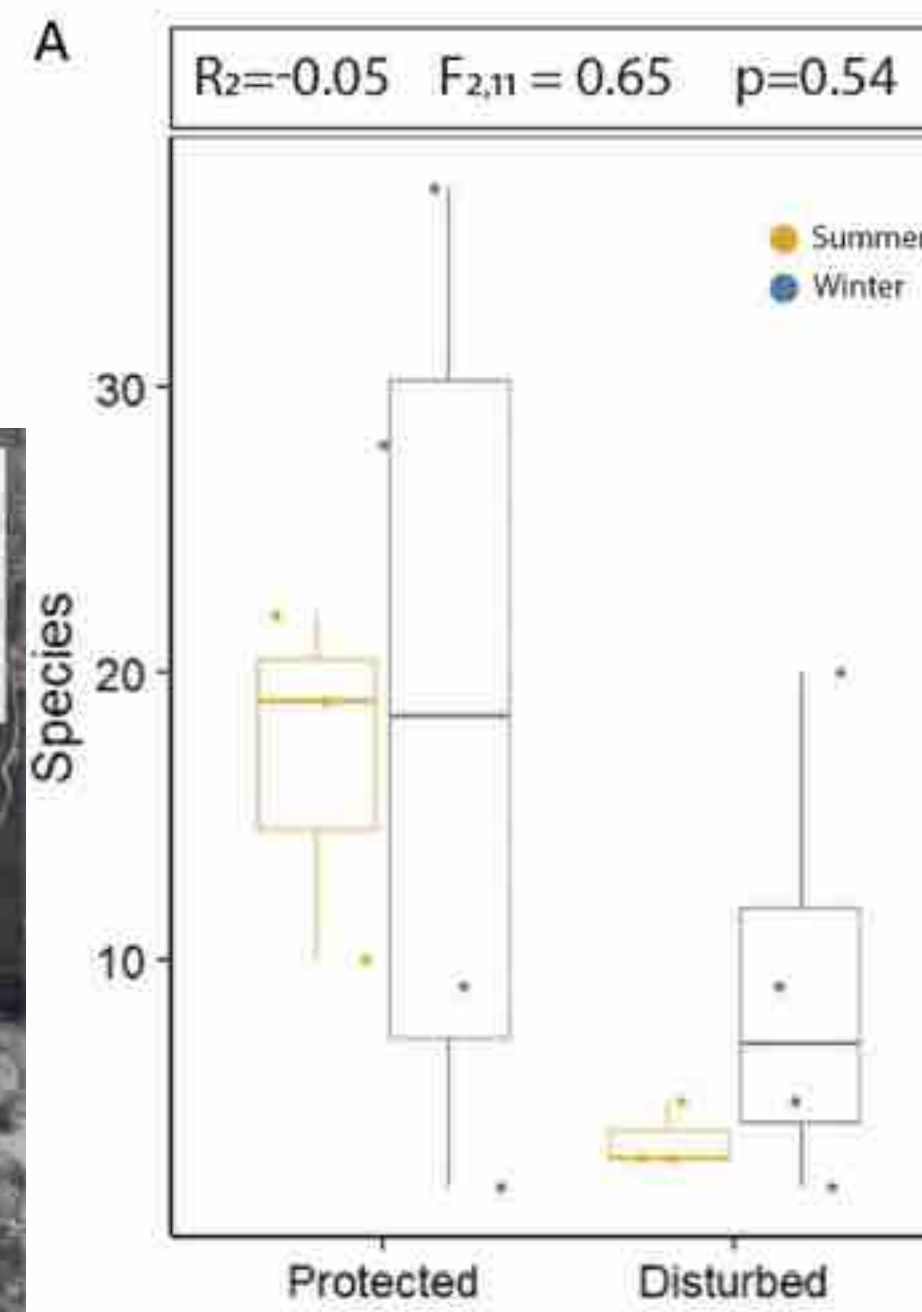


Miniaturized sensor providing information to the controller

Control the robot based on task and wind conditions

Test strategy versus state-of-the-art, covering more upwind directions.

Field testing campaign



Farinha A.*, Romanello L.*, ..., Kovac M., SailMAV: Water-surface locomotion and applications of aerial-aquatic sailing vehicles *IEEE Transactions in Field Robotics*, 2025.

Aerial - Aquatic SailMAV

Vol. 5 • No. 2 • February 2023

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ADVANCED INTELLIGENT SYSTEMS

46

Open Access

Gortat, D., Ortega Ancel, A., Farhina, A., Zufferey, R., Kovac, M.,
**Use of Superhydrophobic Surfaces for Performance
Enhancement of Aerial-Aquatic Vehicles**
Advanced Intelligent Systems 2023 (cover)

WILEY-VCH

Aerial - Aquatic SailMAV

Vol. 5 • No. 2 • February 2023

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ADVANCED INTELLIGENT SYSTEMS

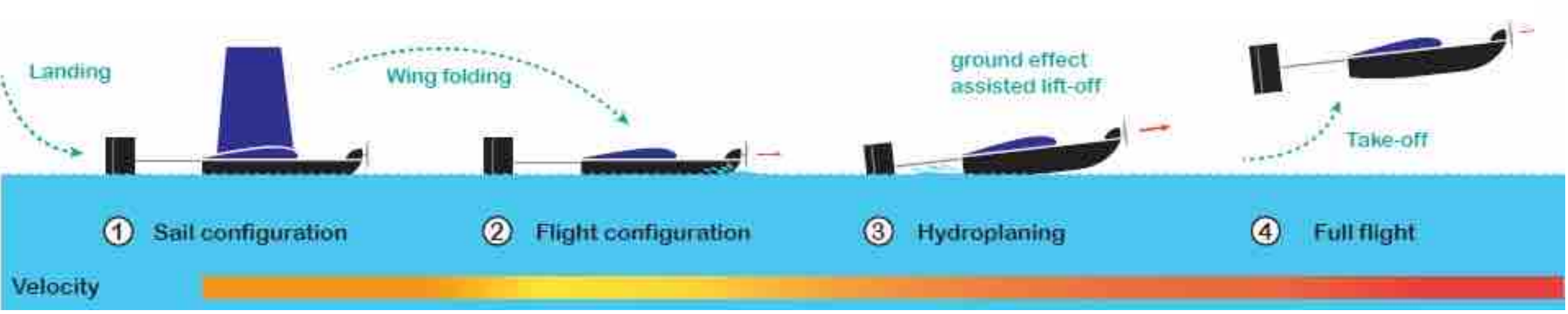
Open Access



Gortat, D., Ortega Ancel, A., Farhina, A., Zufferey, R., Kovac, M.,
**Use of Superhydrophobic Surfaces for Performance
Enhancement of Aerial-Aquatic Vehicles**
Advanced Intelligent Systems 2023 (cover)

WILEY-VCH

Concept to system to insights



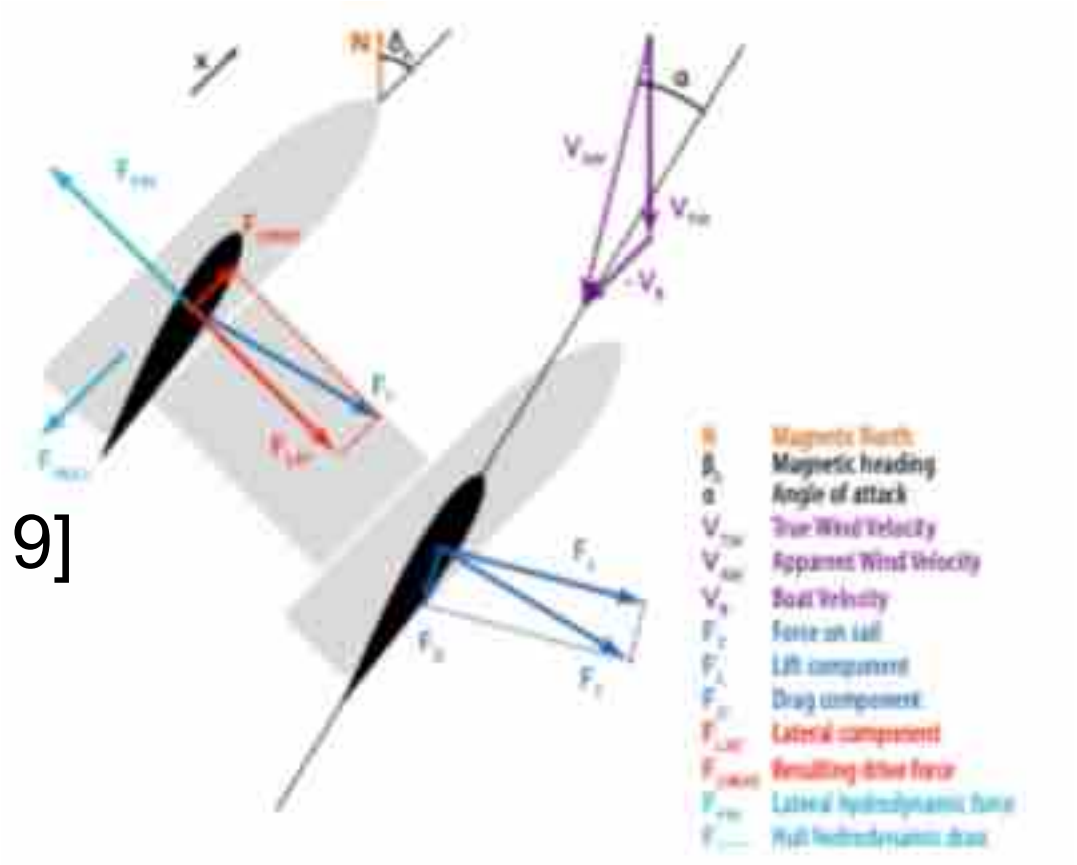
Testing

Design iteration

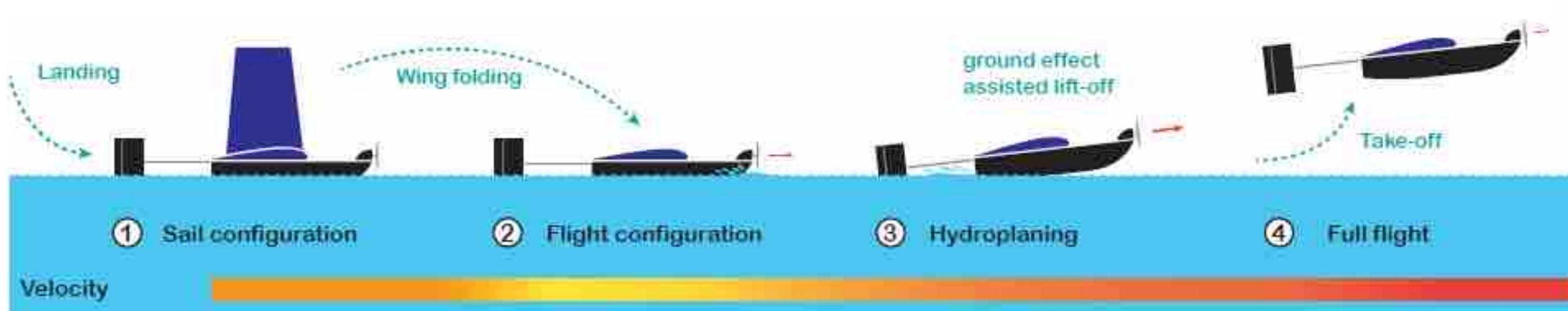
Laboratory of Sustainability Robotics



[Zufferey et al *IEEE RAL*, 2019]



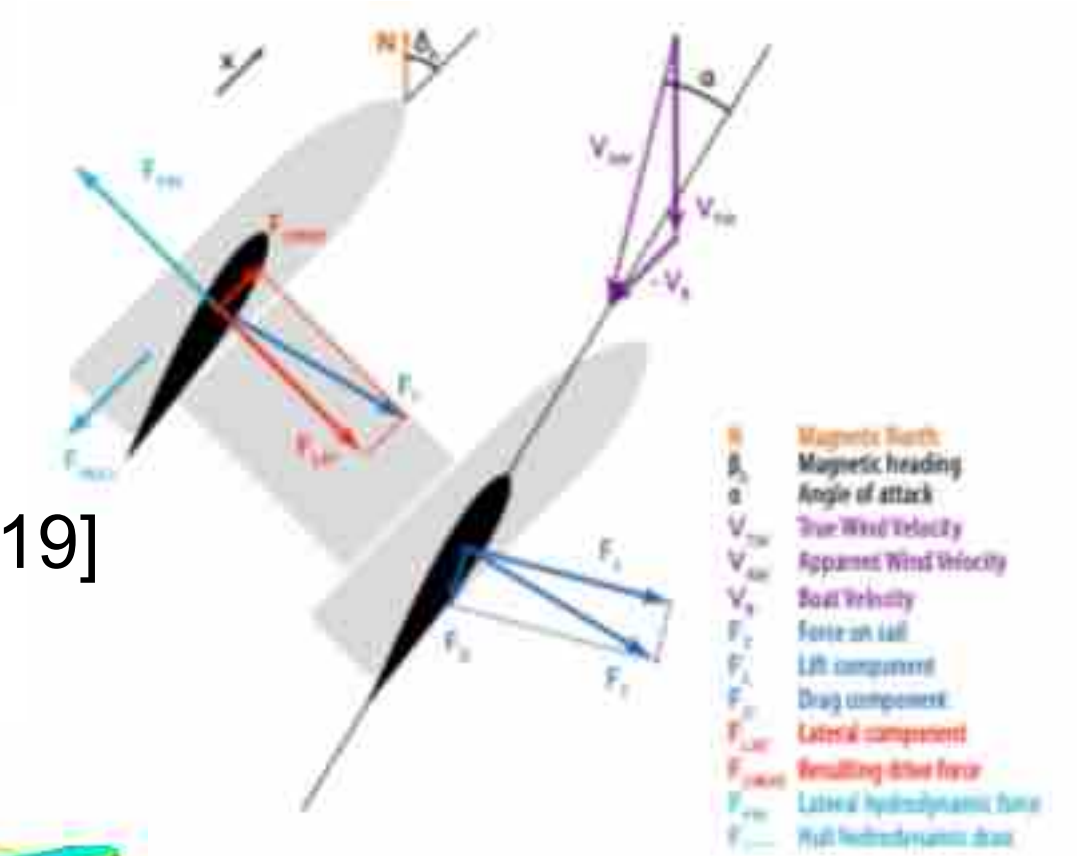
Concept to system to insights



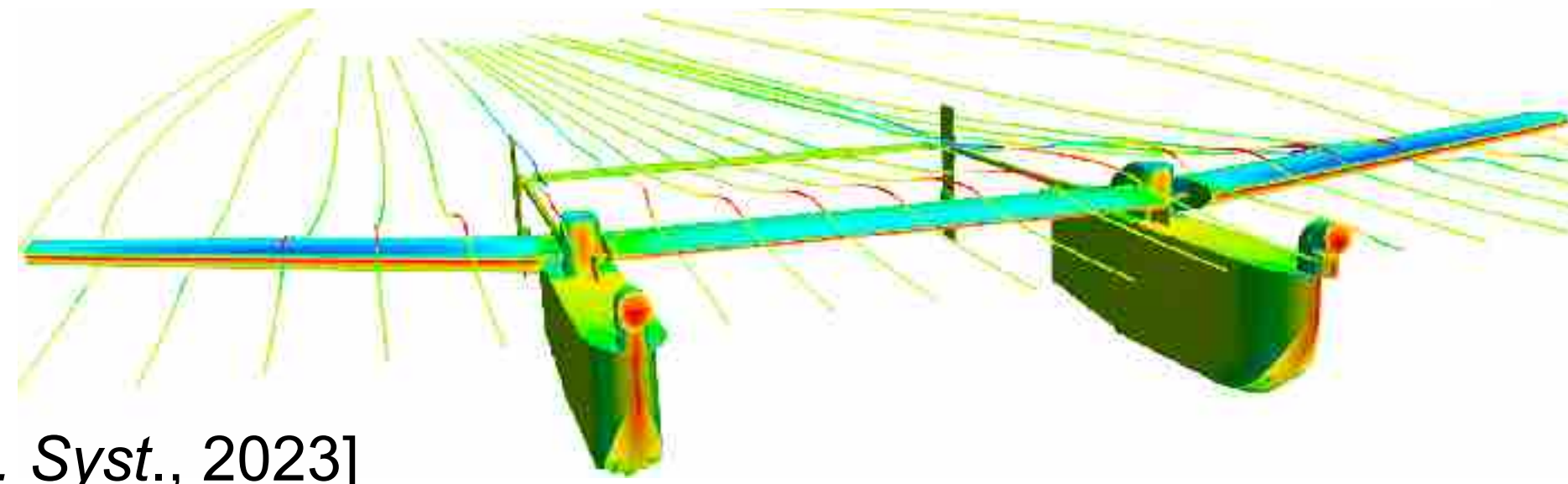
Laboratory of Sustainability Robotics



[Zufferey et al *IEEE RAL*, 2019]



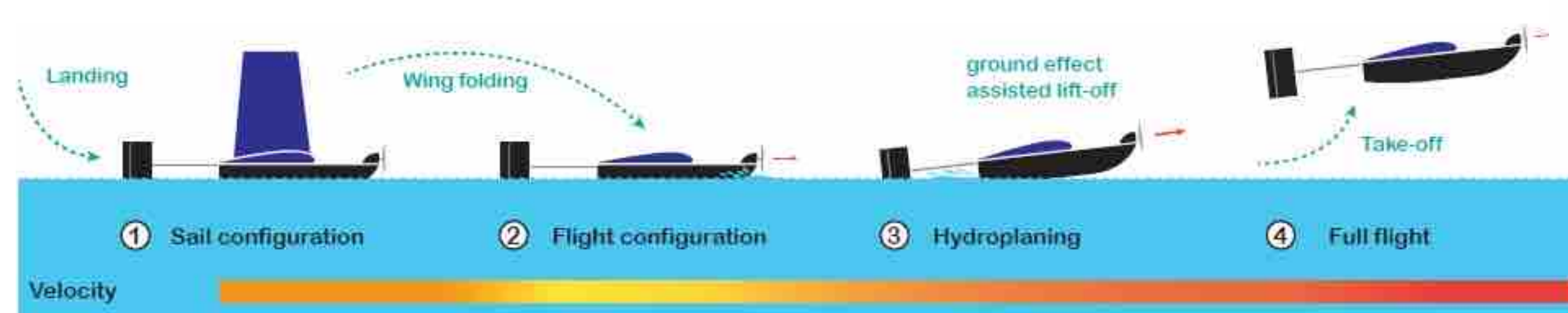
Design iteration



[Gortat et al *Adv. Intel. Syst.*, 2023]

[Farinha et al *IEEE Trans. Field Robotics*, 2025]

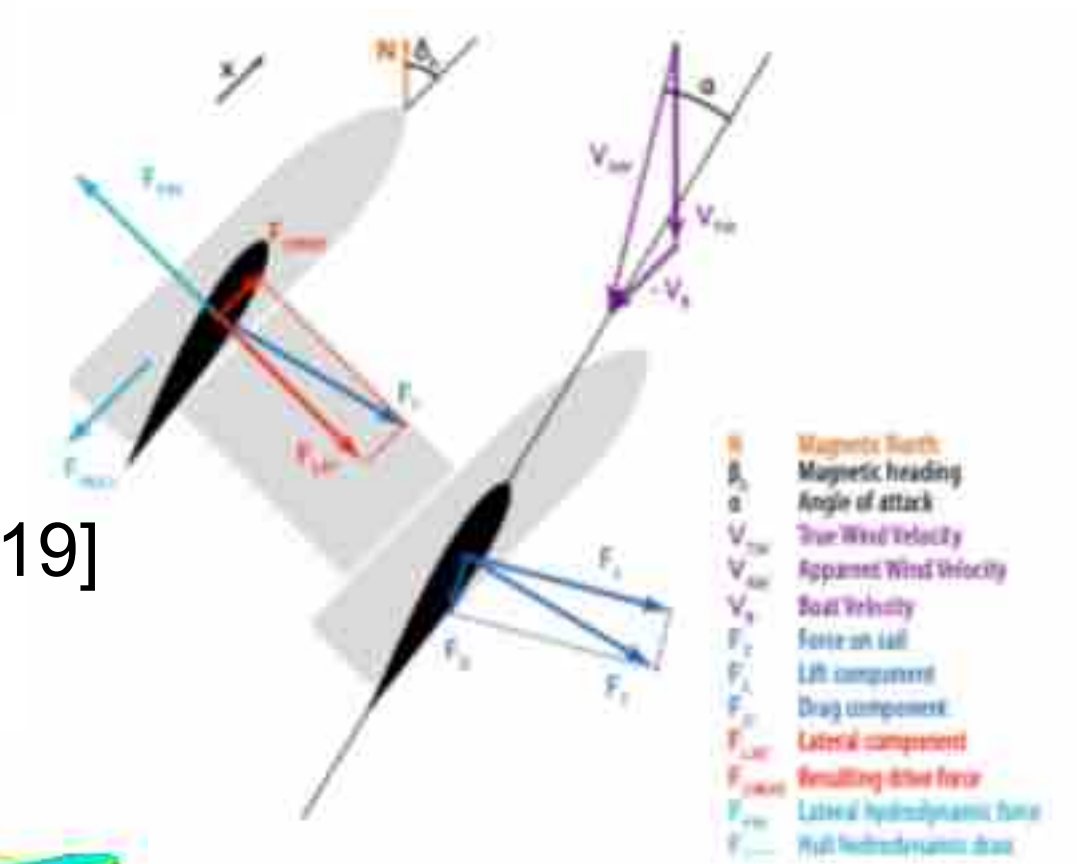
Concept to system to insights



Laboratory of Sustainability Robotics

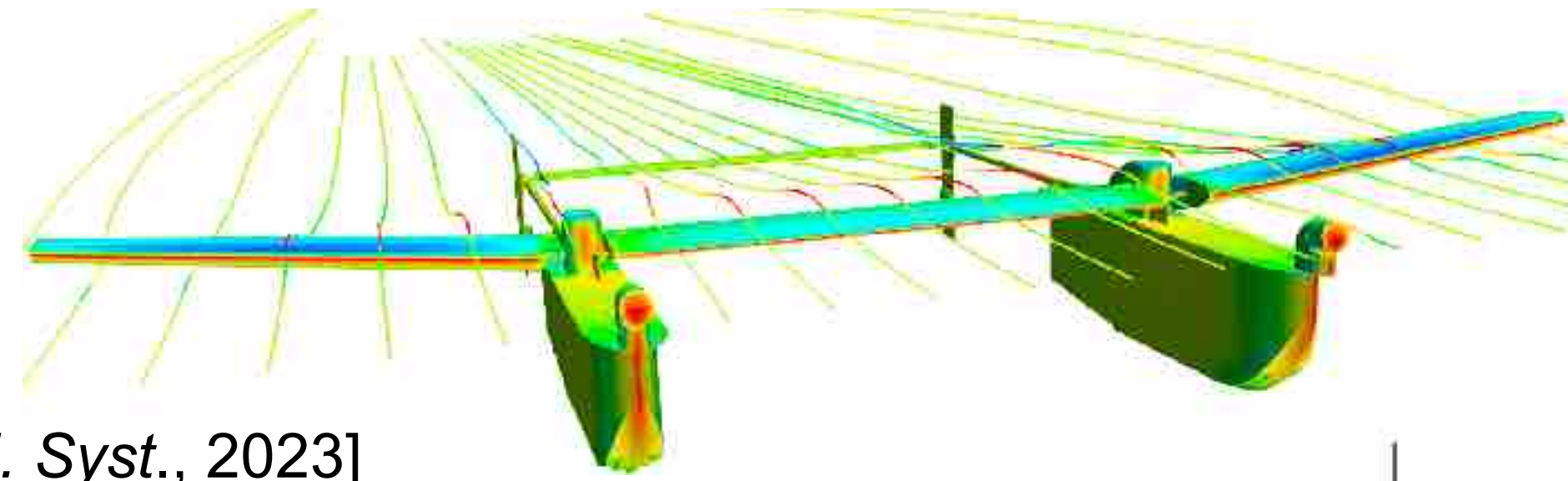


[Zufferey et al *IEEE RAL*, 2019]



Testing

Design iteration



[Gortat et al *Adv. Intel. Syst.*, 2023]

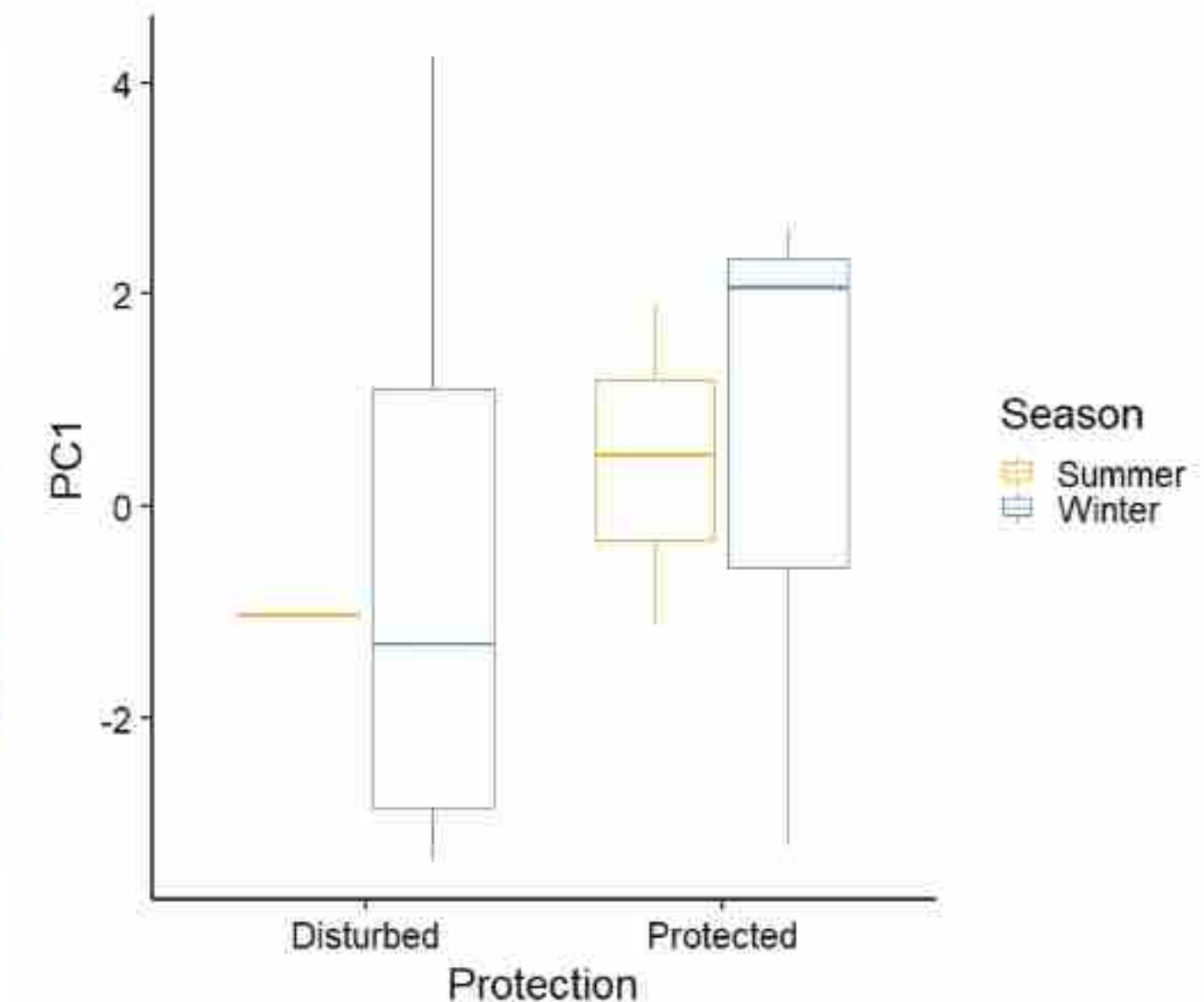
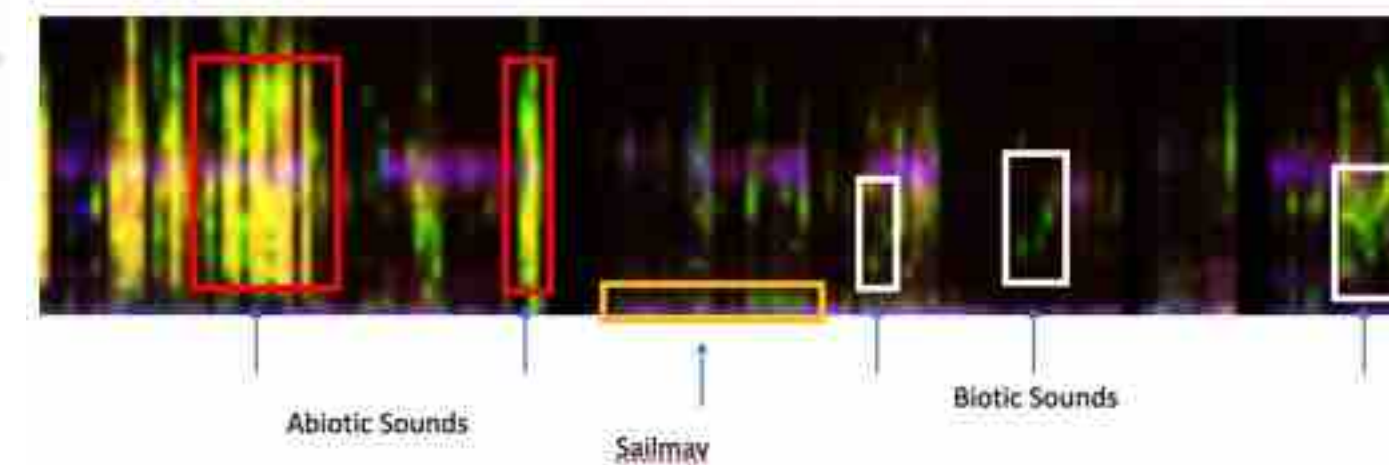
[Farinha et al *IEEE Trans. Field Robotics*, 2025]

Outdoor validation



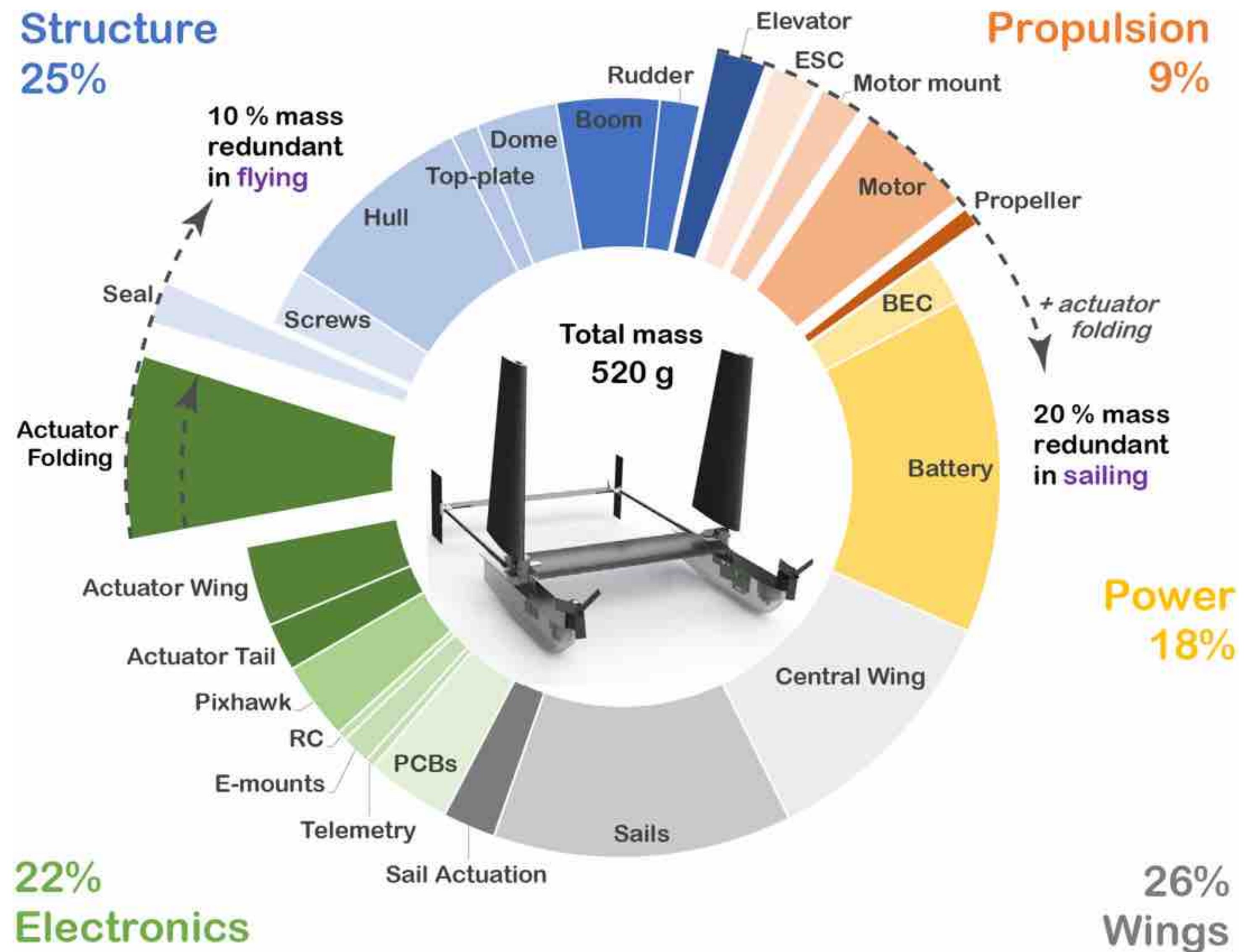
Insights

Soundscape Analysis



[Lawson et al *Remote Sensing in Ecology and Conservation*, 2023]

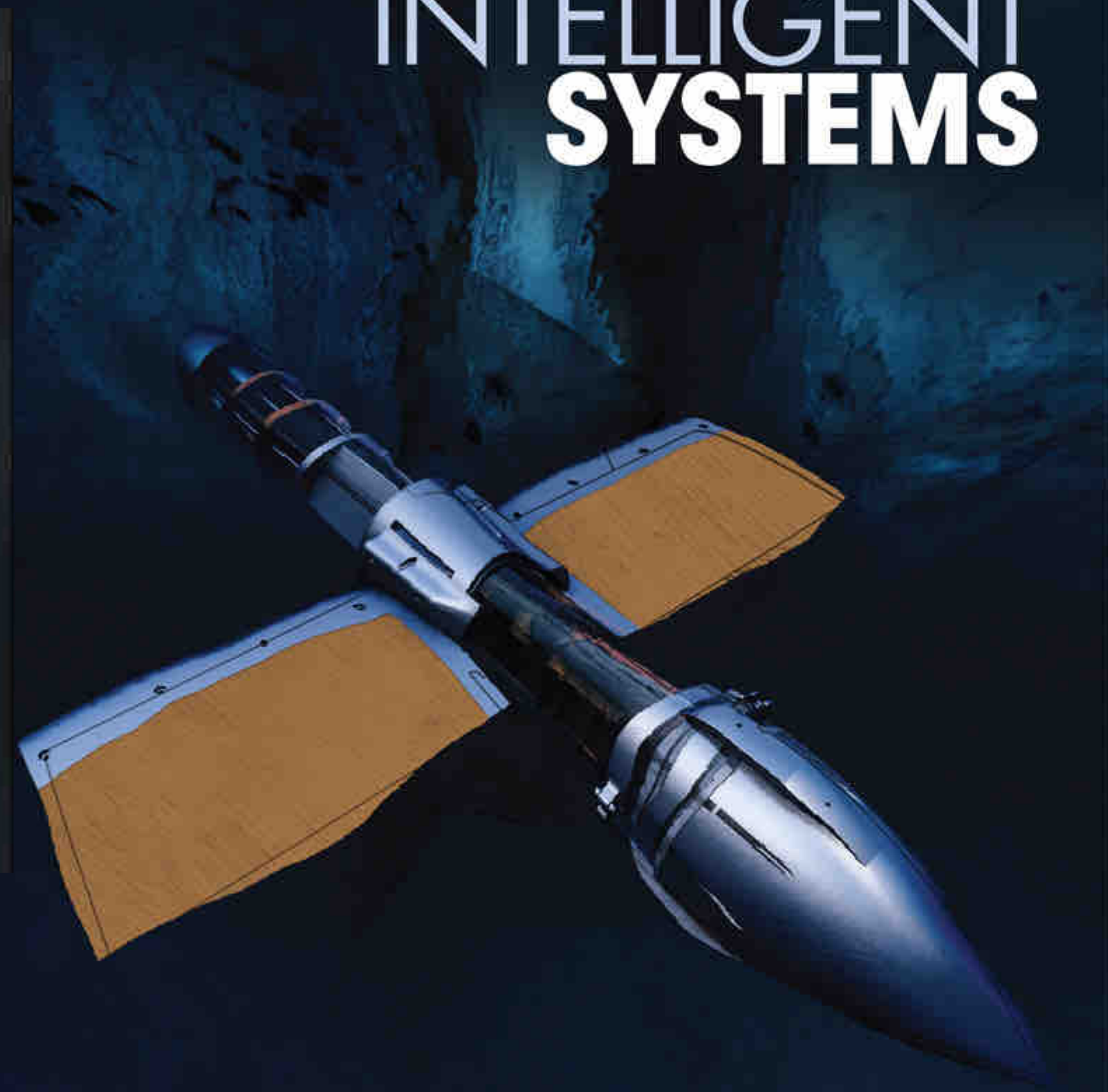
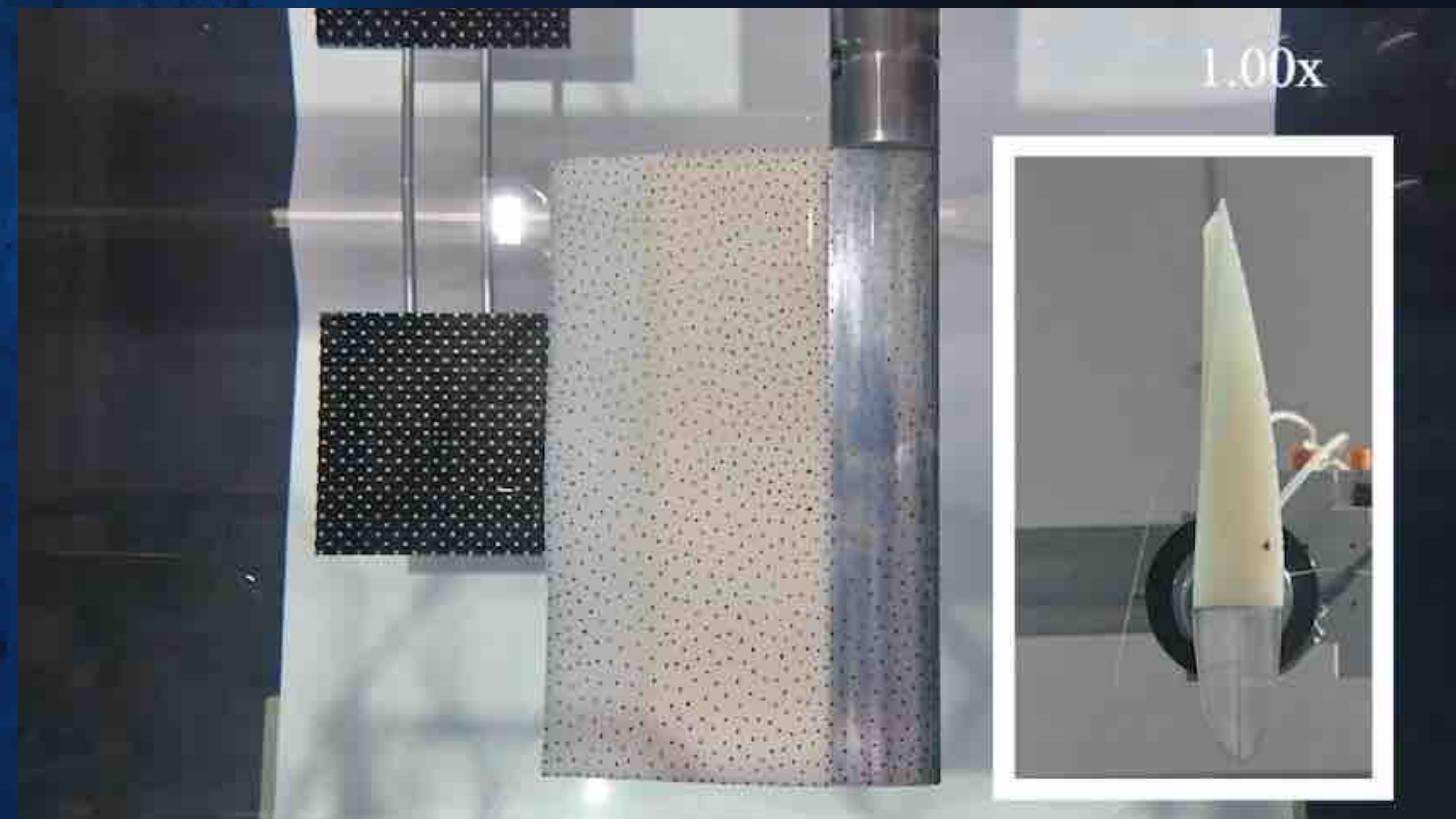
Multi-modality cost



Zufferey, R., Ortega, A., Raposo, C., Armanini, S., Farinha, A., Siddall, R., Barasaluce, I., Zhu, H., Kovac, M. (2019) *IEEE Robotics Automation Letters*

Soft Robotic Wing for hydrobatics

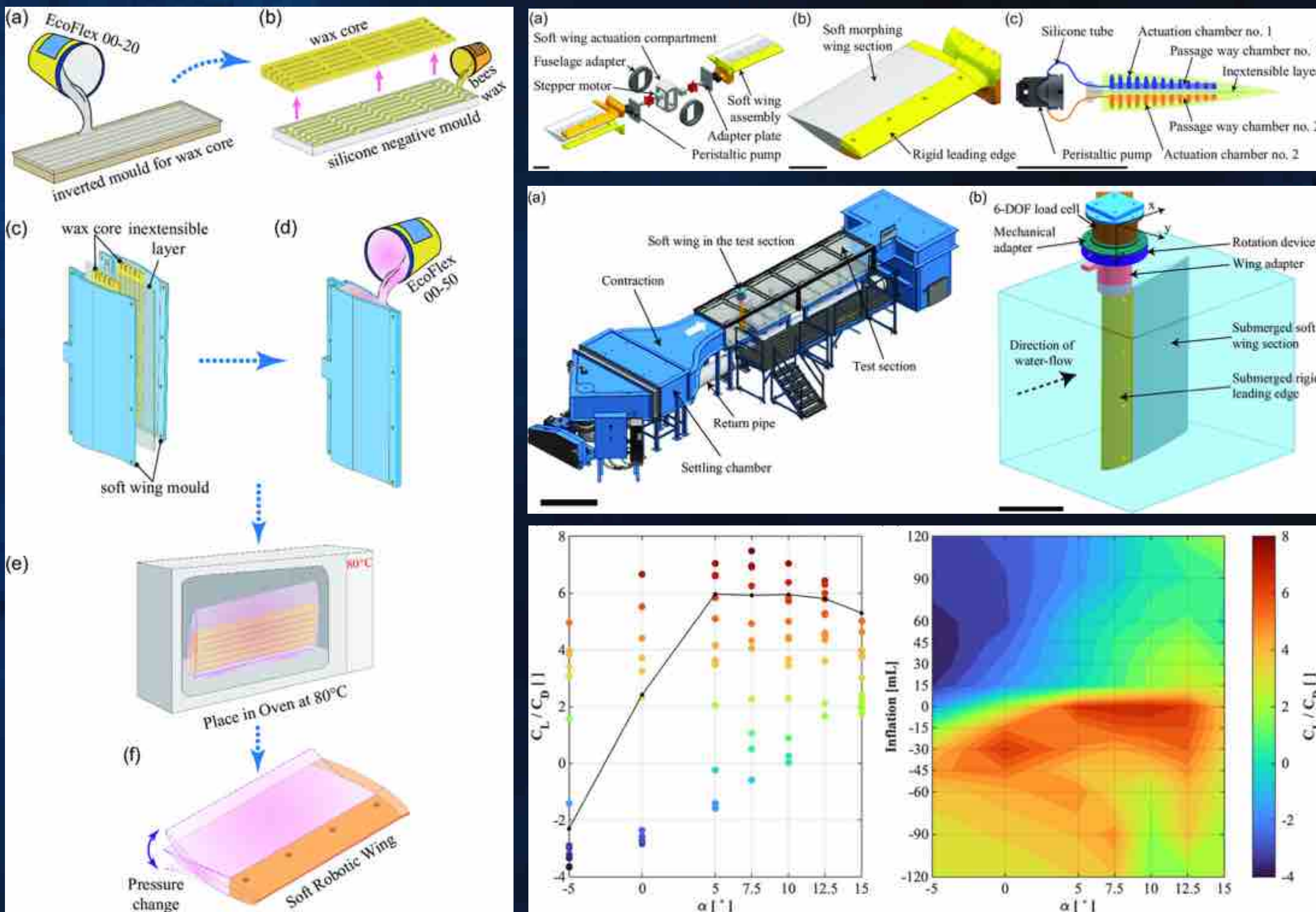
**ADVANCED
INTELLIGENT
SYSTEMS**



Giordano, A., Achenbach, L., Lenggenhager, D., Wiesemüller, F., Vonbank, R., Mucignat, C., Tristany Farinha, A., Nguyen, P.H., Katzschmann, R., Armanini, S.F., Lunati, I, Song, S., and Kovac, M. (2024). Advanced Intelligent Systems [Cover].

Soft Robotic Wing for hydrobatics

ADVANCED INTELLIGENT SYSTEMS



Giordano, A., Achenbach, L., Lenggenhager, D., Wiesemüller, F., Vonbank, R., Mucignat, C., Tristany Farinha, A., Nguyen, P.H., Katzschmann, R., Armanini, S.F., Lunati, I, Song, S., and Kovac, M. (2024). Advanced Intelligent Systems [Cover].

MEDUSA: A multi-environment dual robot

eawag
aquatic research ooo

Empa

Development of integrated water quality sensing solutions for mobile in-situ sensing

Zufferey, R., Ortega, A., Raposo, C., Armanini, S., Farinha, A., Siddall, R., Barasaluce, I., Zhu, H., Kovac, M. (2019) *IEEE Robotics Automation Letters*



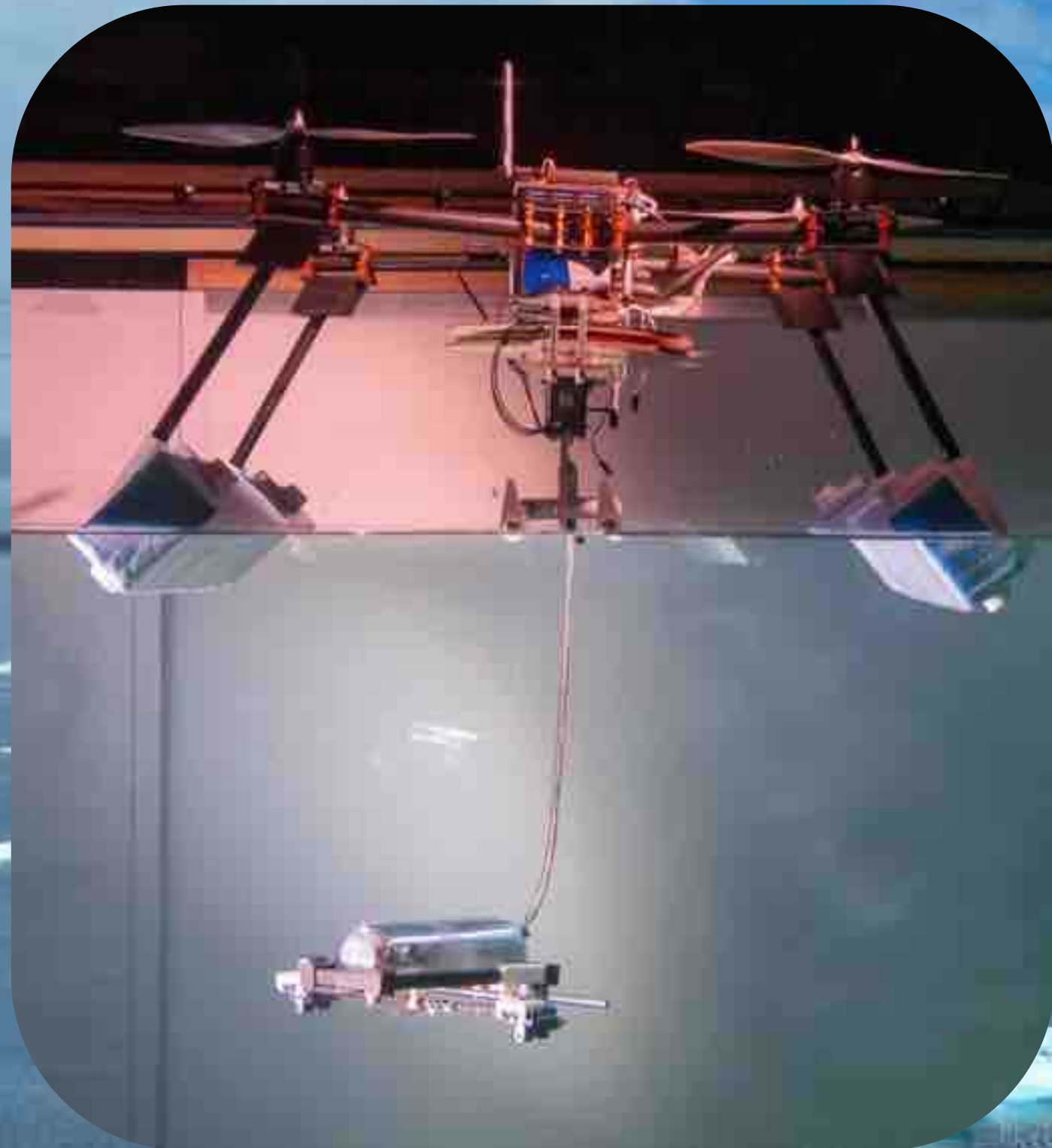
MEDUSA:
a Multi-Environment
Dual-Robot



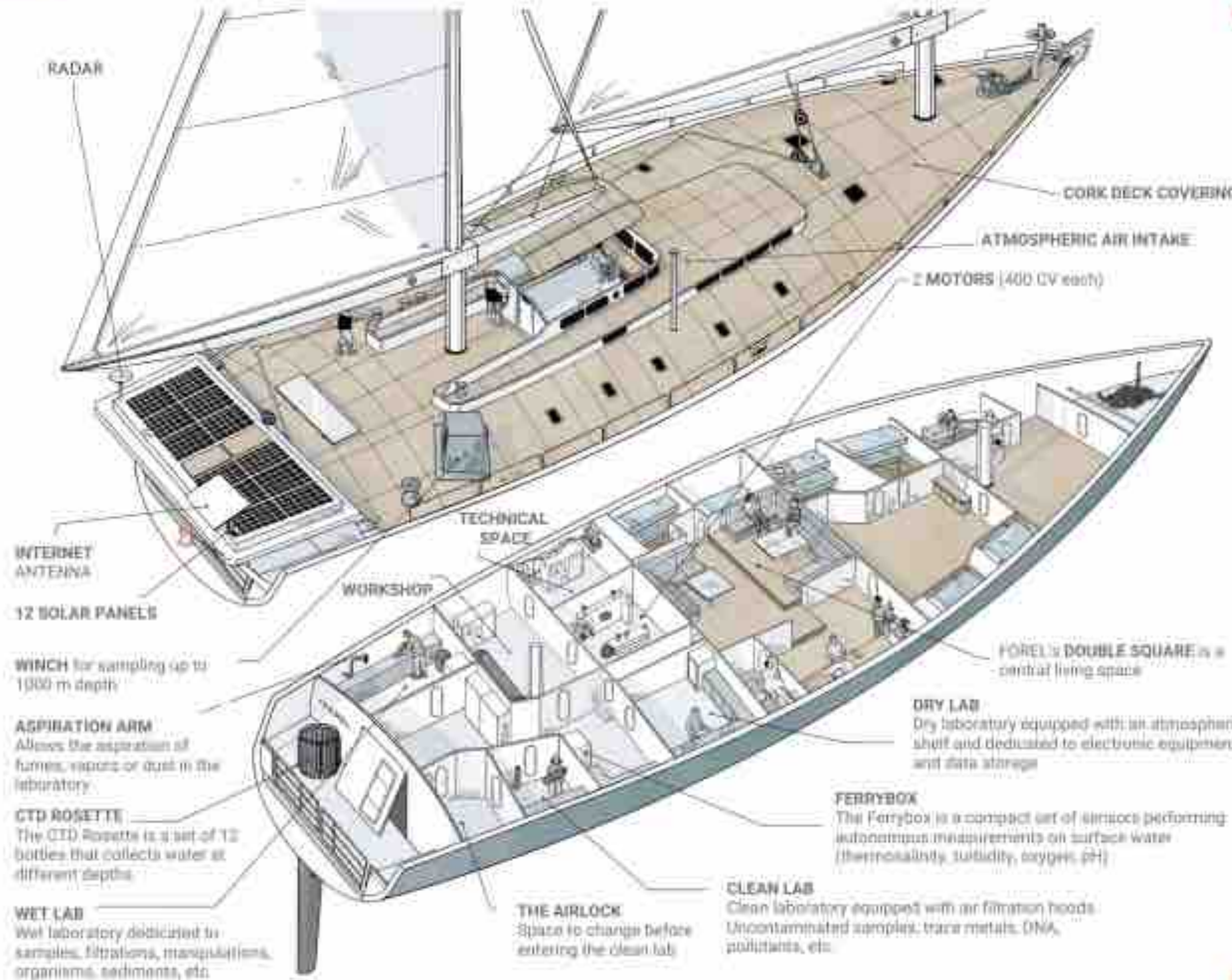
Farinha, A., di Tria, J., Reyes, M., Rosas, C., Pang, O., Zufferey, R., Pomati, F., Kovac, M., *Frontiers in Environmental Science* (2022)

eDNA monitoring in Greenlandic fjords

EPFL
SWISS POLAR
INSTITUTE



The Forel Platform



Scientific equipment

Laboratories

Wet lab (8 m²)

- MilliQ water
- Laboratory articulated suction arms (hood Ø 350 mm)

Dry laboratory (5 m²)

- Stirring cabinet (27 L)

Clean laboratory (5 m²)

- Air extraction hoods (MAC 10 LEDC/STD) 2

SAS/storage room (3 m²)

General facilities

- Chemical cabinets (flame, acid and base)
- Refrigerator +3 to +16°C (558 L)
- Freezer -9 to -30°C (499 L)

- Air compressor
- Diving equipment (2 pers.)
- Oceanographic equipment

Oceanographic equipment

CTD

- CTD unit (SBE 25Plus)
- dO₂ (SBE-43)
- pH (SBE-18)

- CDOM
- PAR (SATPAR ICSW)
- Chlorophyll-a and Turbidity (ECO-FLNTURD)

Rosette

- Rosette 1018 General Oceanics
- Niskin 8L bottles (12)

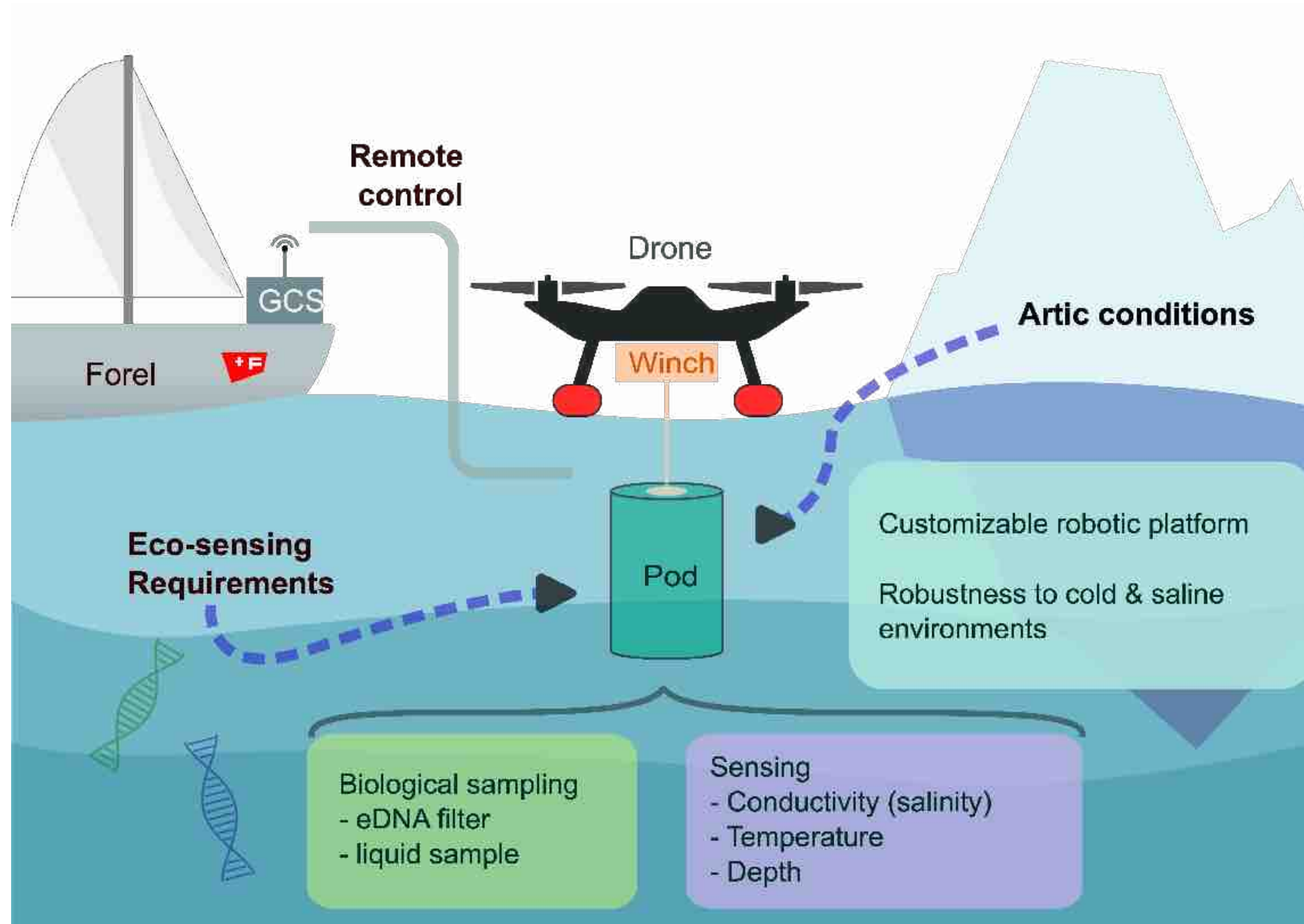
Ferrybox

- OceanPack™ Classic (SubCtech)
- Thermosalinograph (SBE-45)
- Water inlet temperature sensor (SBE-38)
- Oxygen (AADI 4835, Optode 4835)
- pH (SubCtech)

- Chl a (Trios NanoFlu)
- CDOM (Trios NanoFlu)
- Turbidity (STM 880nm)
- Ocean view (Outdoor Notebook)

Depth monitor: ScanMar SS4

MEDUSA System Overview



GCS: Ground Control Station (Drone pilot)

Custom sampling pod

Pod features

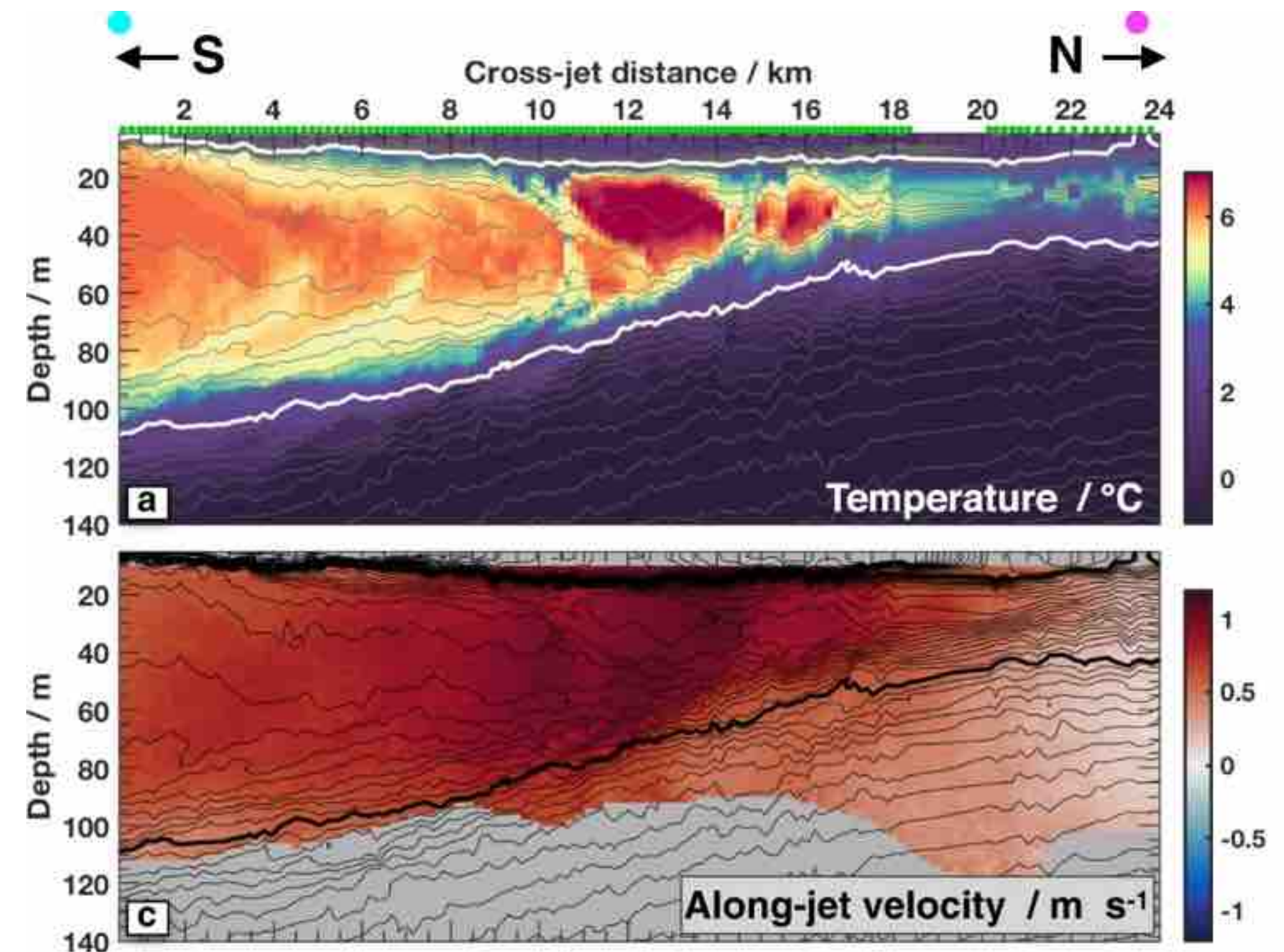
- Sampling
 - eDNA filter, water extraction
 - *Samples only at targeted depth*
- CTD measurements
 - Conductivity, temperature, depth
- Lightweight – only 1.8 kg
 - Lighter than commercial CTDs
 - Completely custom; including PCB



Environmental Challenges

- Unknowns about polar regions and fjords conditions
 - Reliability of system in brackish, cold water
 - Need extensive field testing before landing drone beyond retrieval
 - E.g., close to glaciers
- Need to characterise:
 - Drone surface movement vs weather conditions
 - Drone surface vs underwater current conditions
 - Different lengths of pod
 - How subject to currents? Tides?
- Other unknowns
 - Other environmental events which could effect drone flight?
 - Polar heat bombs cause high currents?¹

1) <https://www.nature.com/articles/s41467-021-22505-5>



Measuring the Arctic is challenging



Future / ongoing Projects

Forel

2026 – Greenland
2027 – Antarctica?



Tara Polar Station

2027 – Arctic (Summer + Winter)



LéXPLORE

2026 – Fully Automated station



Forel



Helikite



Aerial
measurements

MEDUSA



Disturbed
water

Undisturbed
water

Surface water
measurements

SailMAV
(Forel-lite)



Distant
measurements

Deep sea
measurements

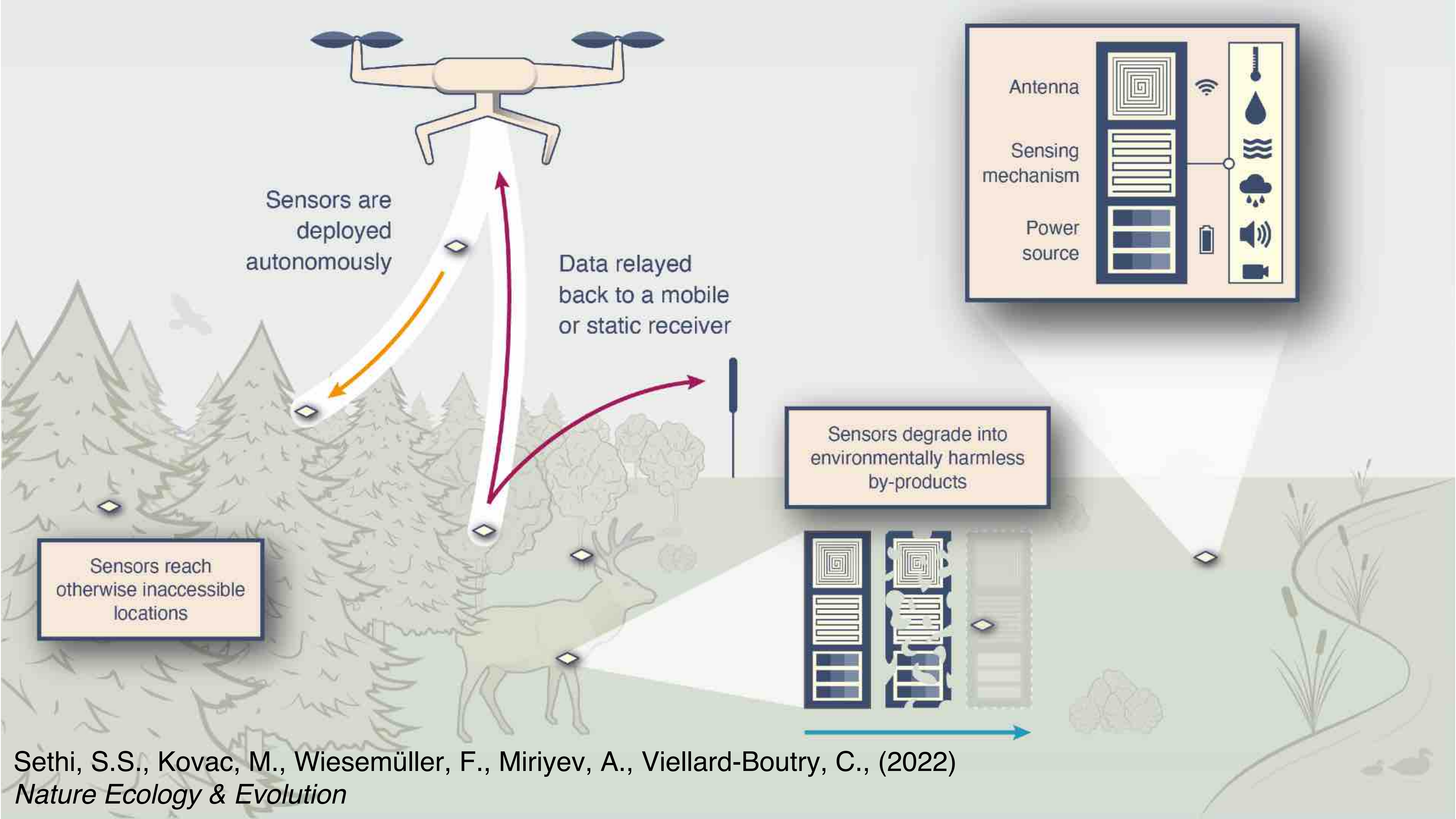
Vision: The Digital (Ant)Arctic

AIR

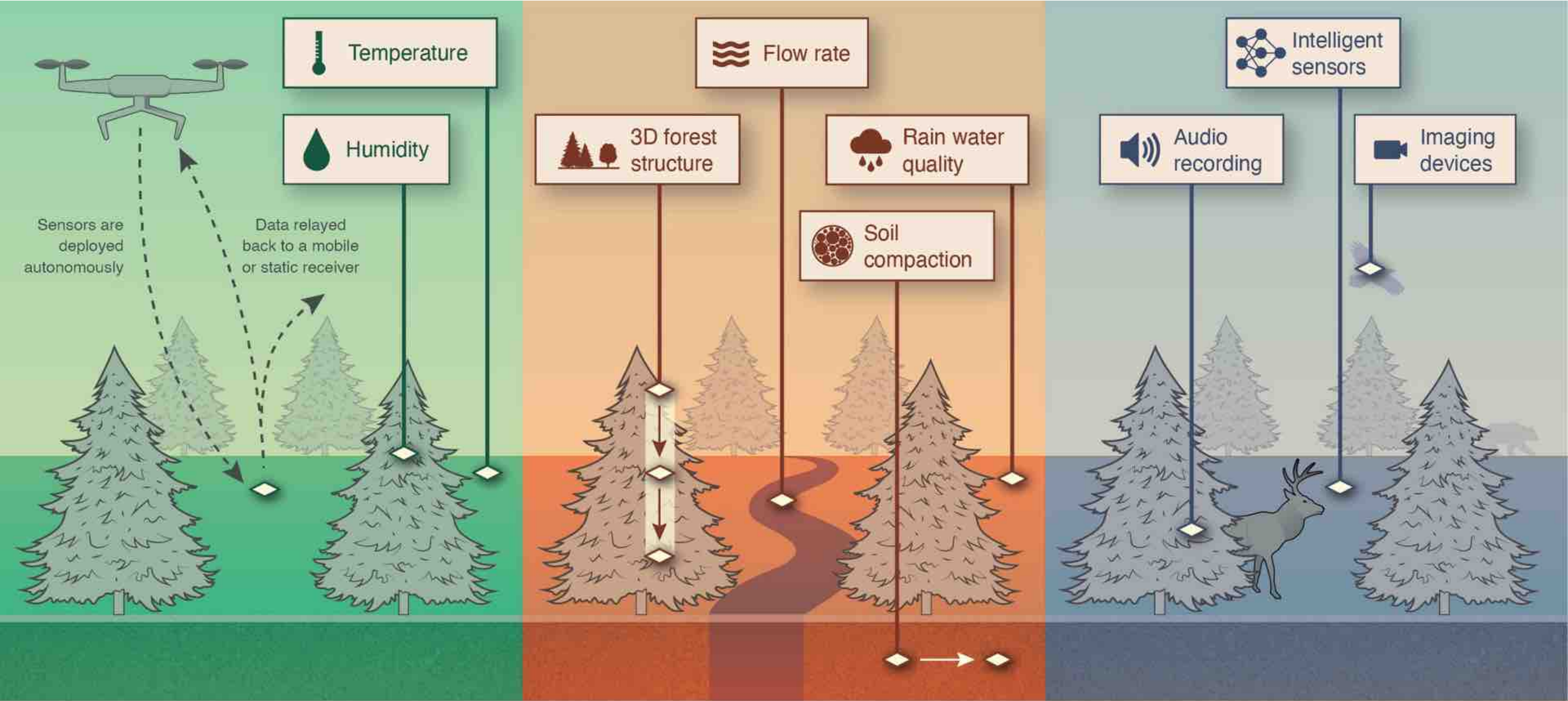




Illustration: Yusuf Kaya Furkan



Sethi, S.S., Kovac, M., Wiesemüller, F., Miriyev, A., Viellard-Boutry, C., (2022)
Nature Ecology & Evolution



Near future

Data transmission is refined

Mid-term

Advance placement, locomotion, and degradation strategies

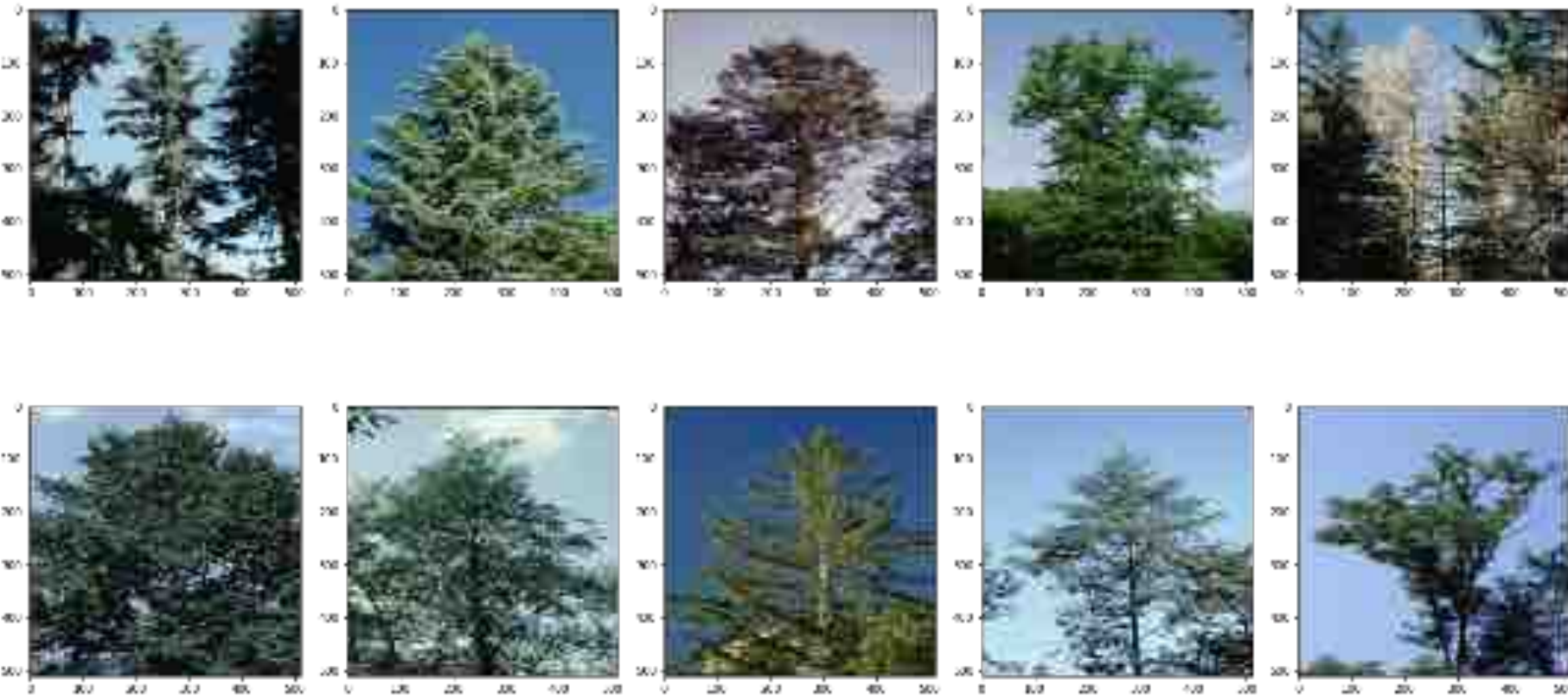
Long-term

Sensors match and surpass today's non-transient electronics

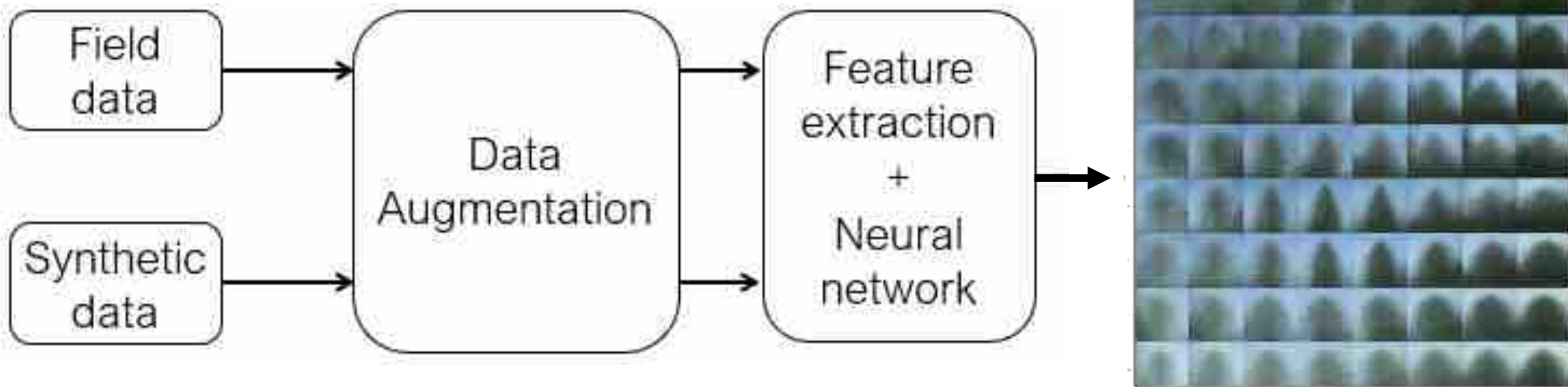
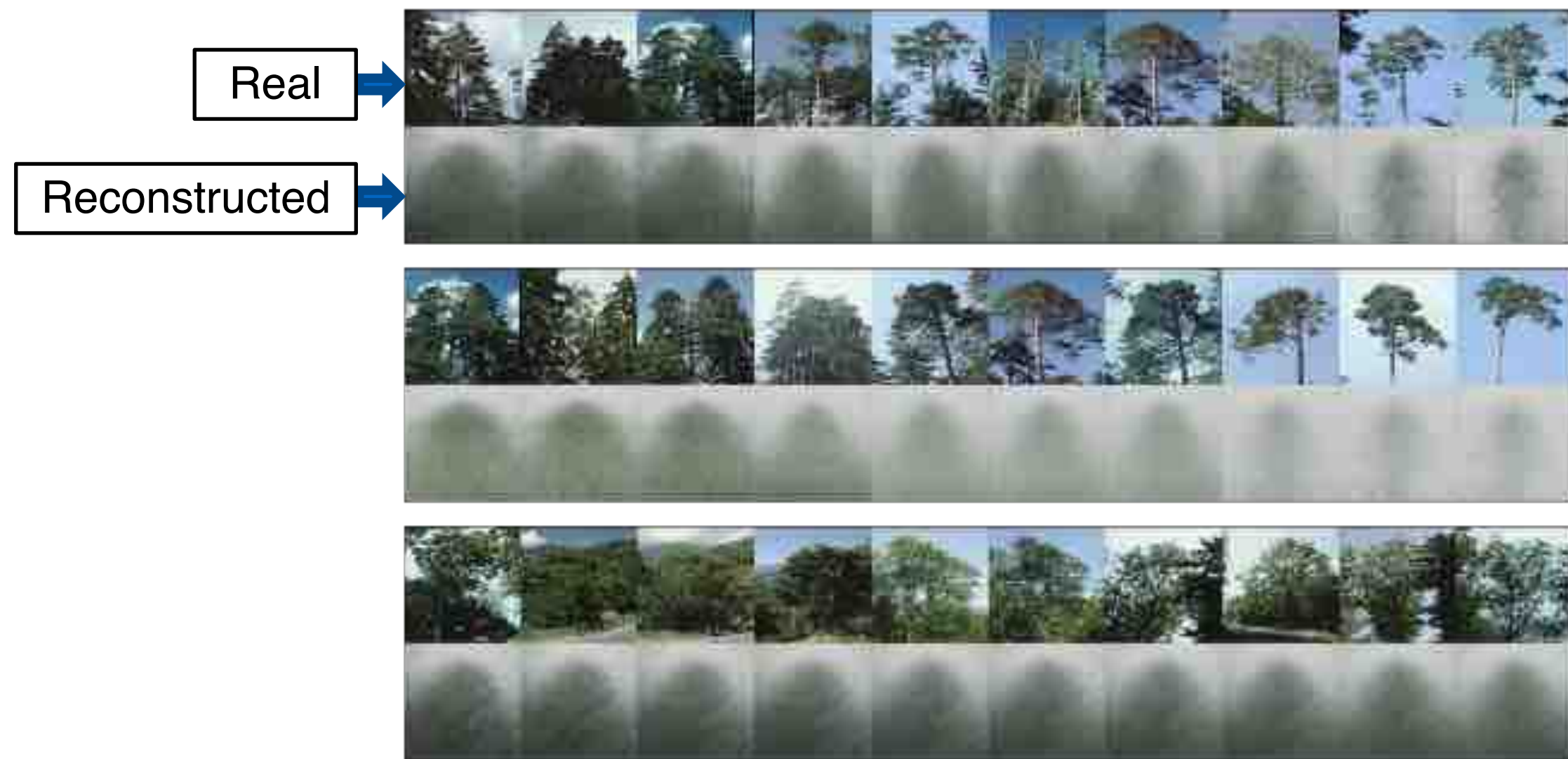
Sethi, S.S., Kovac, M., Wiesemüller, F., Miriyev, A., Viellard-Boutry, C., (2022)

Nature Ecology & Evolution

Autonomous crown loss estimation



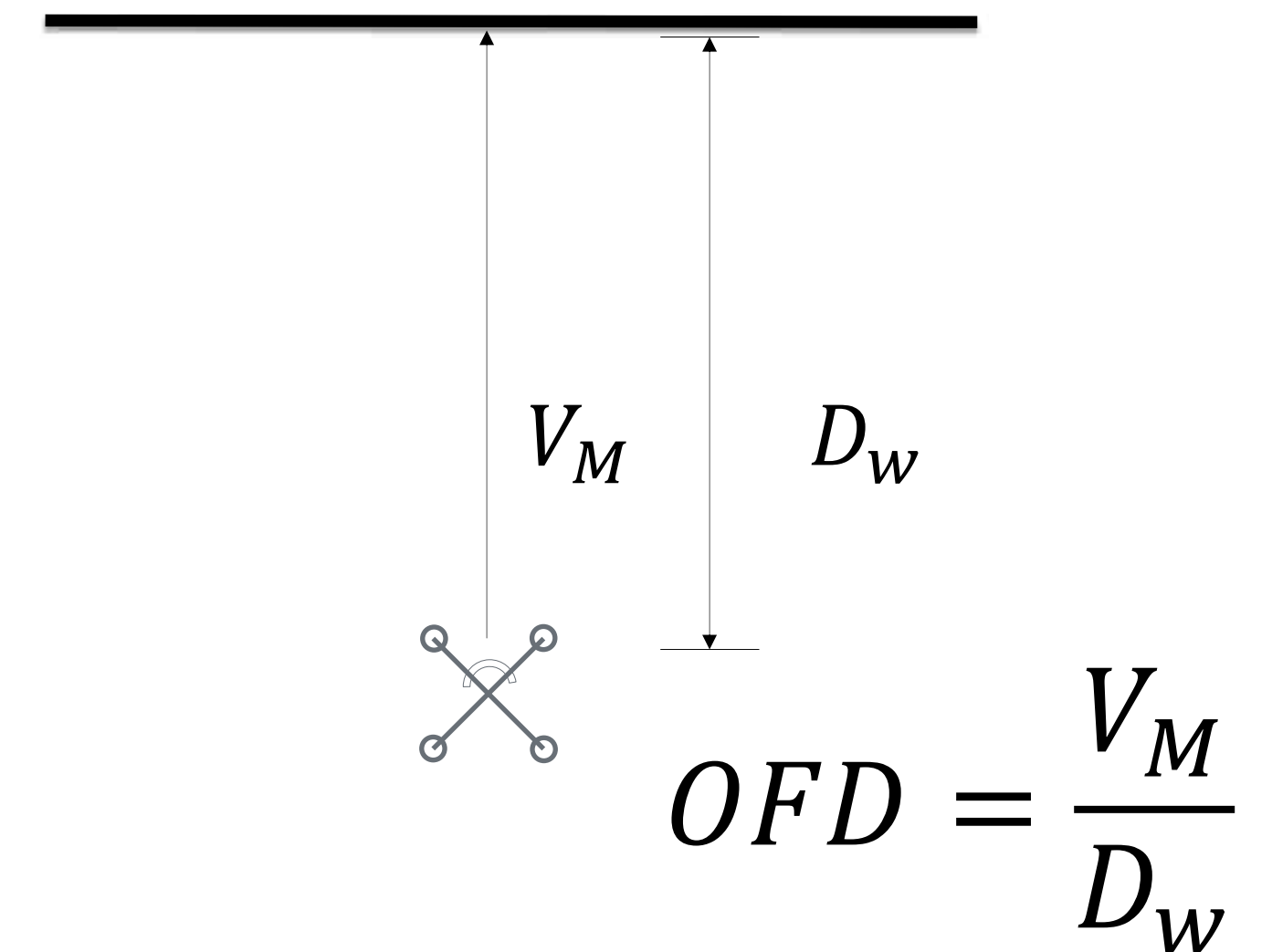
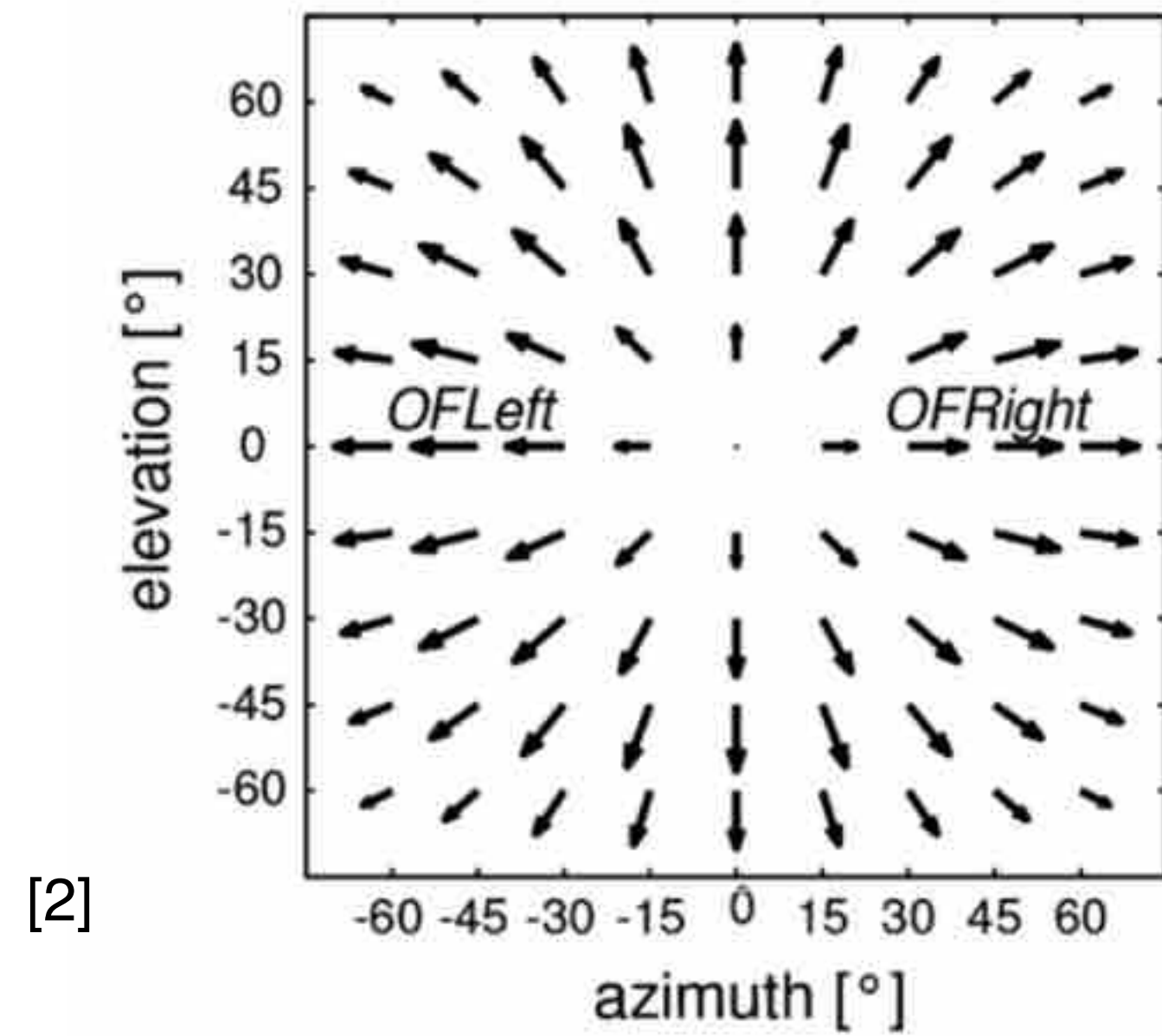
WSL tree dataset



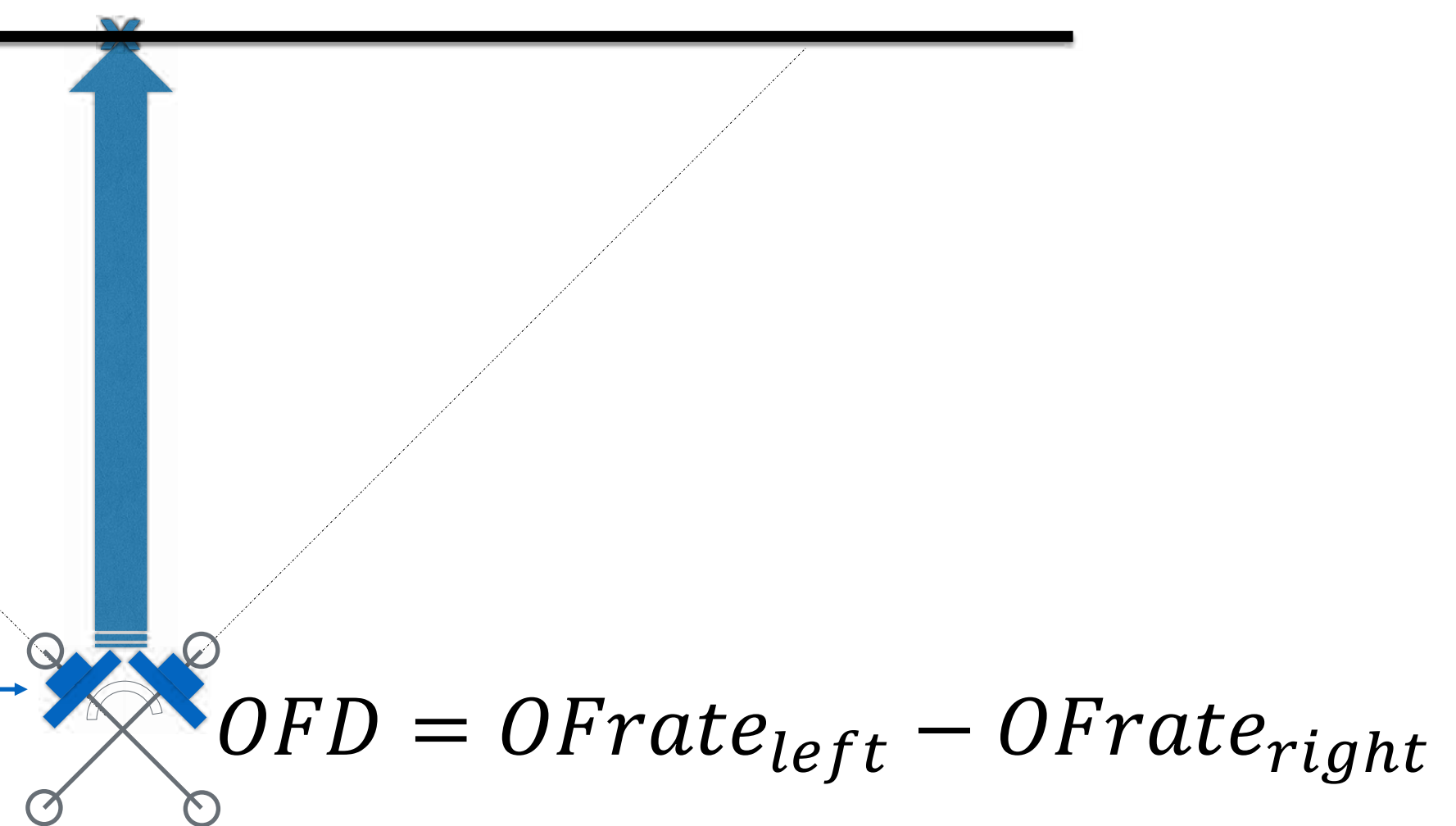
Density map (estimated)



Bio-inspired forrest flight autonomy

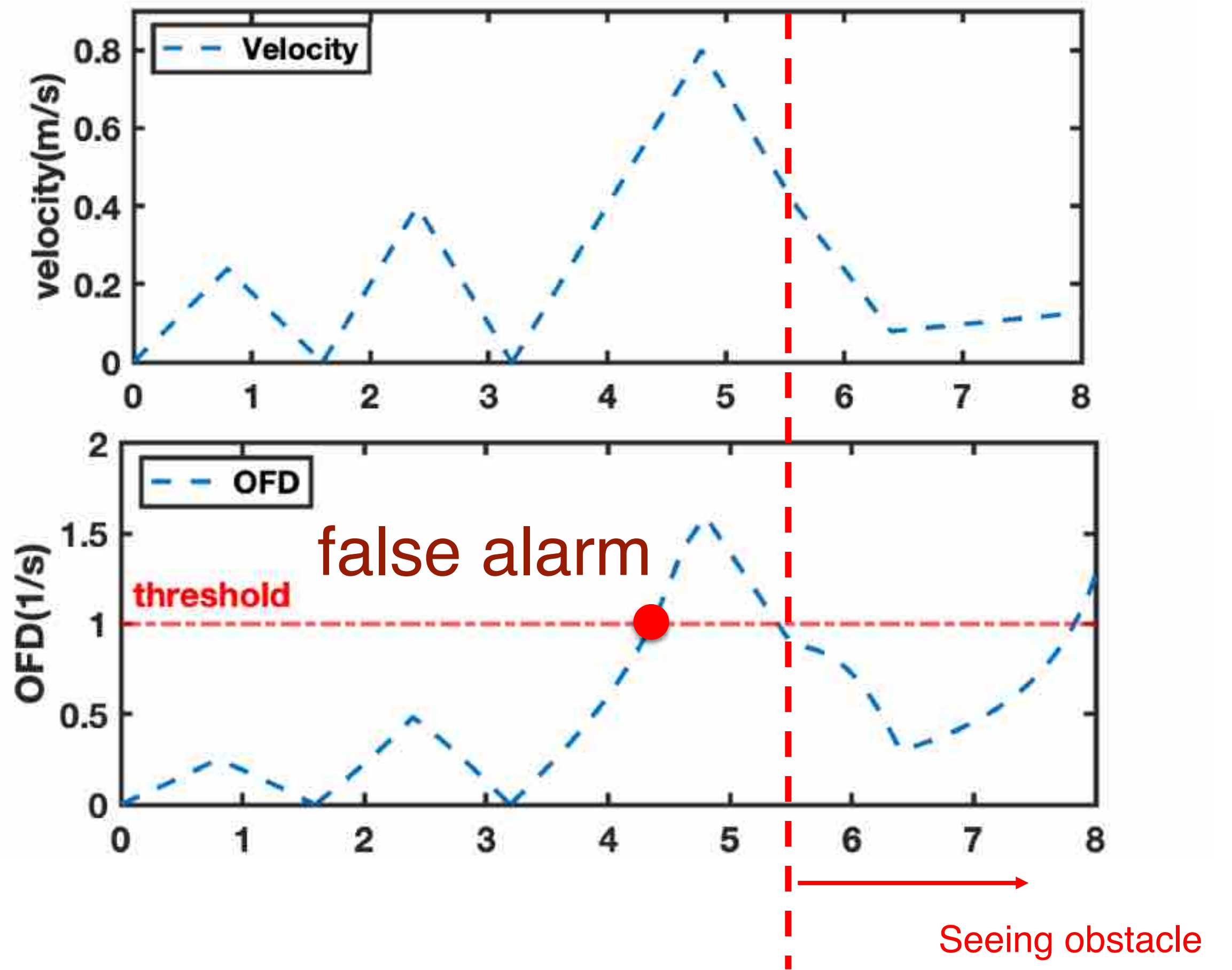
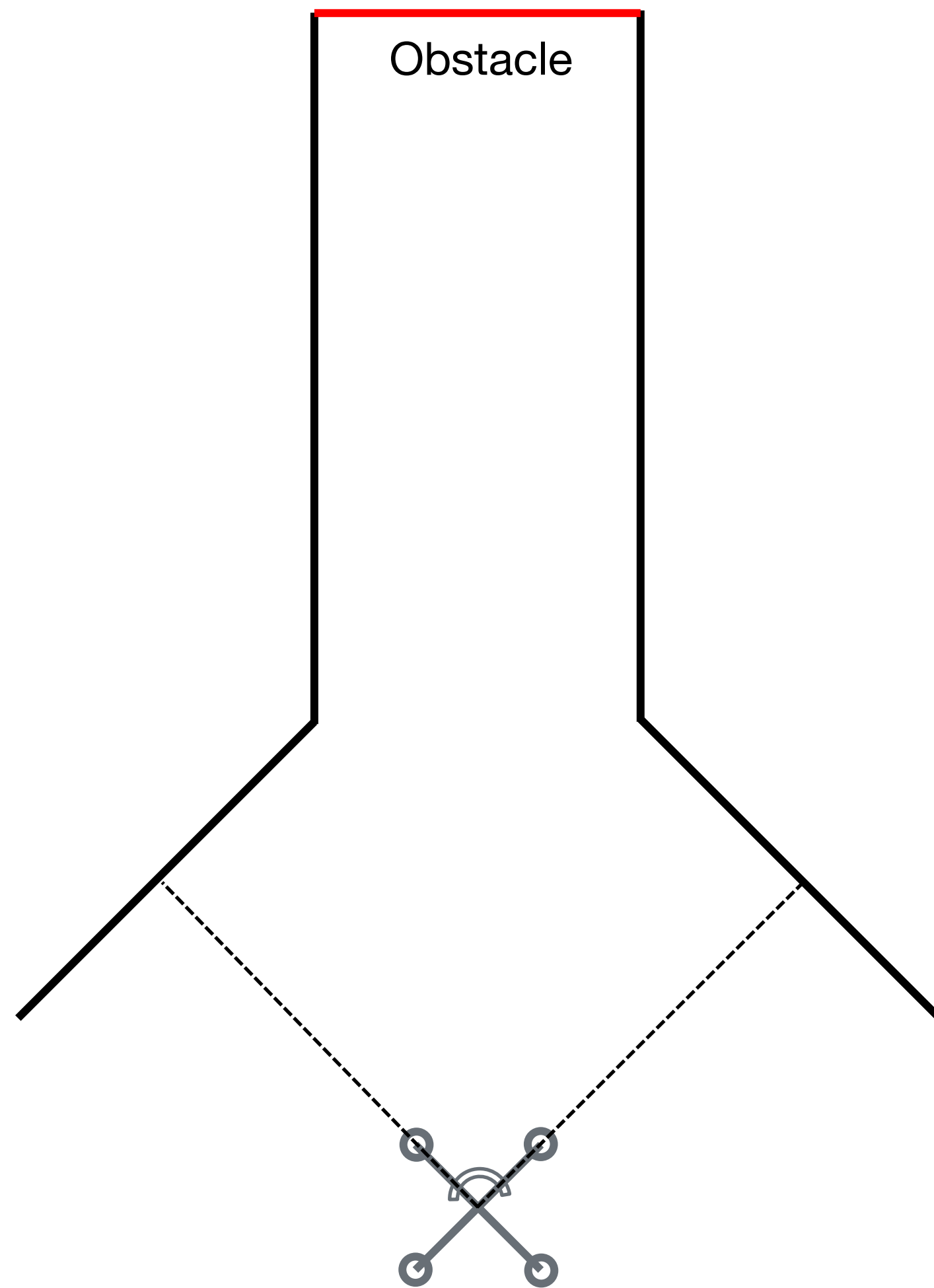


Divergent Optical Flow Pair (DOFP)



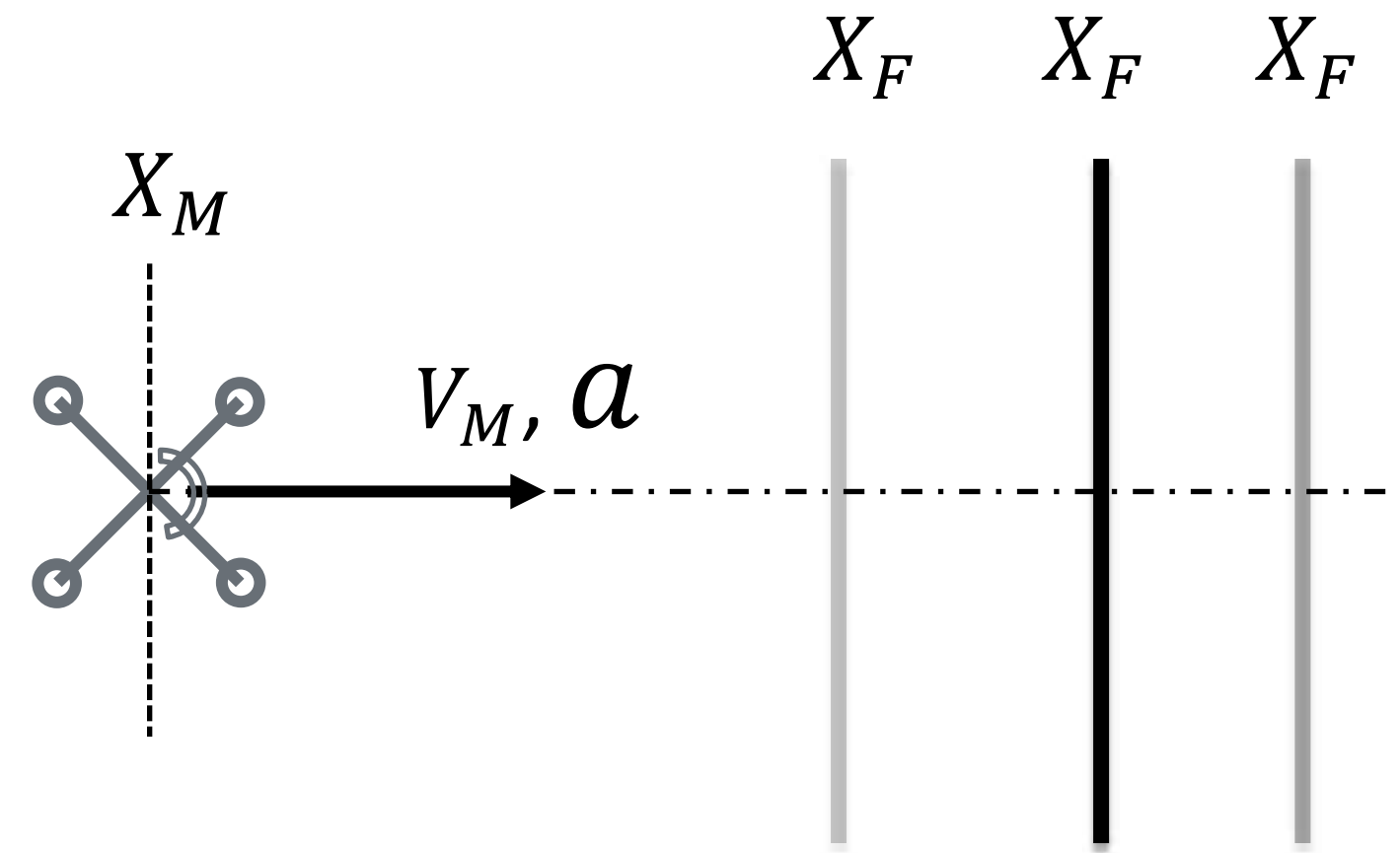
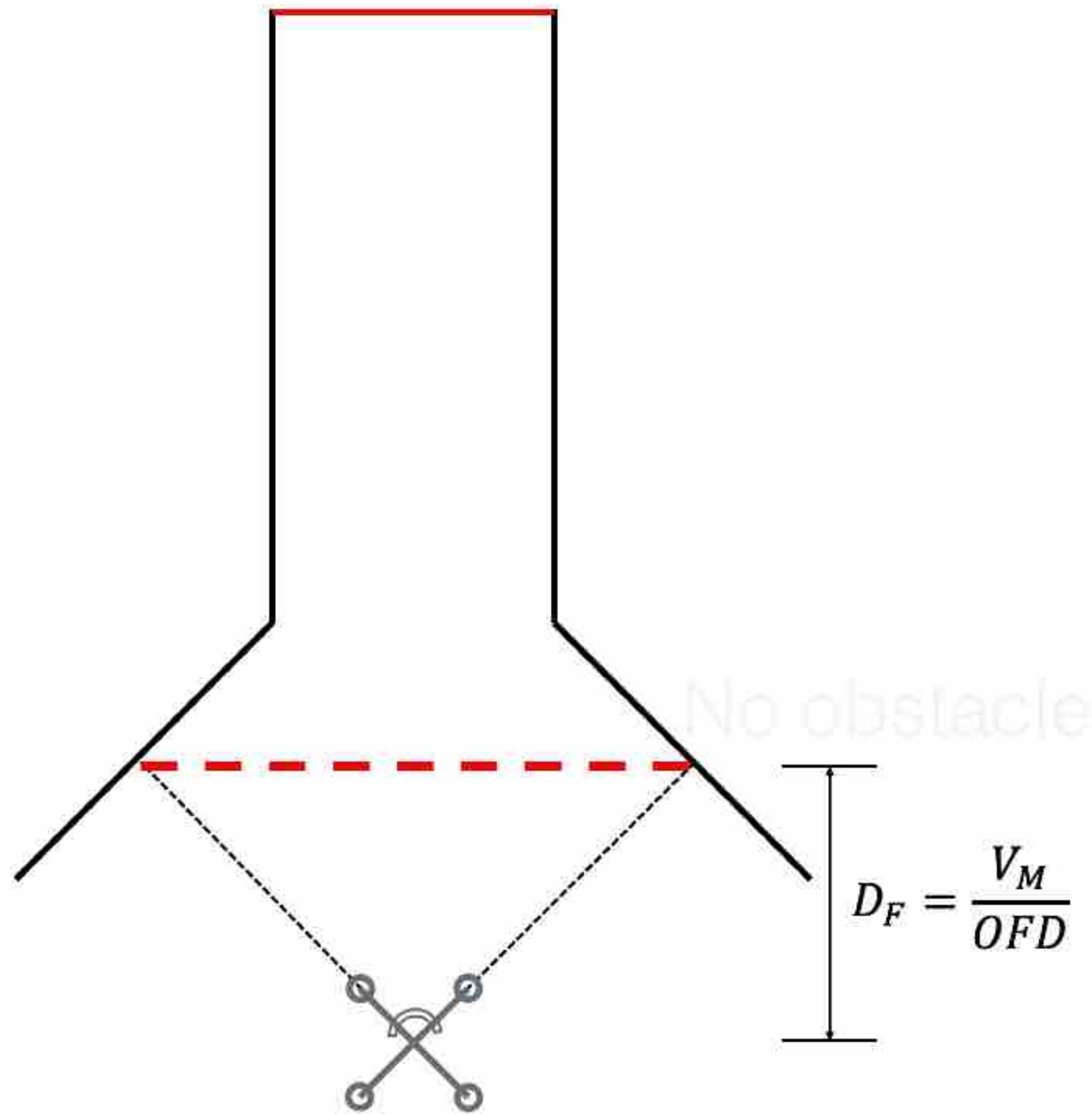
[1] Evangelista C, Kraft P, Dacke M, Reinhard J, Srinivasan MV (2010) The moment before touchdown: Landing manoeuvres of the honeybee *Apis mellifera*

Constant OFD threshold could give false alarm



$$OFD = OFrate_{left} - OFrate_{right}$$

Fictitious wall hypothesis



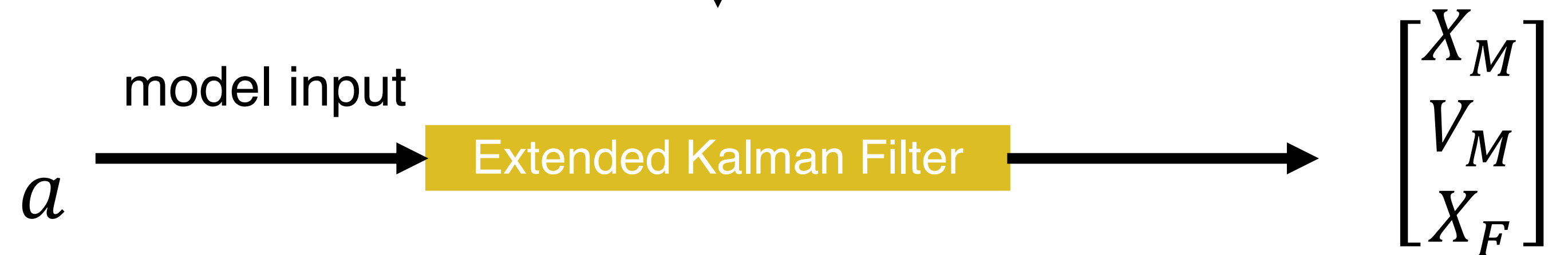
State vector: $x = [X_M \quad V_M \quad X_F]^T$

System model: $\dot{x} = [V_M \quad a \quad 0]^T$

Observation model:

$y = OFD = V_M / X_F - X_M$

↓ OFD observation



Distance: $D_F = X_F - X_M$





Xiao, F., Kovac, M., et. al. (in revision)

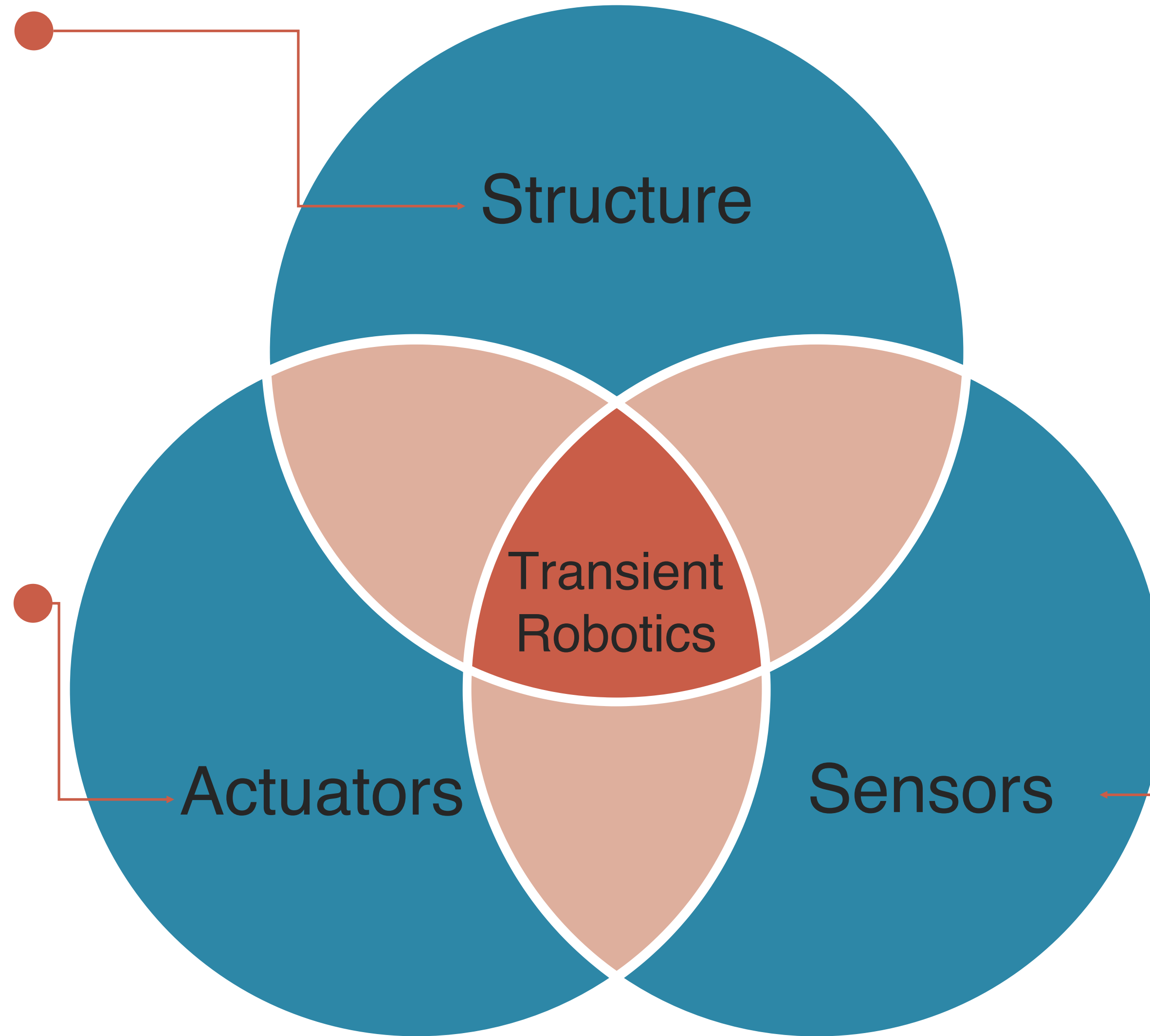
Transient Robotics

Structural materials

- Lightweight, high strength biodegradable structures (cryogels, aerogels etc.)
- Biodegradable polymers (3D printing, casting, moulding)
- Incorporation of living cells

Actuating materials

- Electro thermal actuators
- Humidity responsive composites (swelling, bending etc.)
- Micro-organisms induces shape changes (e.g. bacteria growth)
- Eco-friendly electro active polymers (e.g. polypyrrole)



Sensing materials

- Biodegradable tactile sensors (e.g. strain)
- Biodegradable environmental sensors (e.g. temperature, humidity, UV)
- Carbon or transient metal (e.g. Zn, Mg, Fe) based electronics
- Degradable & eco-friendly chemical sensing (e.g. pH, micropollutants)

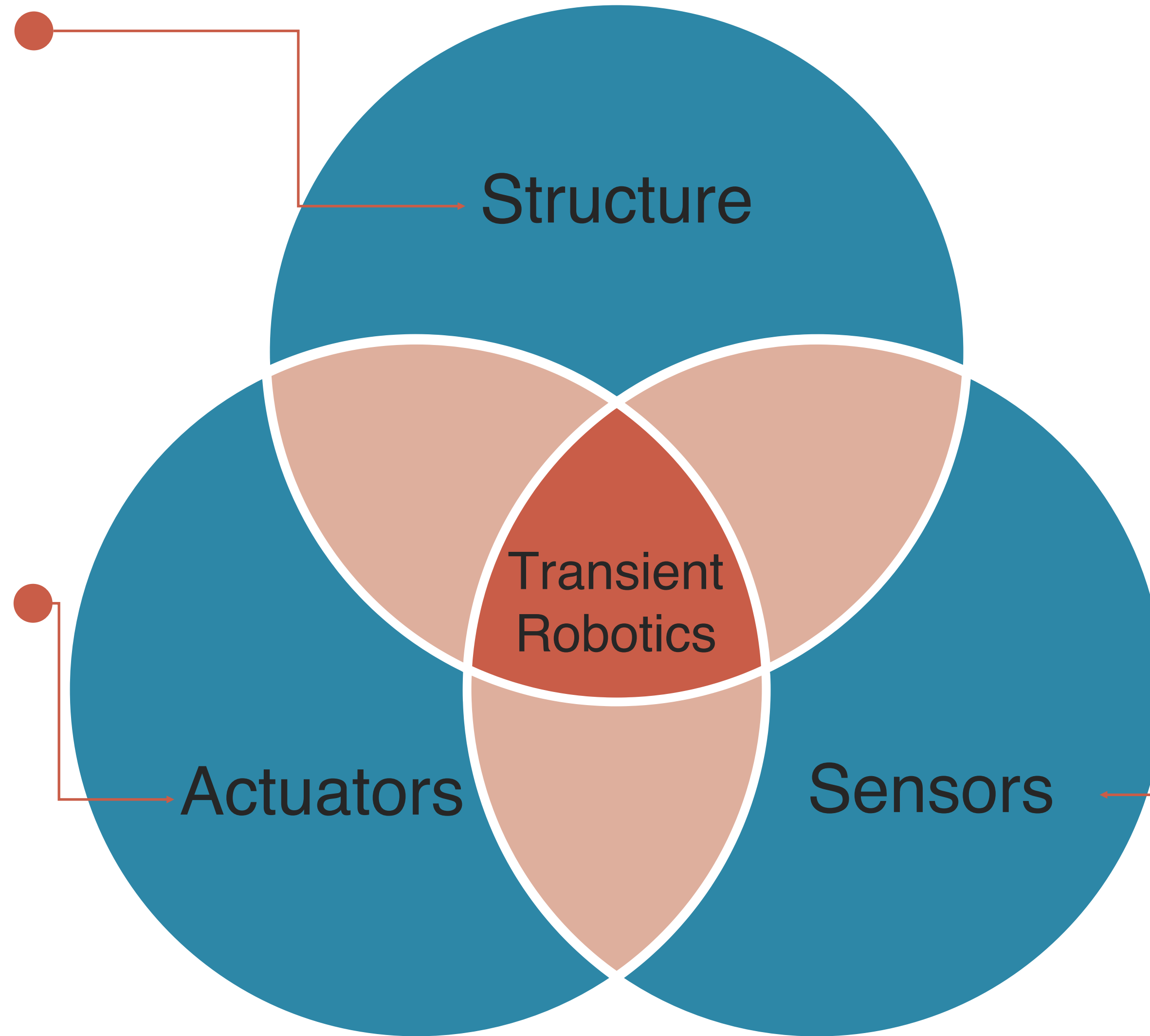
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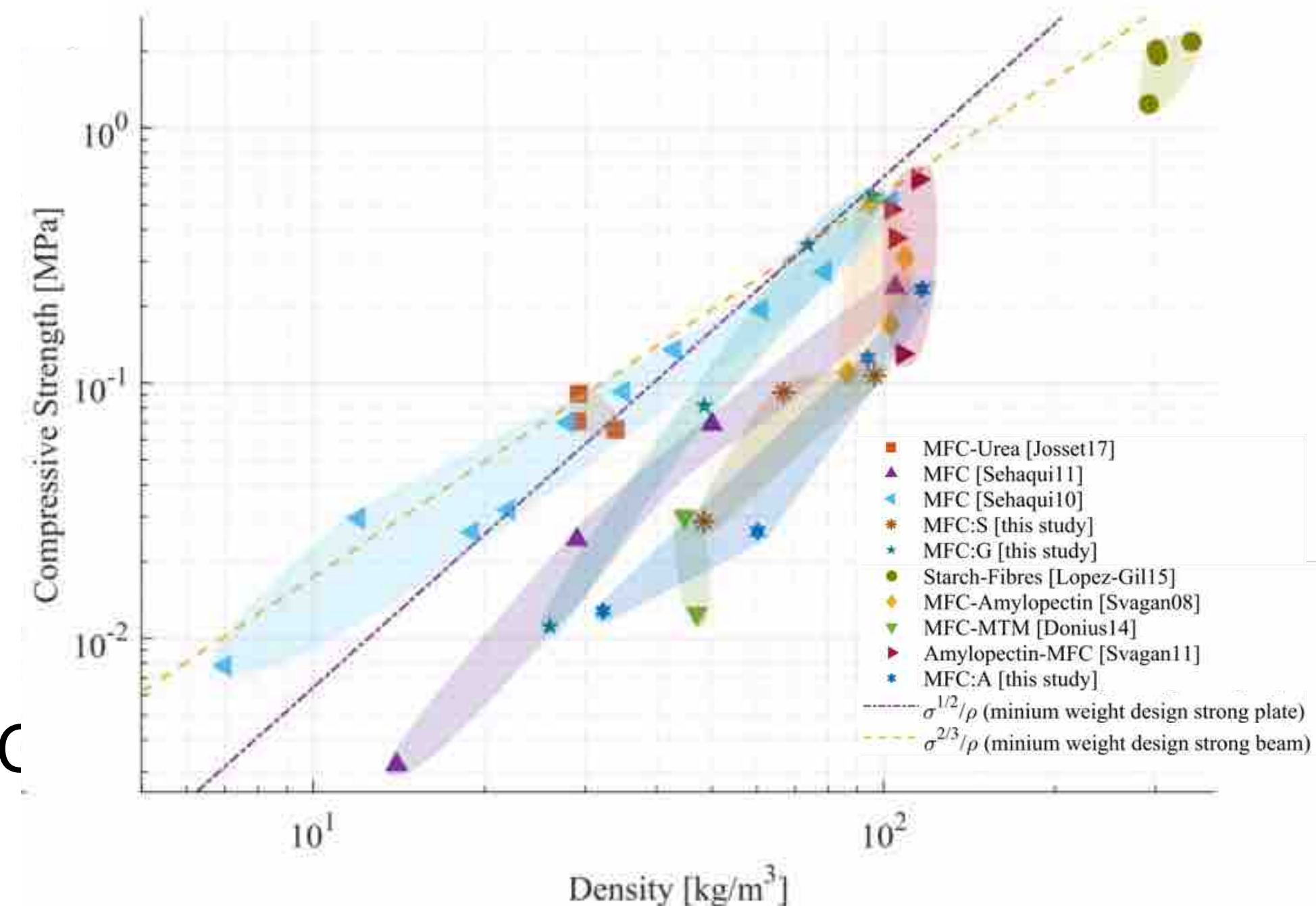
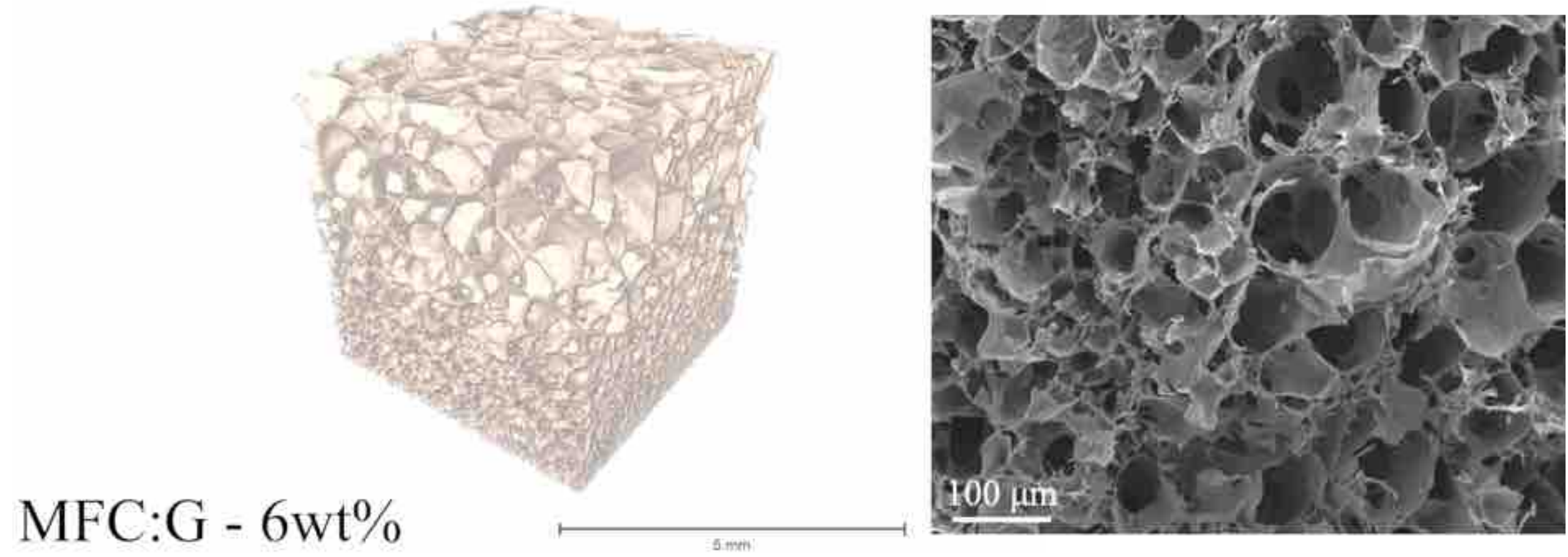
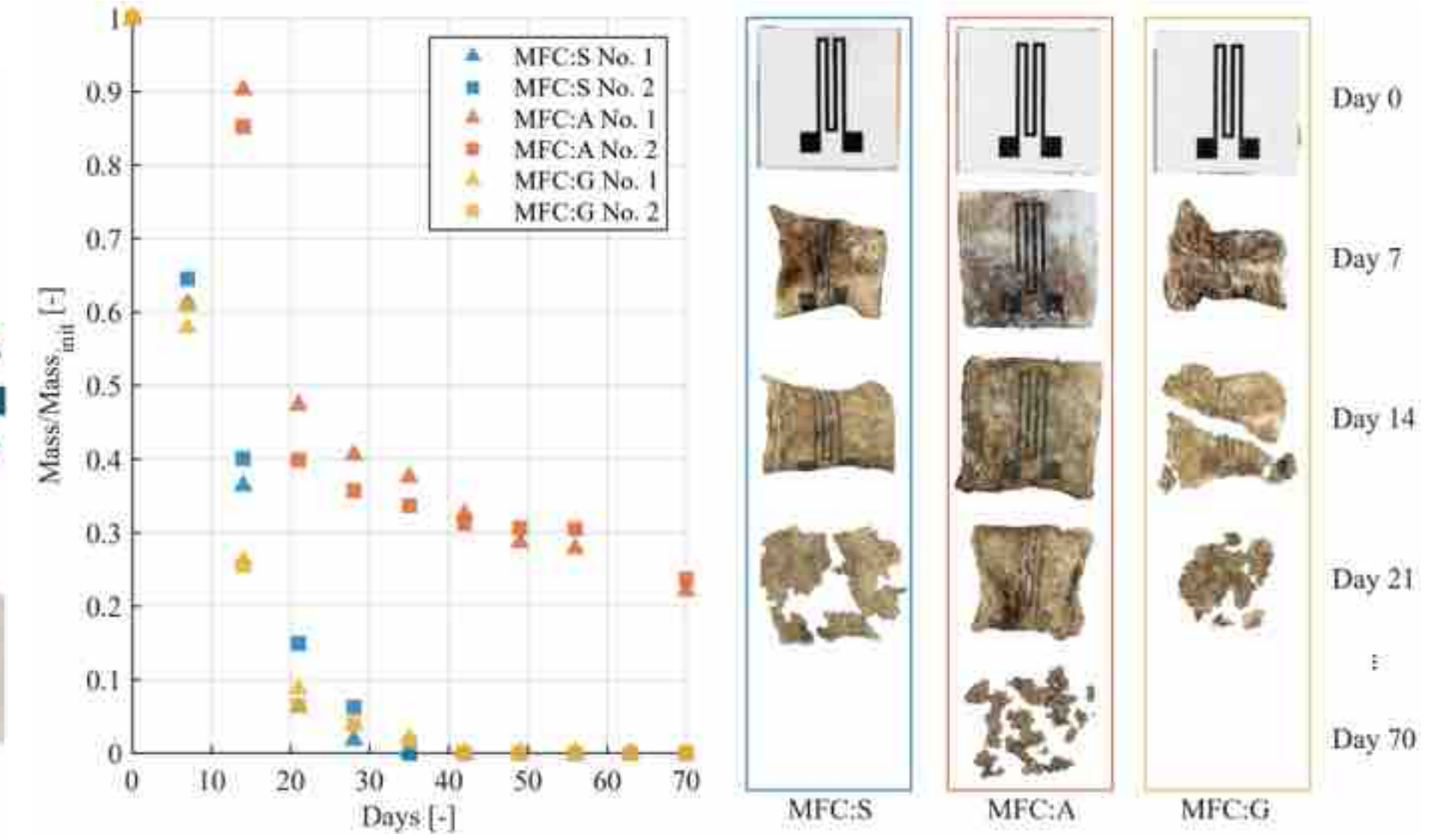
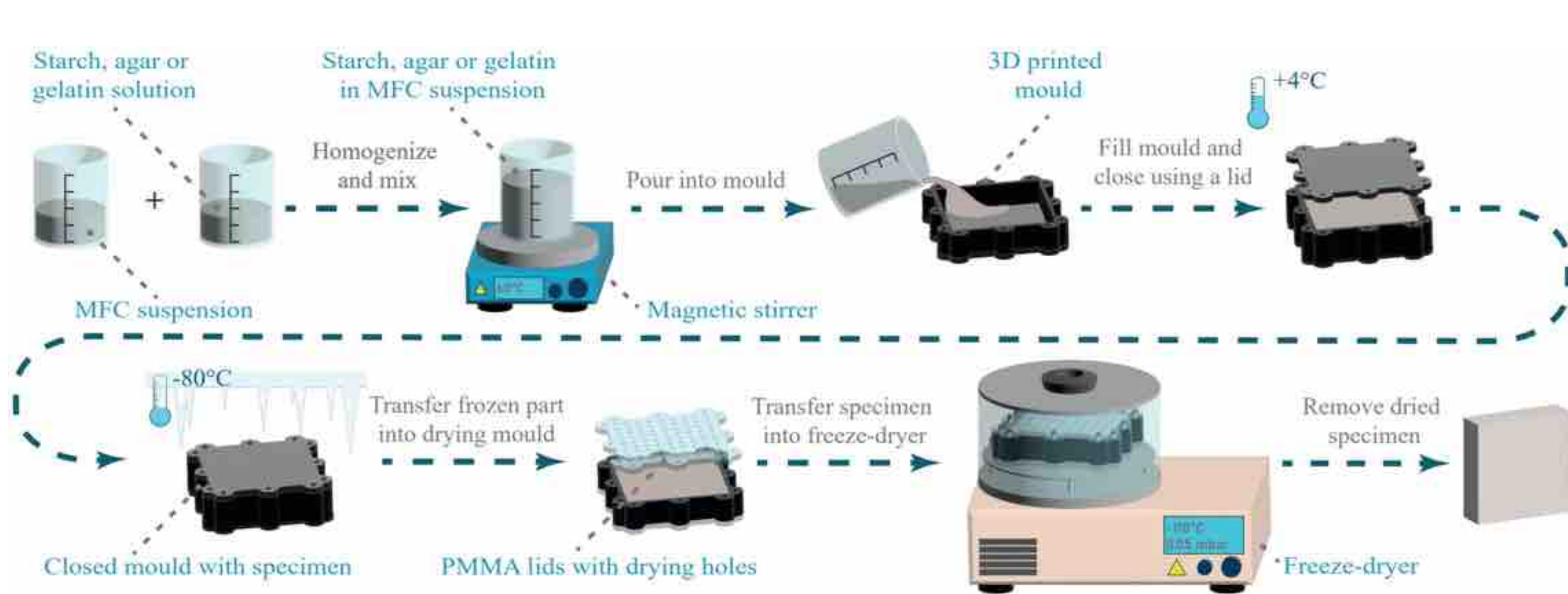
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Sensing materials

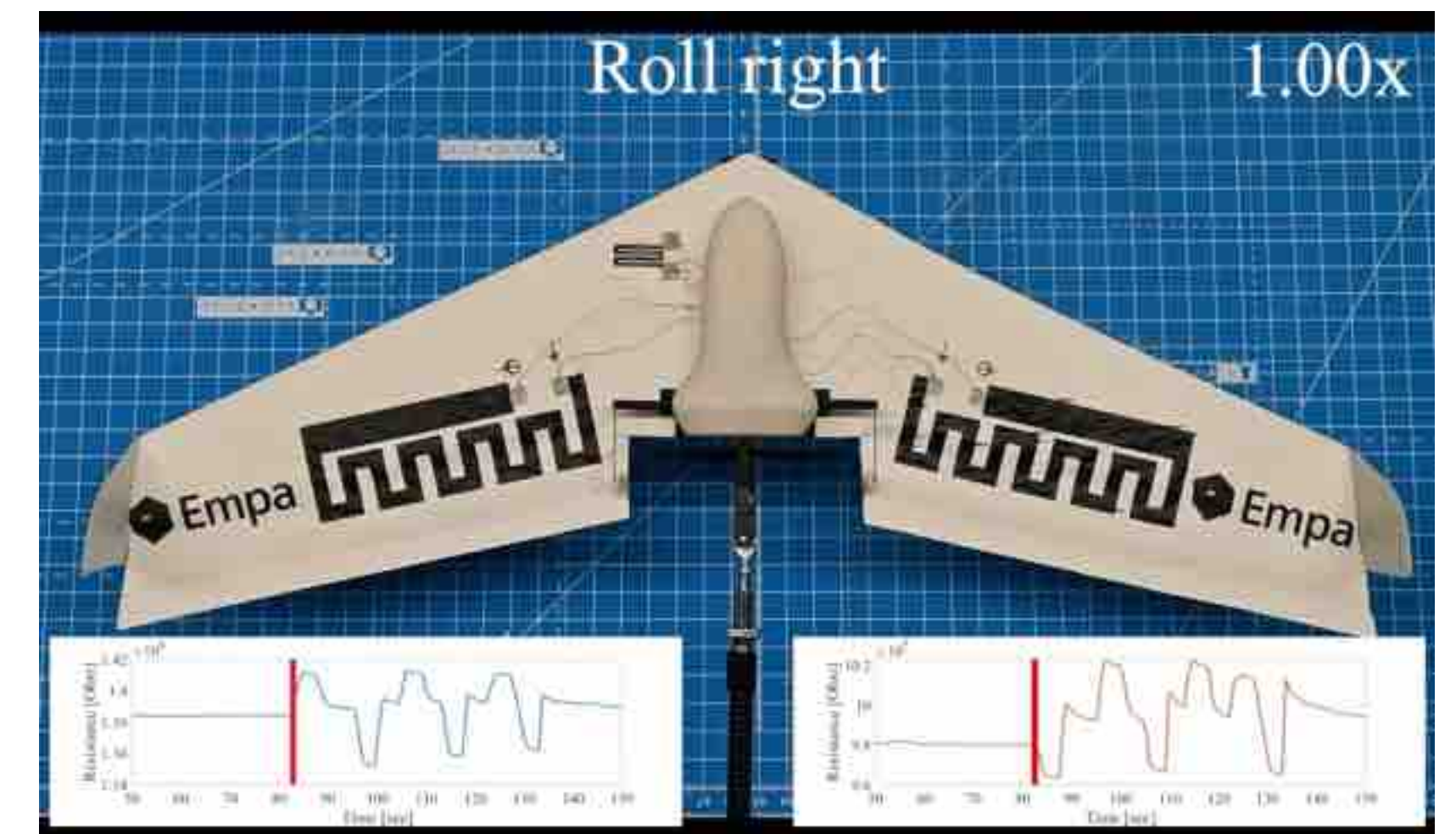
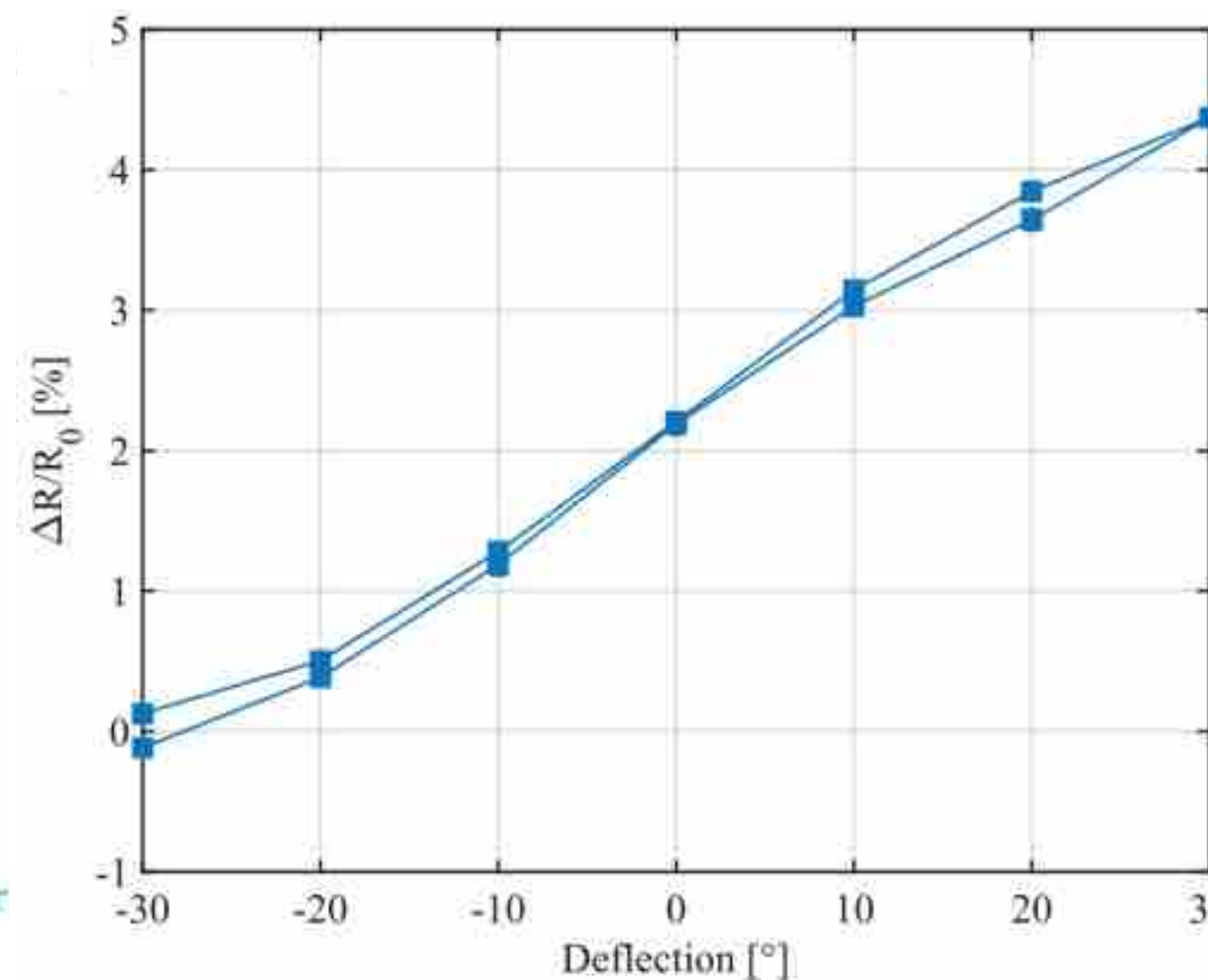
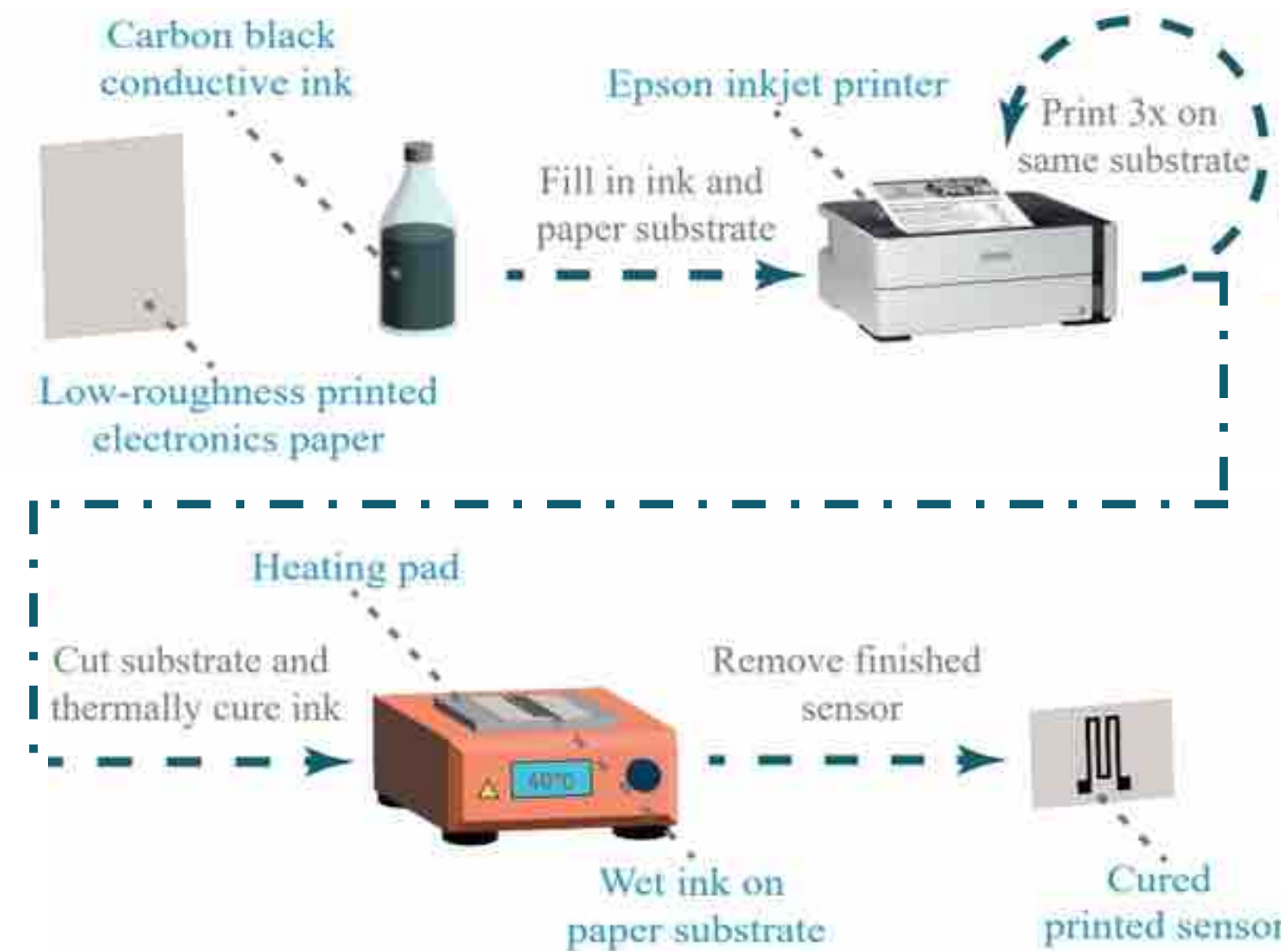
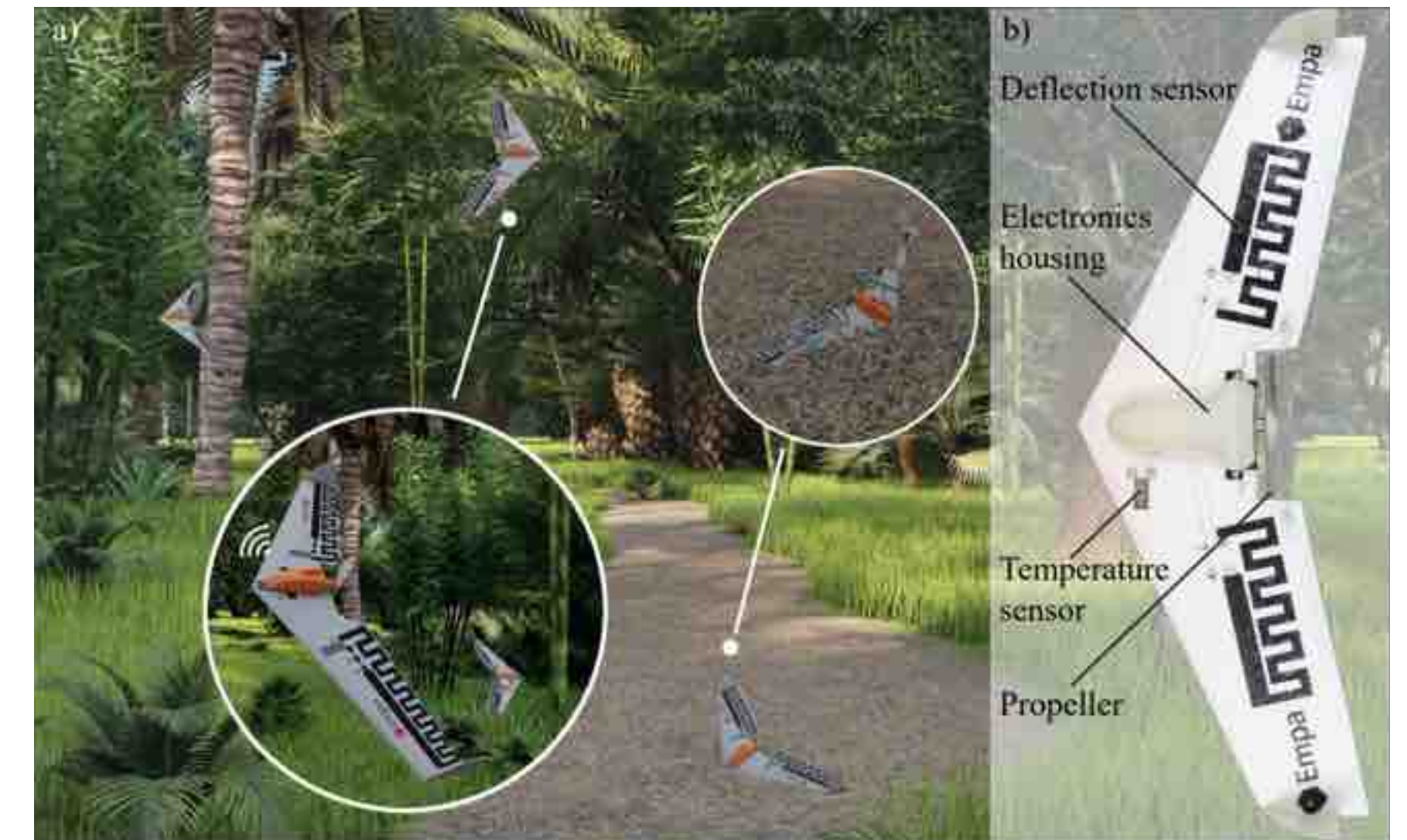
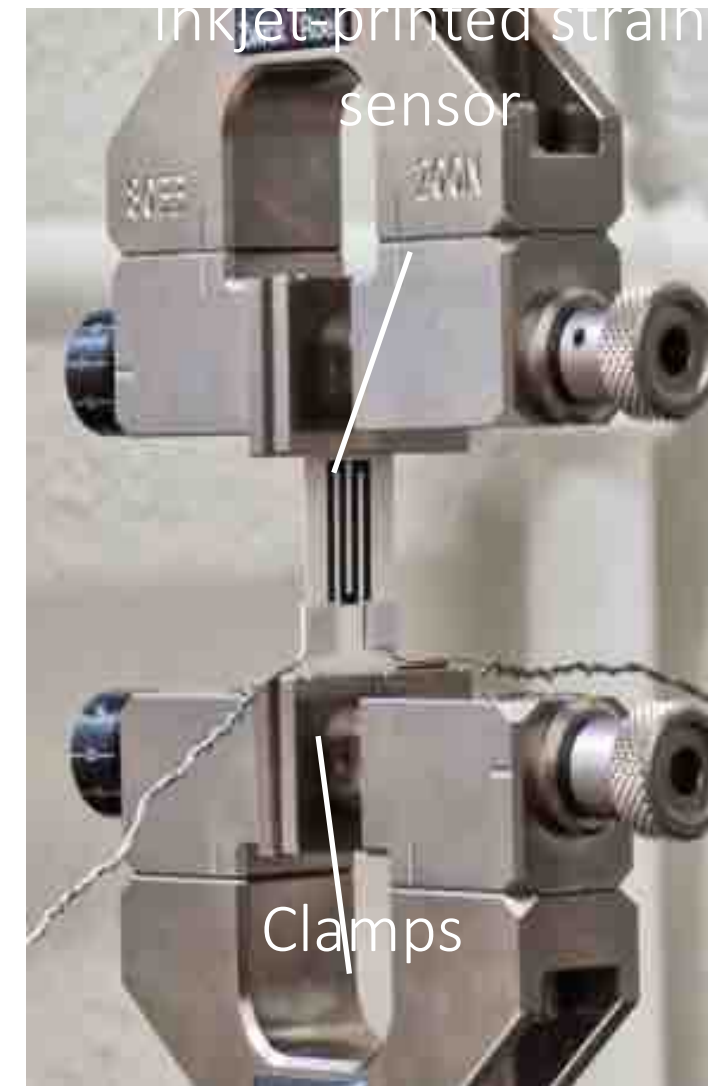
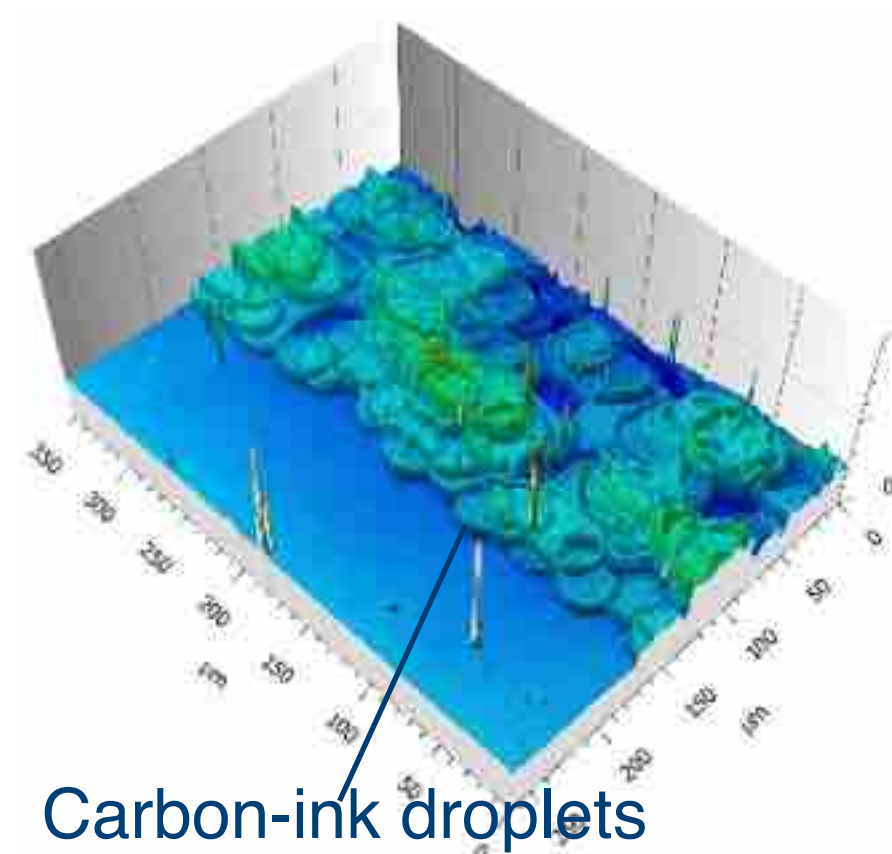
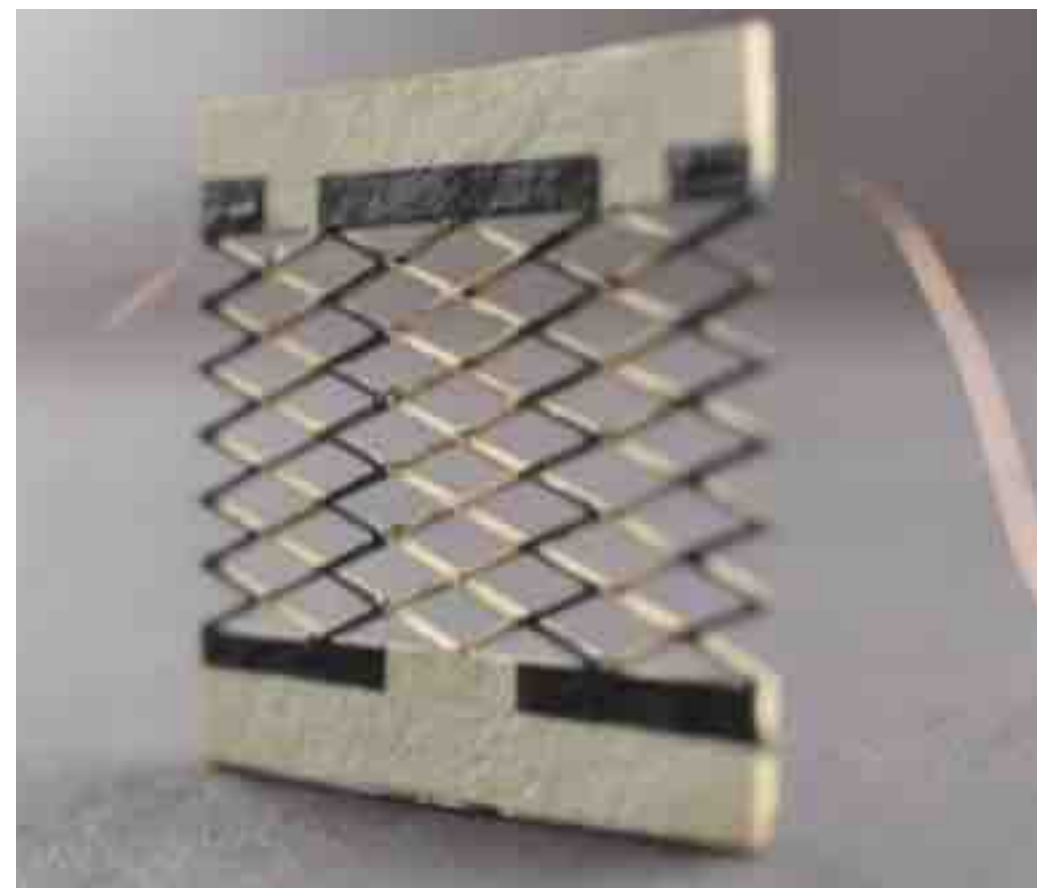
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- Carbon or transient metal (e.g. Zn, Mg, Fe) based electronics
- Degradable & eco-friendly chemical sensing (e.g. pH, micropollutants)

Structure: Cellulose composite cryogels



Wiesemüller, F., Meyer, S., Hu Y., Bachmann, D., Parrilli, A., Nyström, C
Kovac, M., (2023) *Advanced Intelligent Systems*

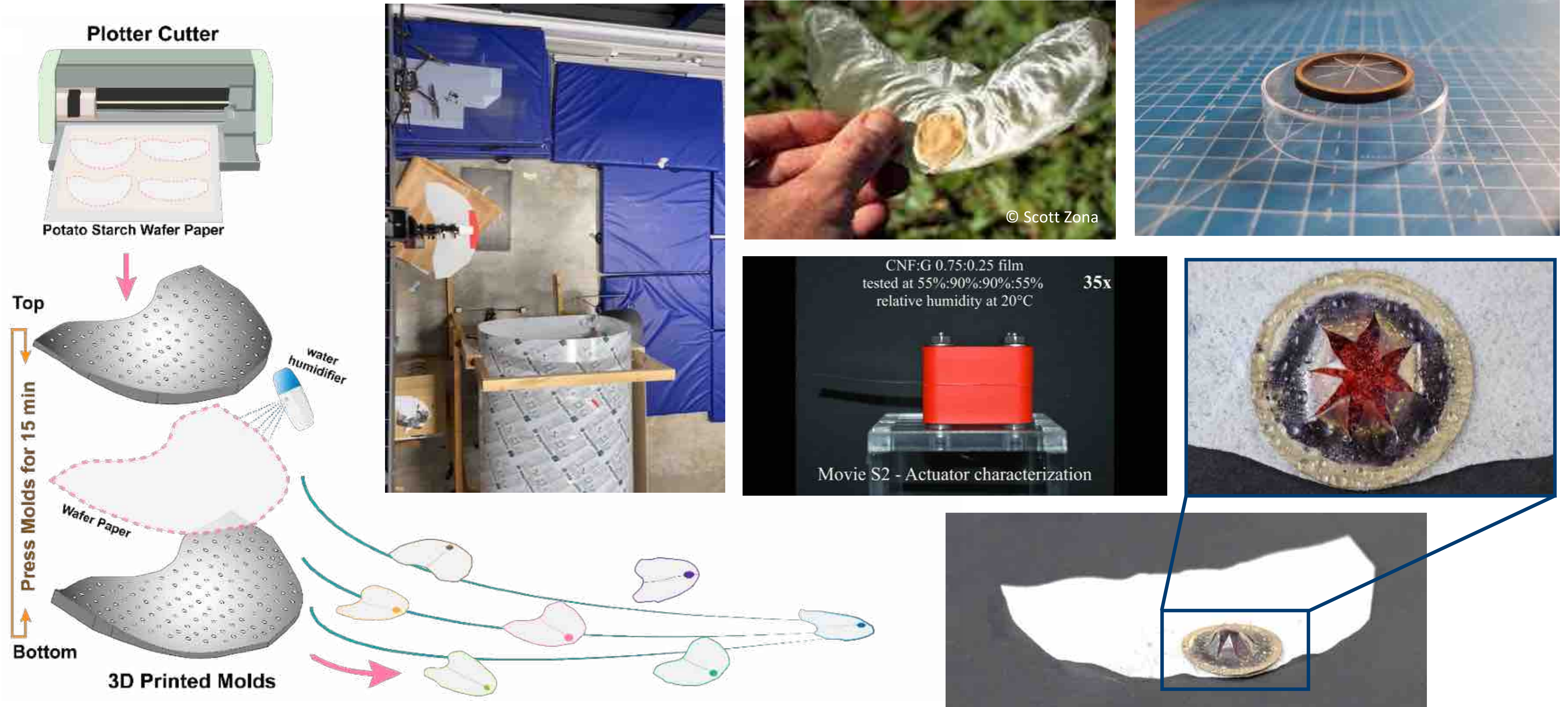
Sensing: Functionalised cellulose substrates



Wiesemüller, F., Nyström, G., Kovac, M., et al.

Advanced Intelligent Systems (2023) & *IEEE Robotics & Automation Letters* (2021)

Actuation: Humidity responsive composites



F. Wiesemüller, G. Nyström, M. Kovac et al.,
Frontiers in Robotics & AI (2022) & *N.I.C.E.* (2022)

Transient Robotics

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Wiesemüller, F., Meyer, S., Hu Y., Bachmann, D., Parrilli, A., Nyström, G.
Kovac, M., (2023) *Advanced Intelligent Systems* (cover)

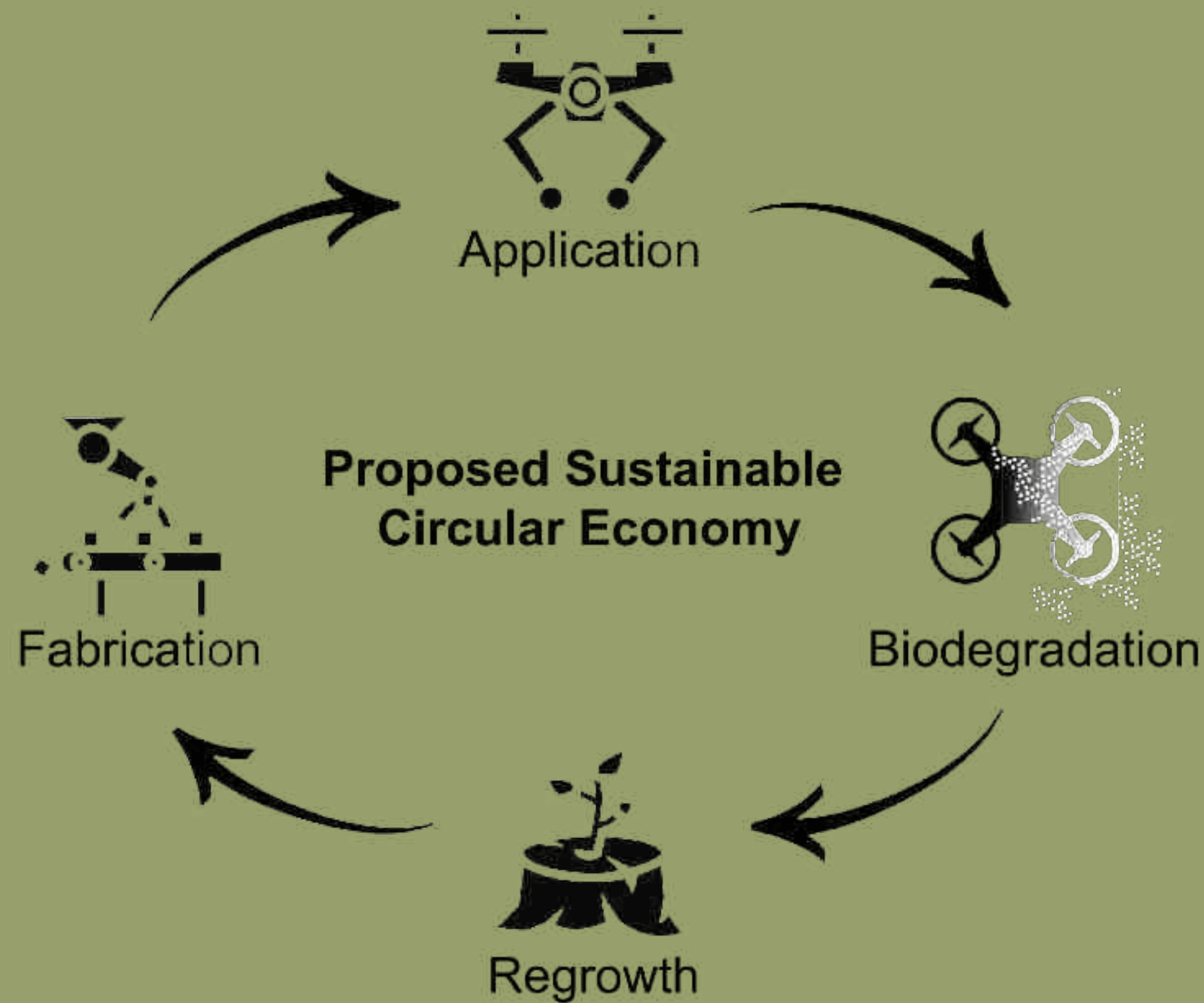
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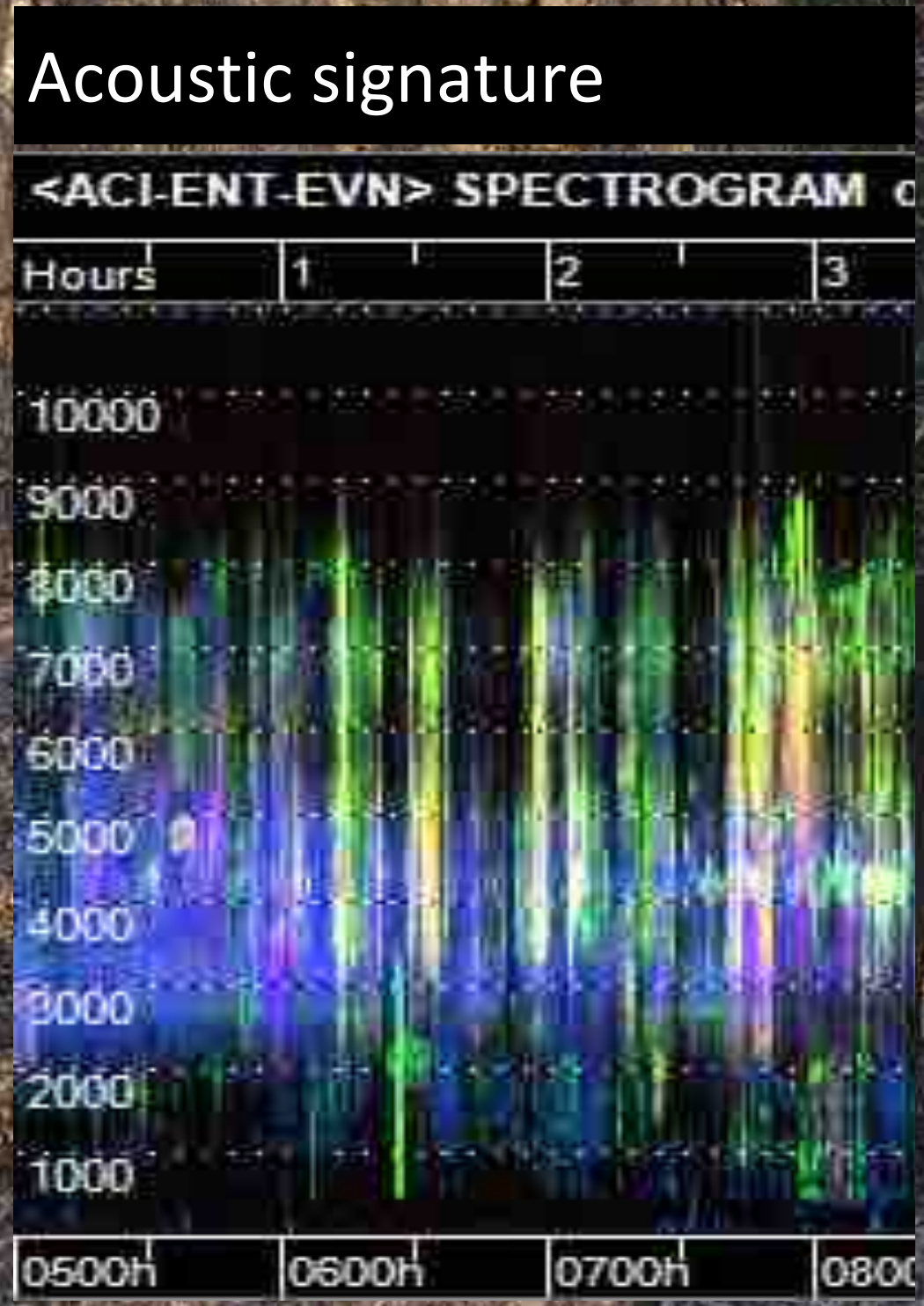
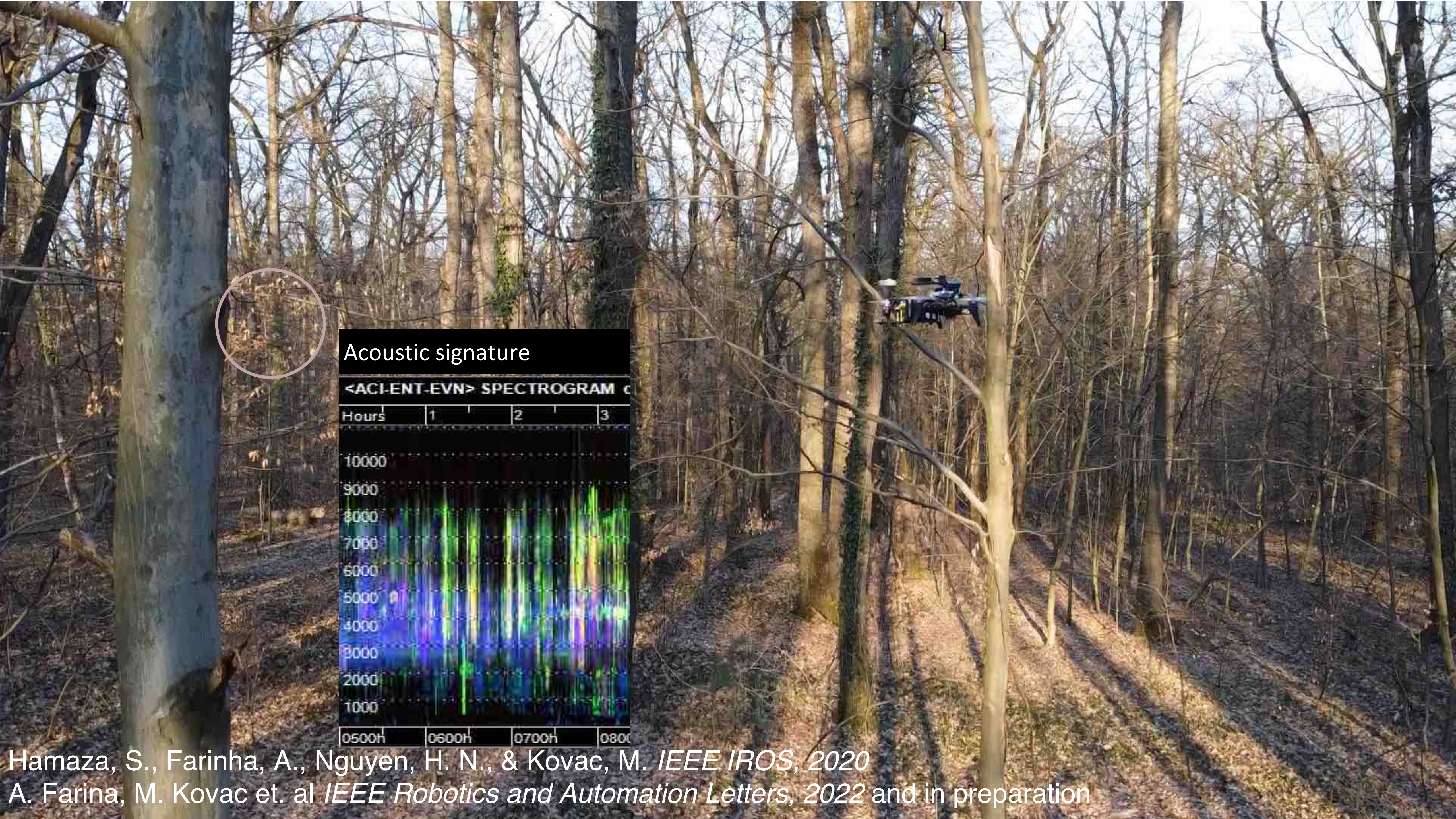
Open Access



Wiesemüller, F., Meyer, S., Hu Y., Bachmann, D., Parrilli, A., Nyström, G. Kovac, M., (2023) *Advanced Intelligent Systems* (cover)
Wiesemüller, F., Miriyev, A., Kovac, M., (2021) AIRPHARO

WILEY-VCH

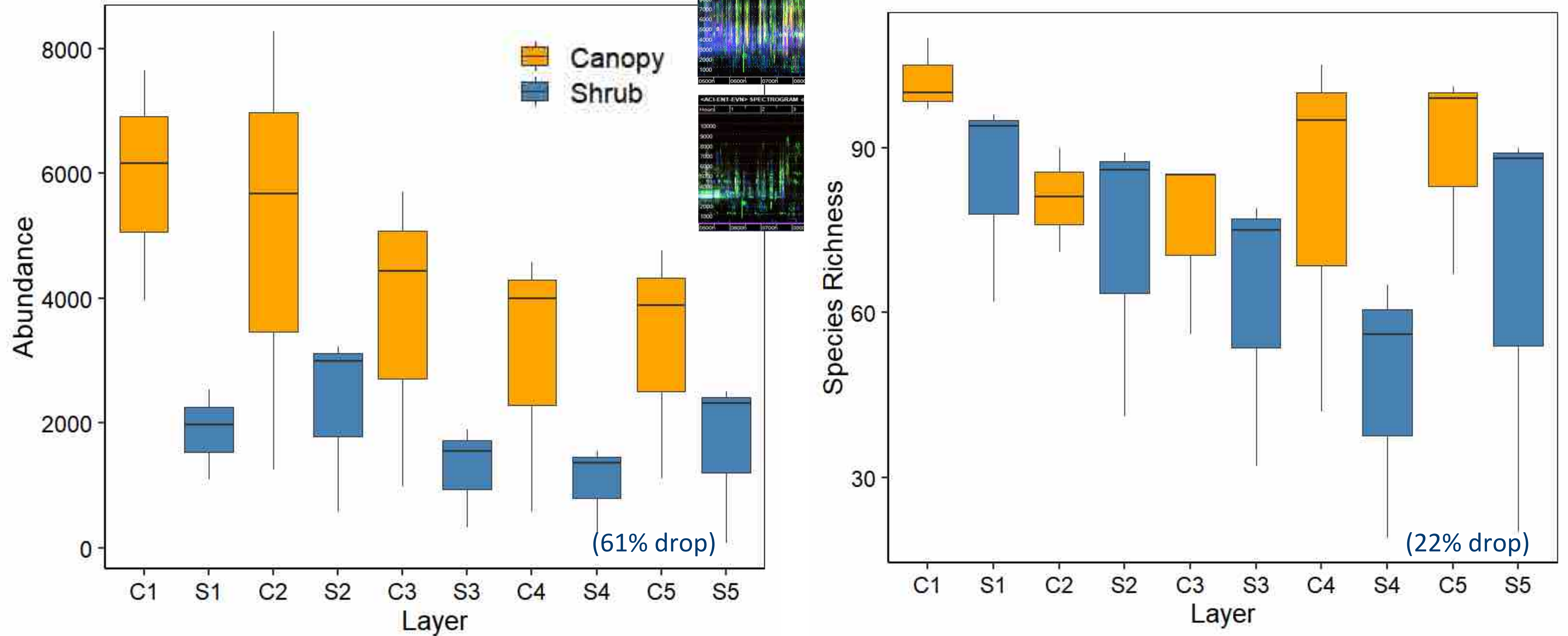




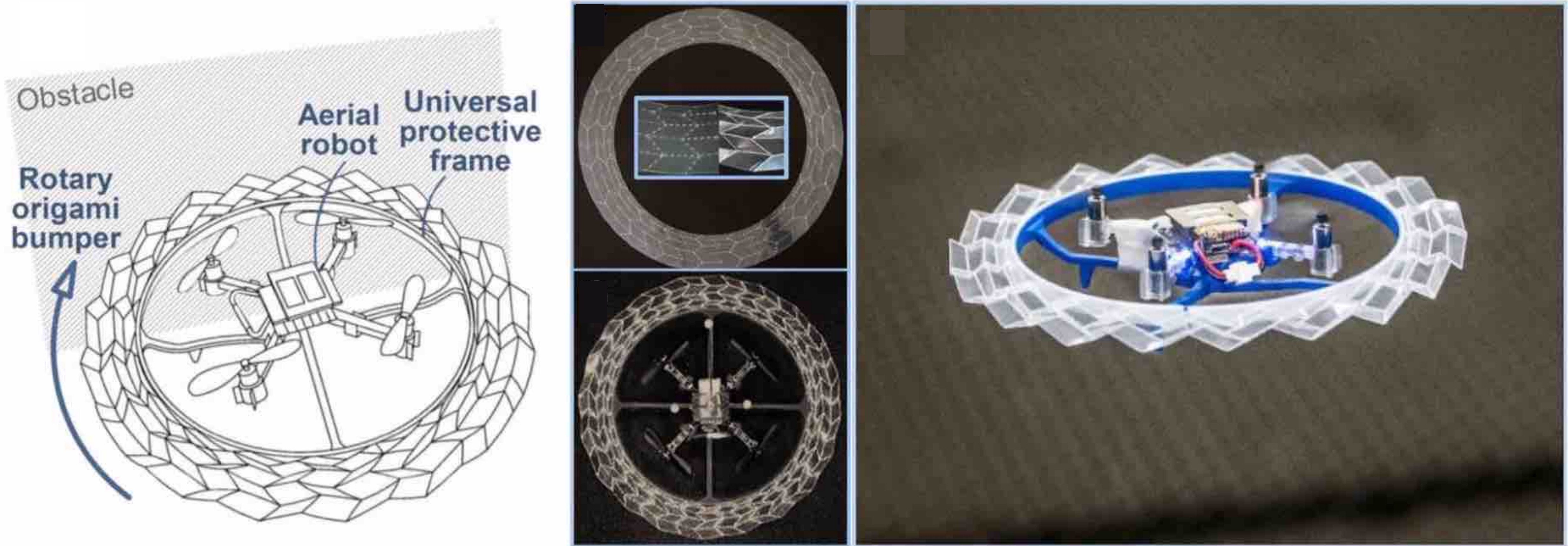
Hamaza, S., Farinha, A., Nguyen, H. N., & Kovac, M. *IEEE IROS, 2020*
A. Farina, M. Kovac et. al *IEEE Robotics and Automation Letters, 2022* and in preparation

Bird abundance and richness differs across layers

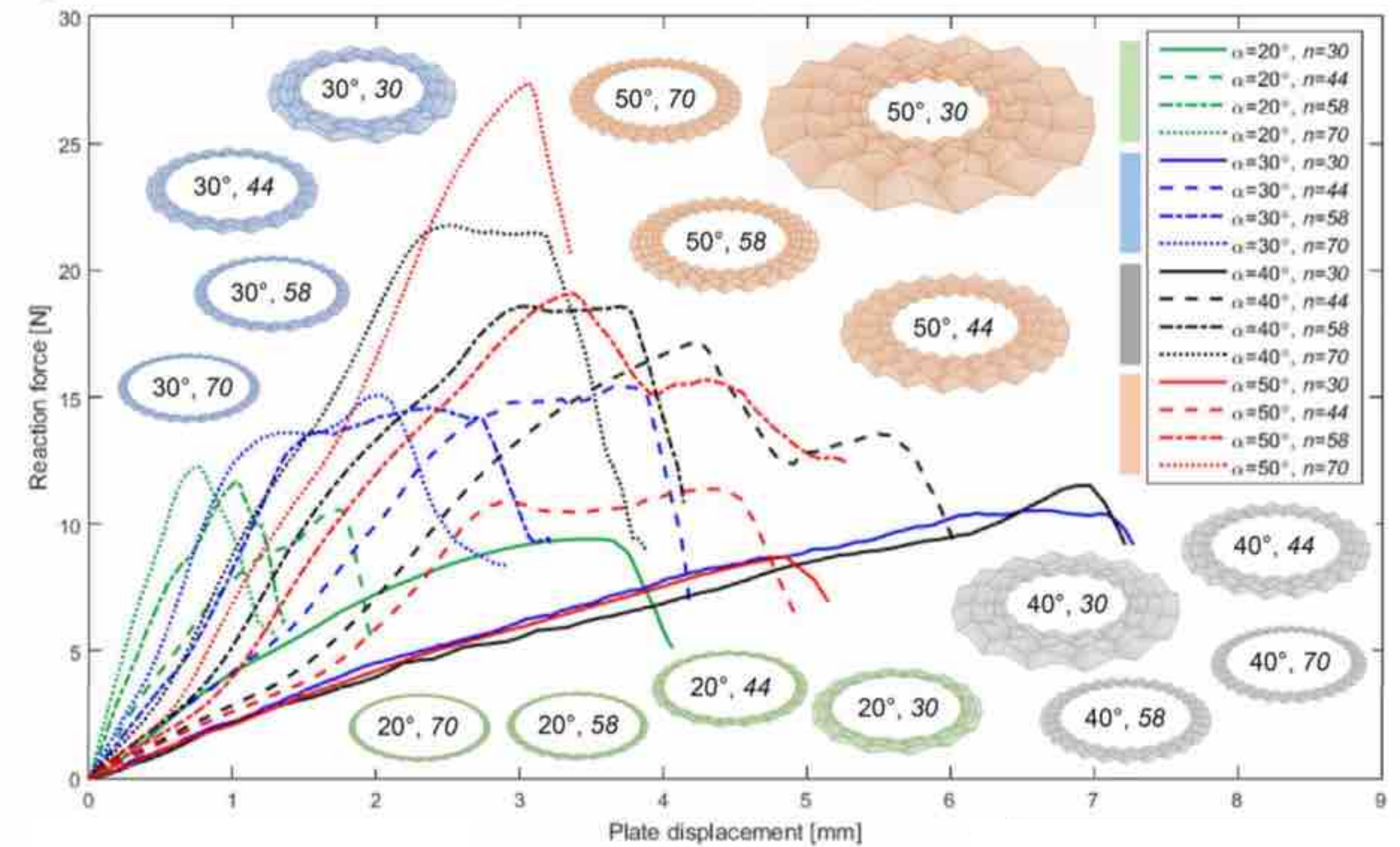
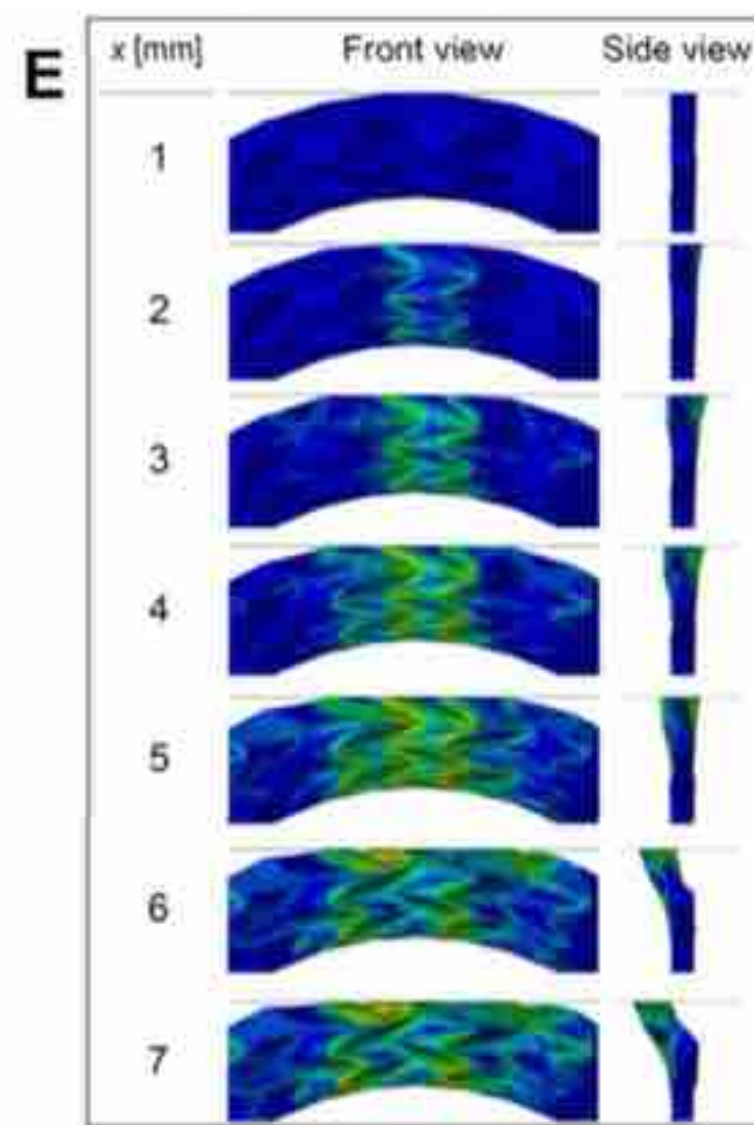
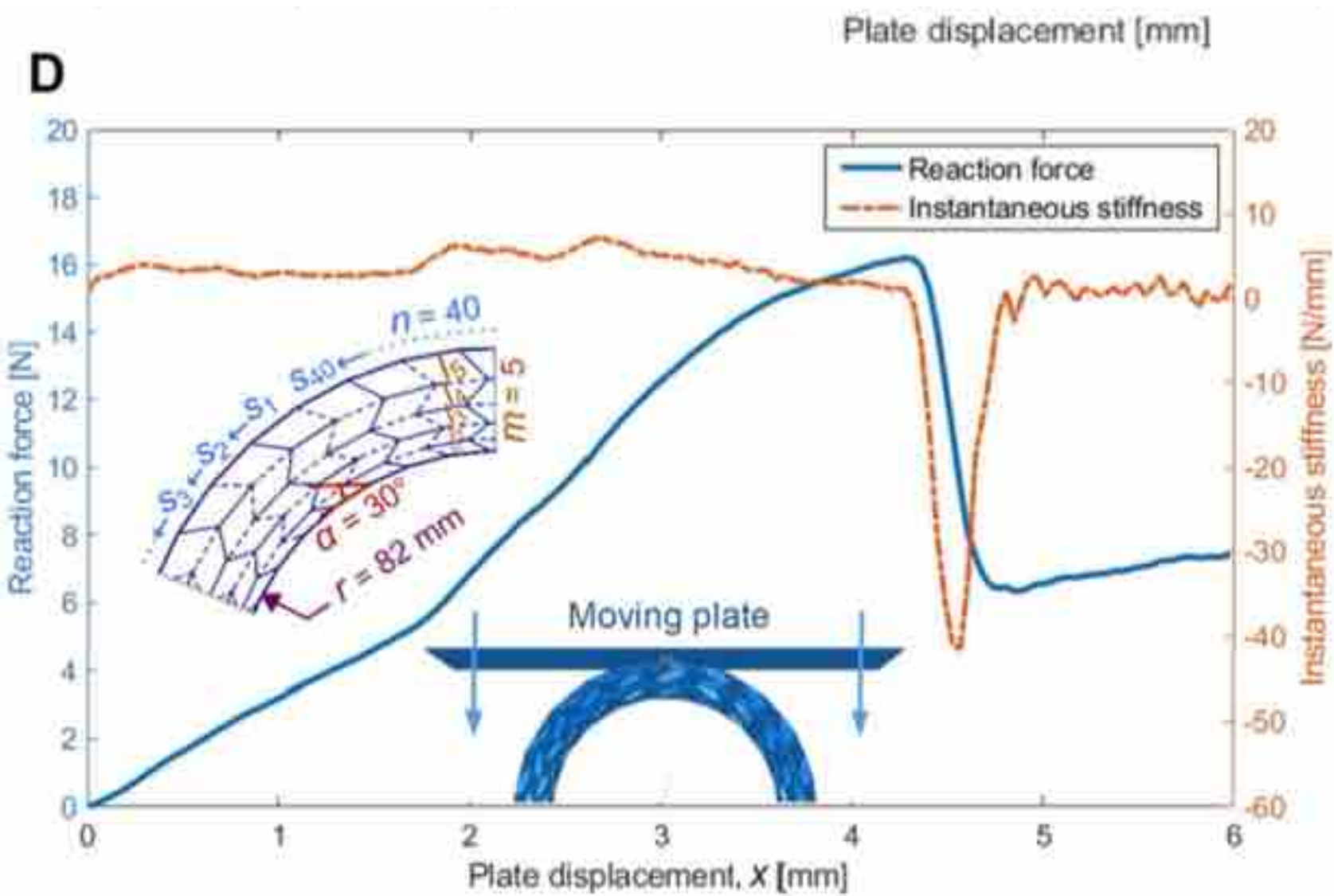
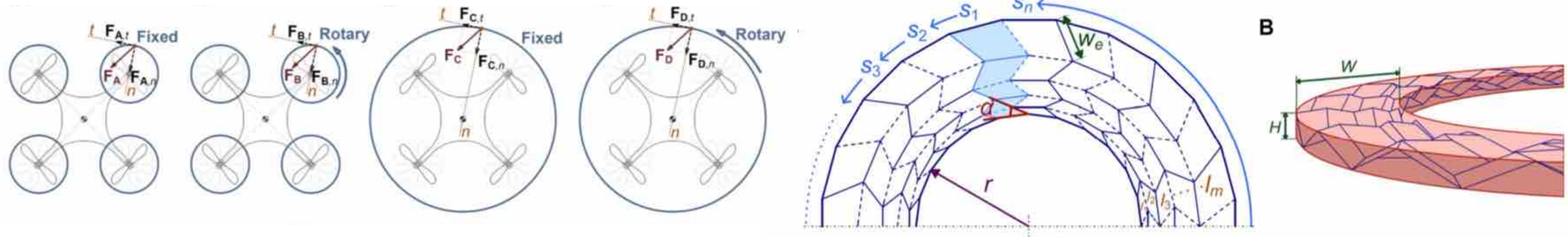
135 species recorded



Rotorigami for impact protection



Rotorigami for impact protection

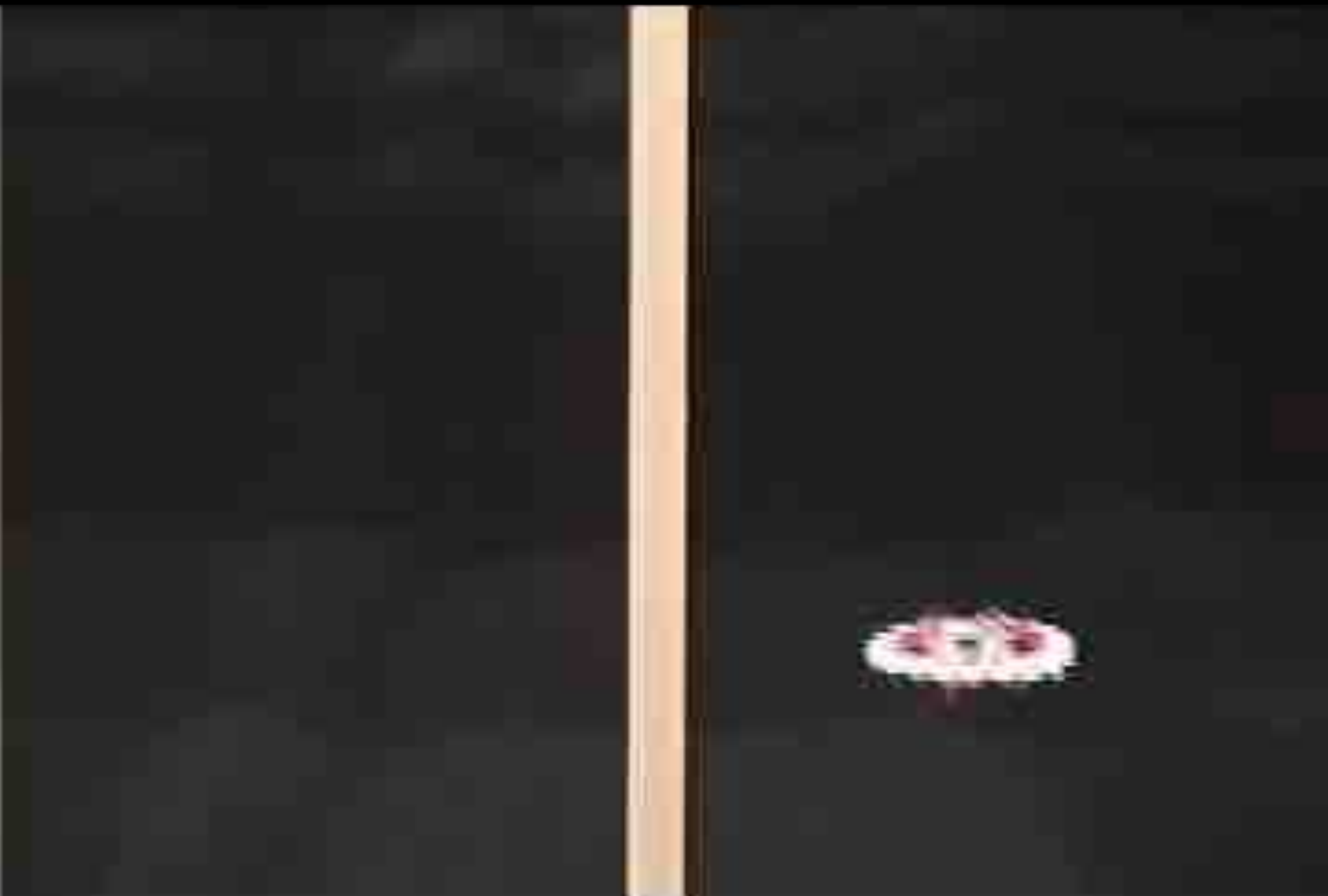


P. Sareh, P. Chermprayong, M. Emmanuelli, H. Nadeem, M. Kovac
Science Robotics (2018)

Rotorigami for impact protection



Fixed-Naked



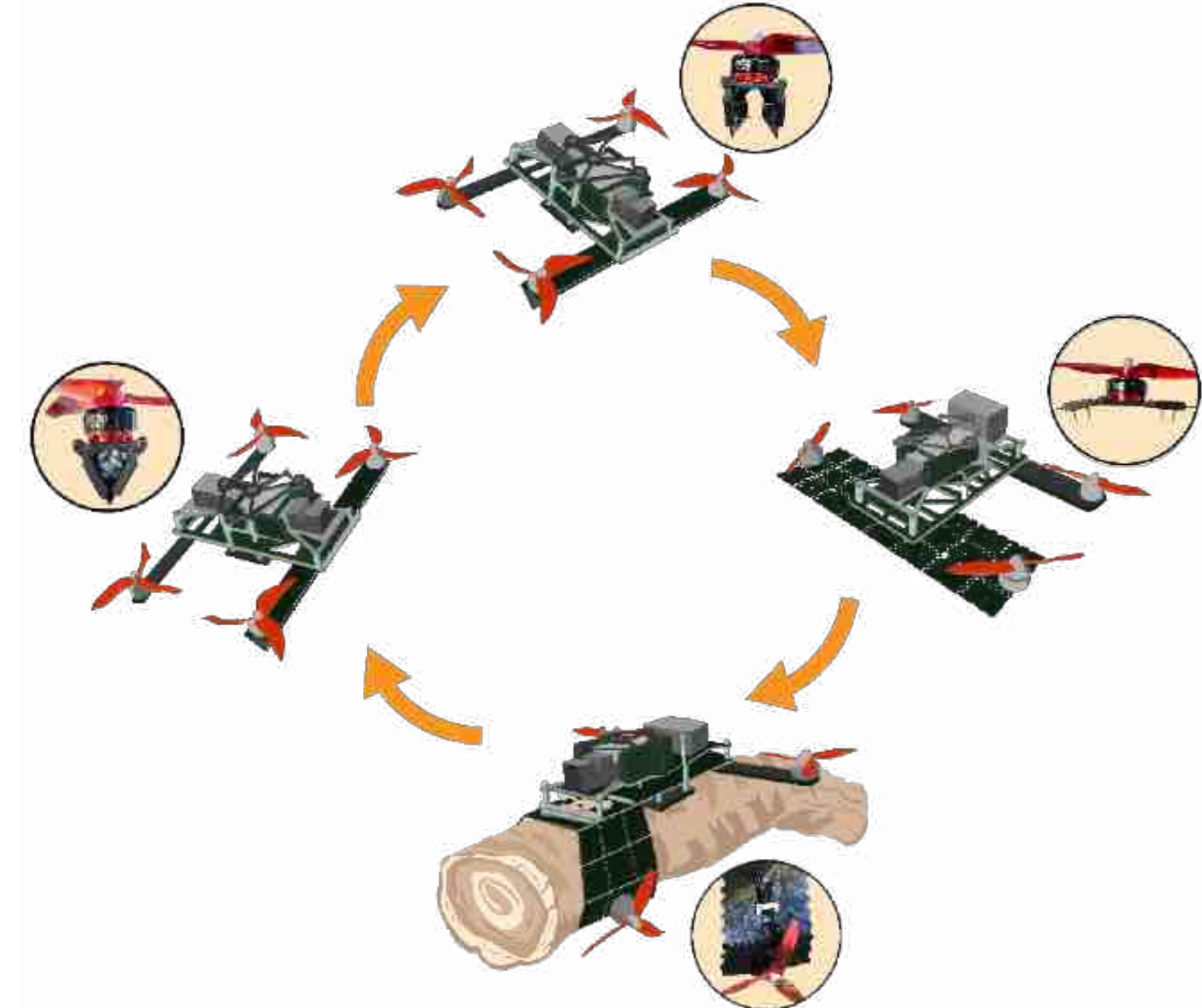
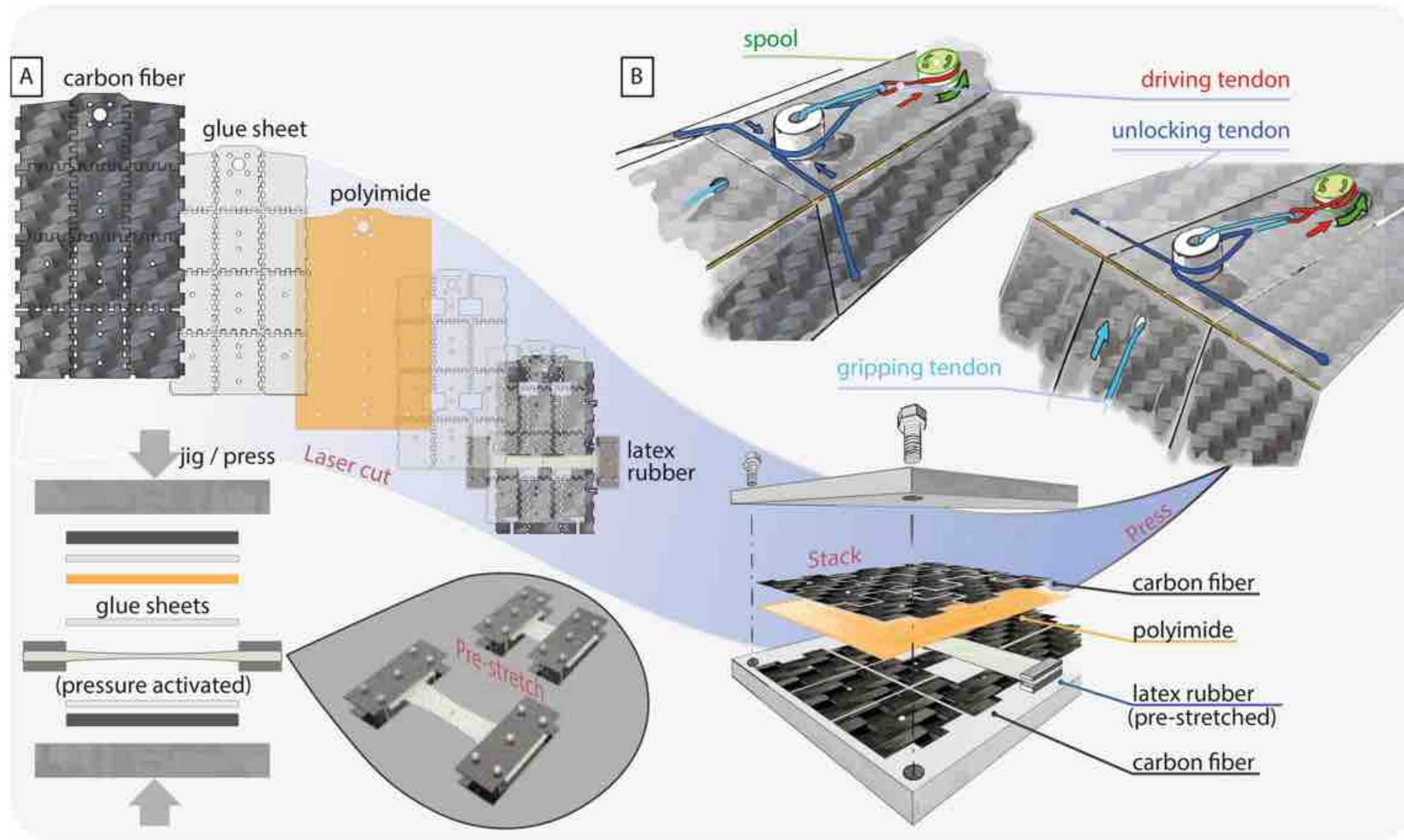
Rotary-Origami

Meta-morphic full body perching



Zheng, P., Xiao, F., Nguyen, P. H., Farinha, A. and Kovac, M., (2023) Metamorphic Aerial Robot capable of mid-air shape morphing for rapid perching, *Nature Scientific Reports*

Meta-morphic full body perching



Zheng, P., Xiao, F., Nguyen, P. H., Farinha, A. and Kovac, M., (2023) Metamorphic Aerial Robot capable of mid-air shape morphing for rapid perching, *Nature Scientific Reports*

Meta-morphic full body perching



Zheng, P., Xiao, F., Nguyen, P. H., Farinha, A. and Kovac, M., (2023) Metamorphic Aerial Robot capable of mid-air shape morphing for rapid perching, *Nature Scientific Reports*



Autonomous Tensile Perching

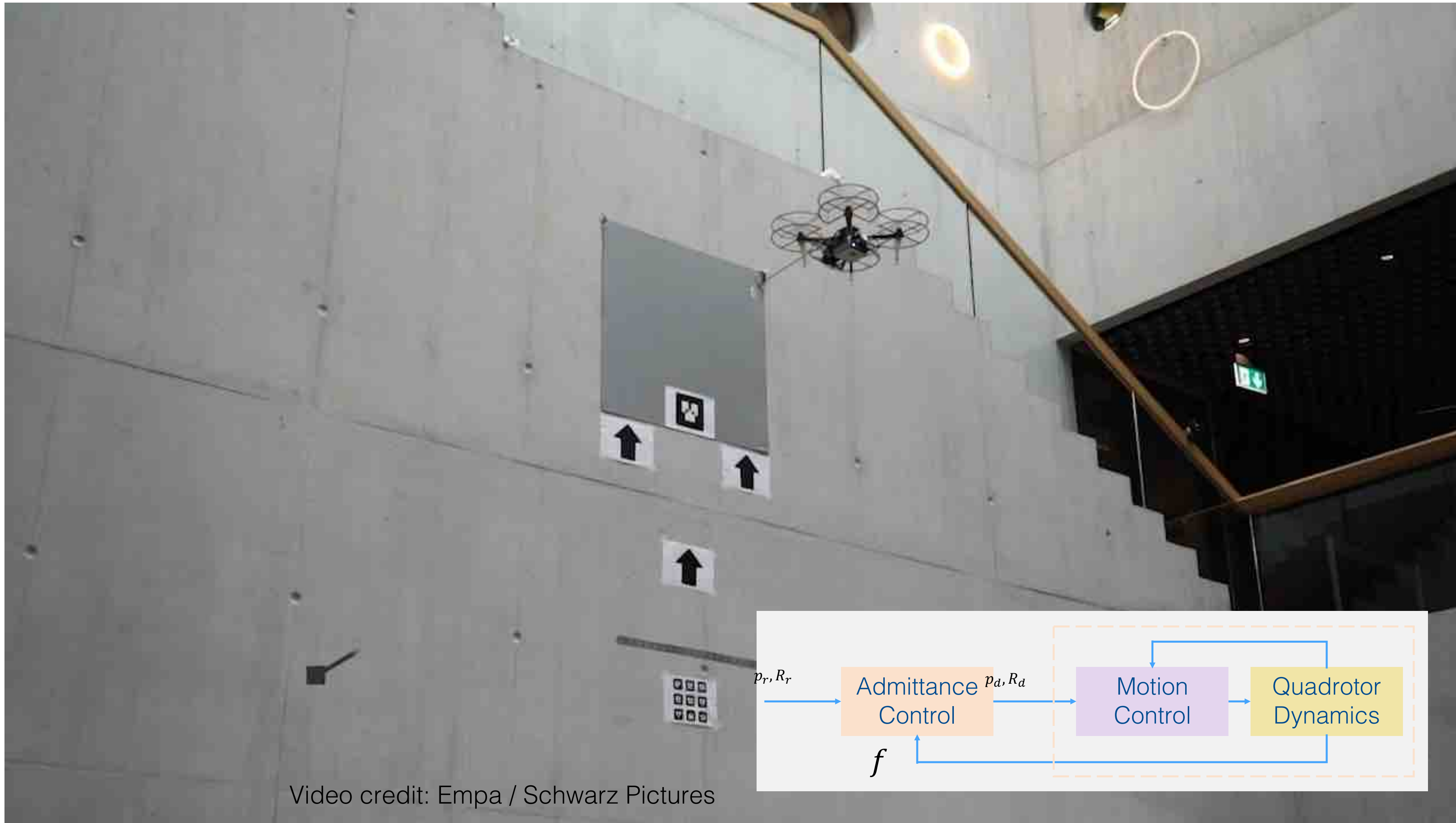
93

2x speed

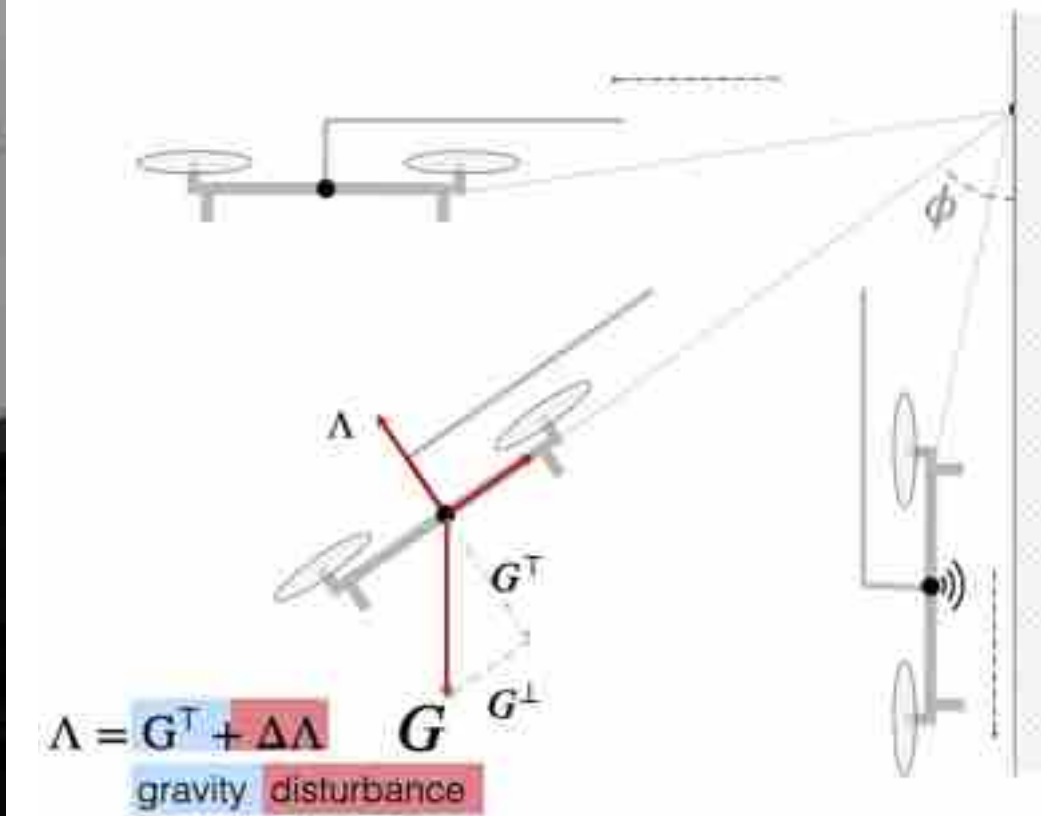
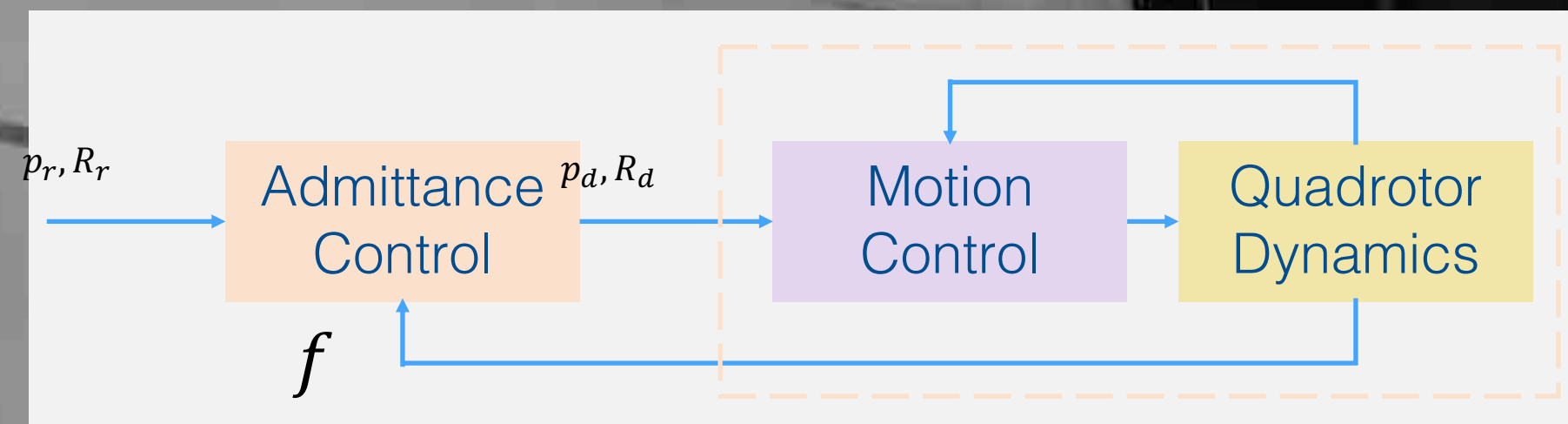


Braithwaite, A., Alhinai, T., Haas-Heger, M., McFarlane, E., Kovac, M., (2018)
Robotics Research: International Symposium ISRR, Springer International Publishing,

Autonomous Tensile Perching



Video credit: Empa / Schwarz Pictures

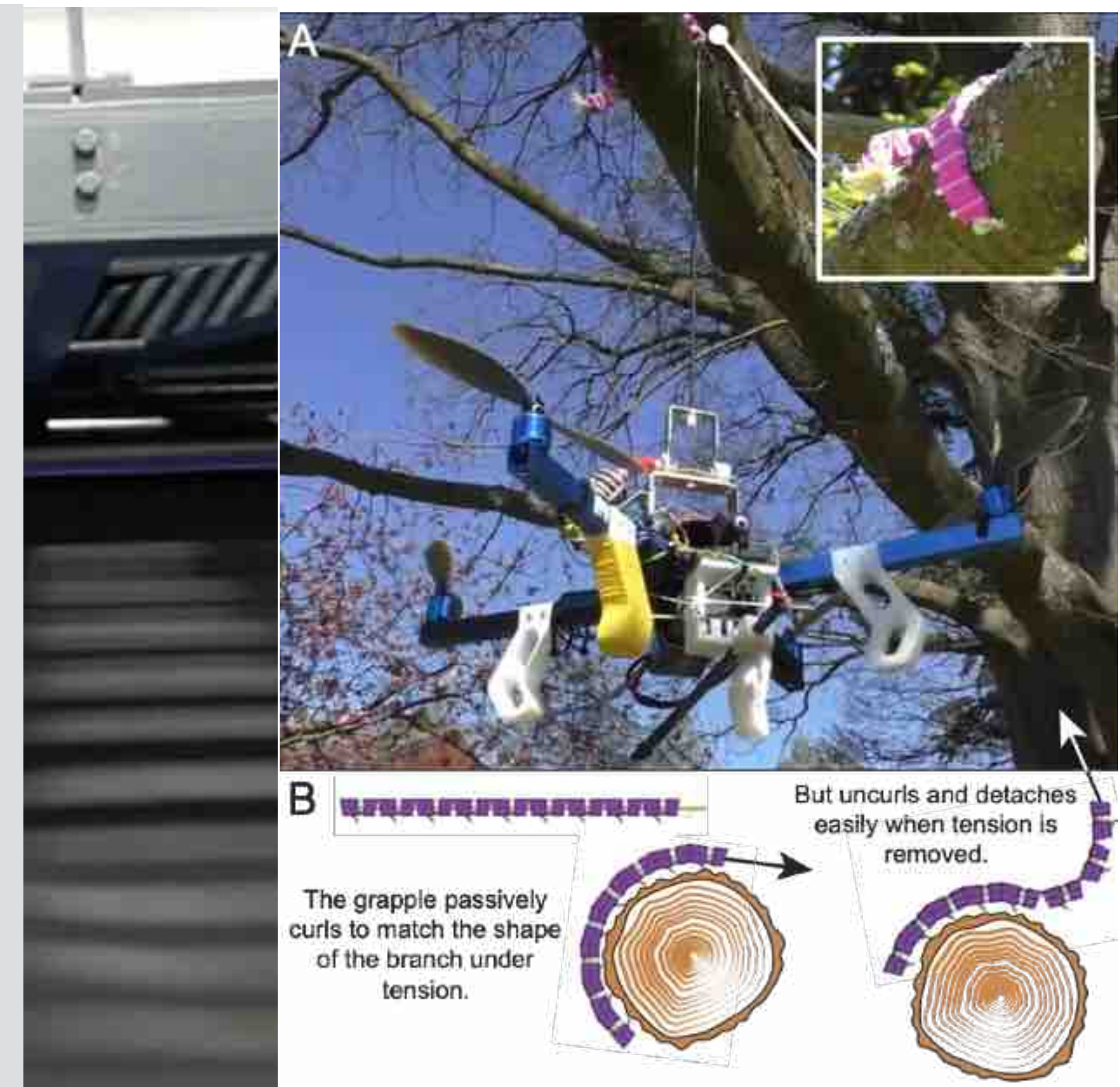
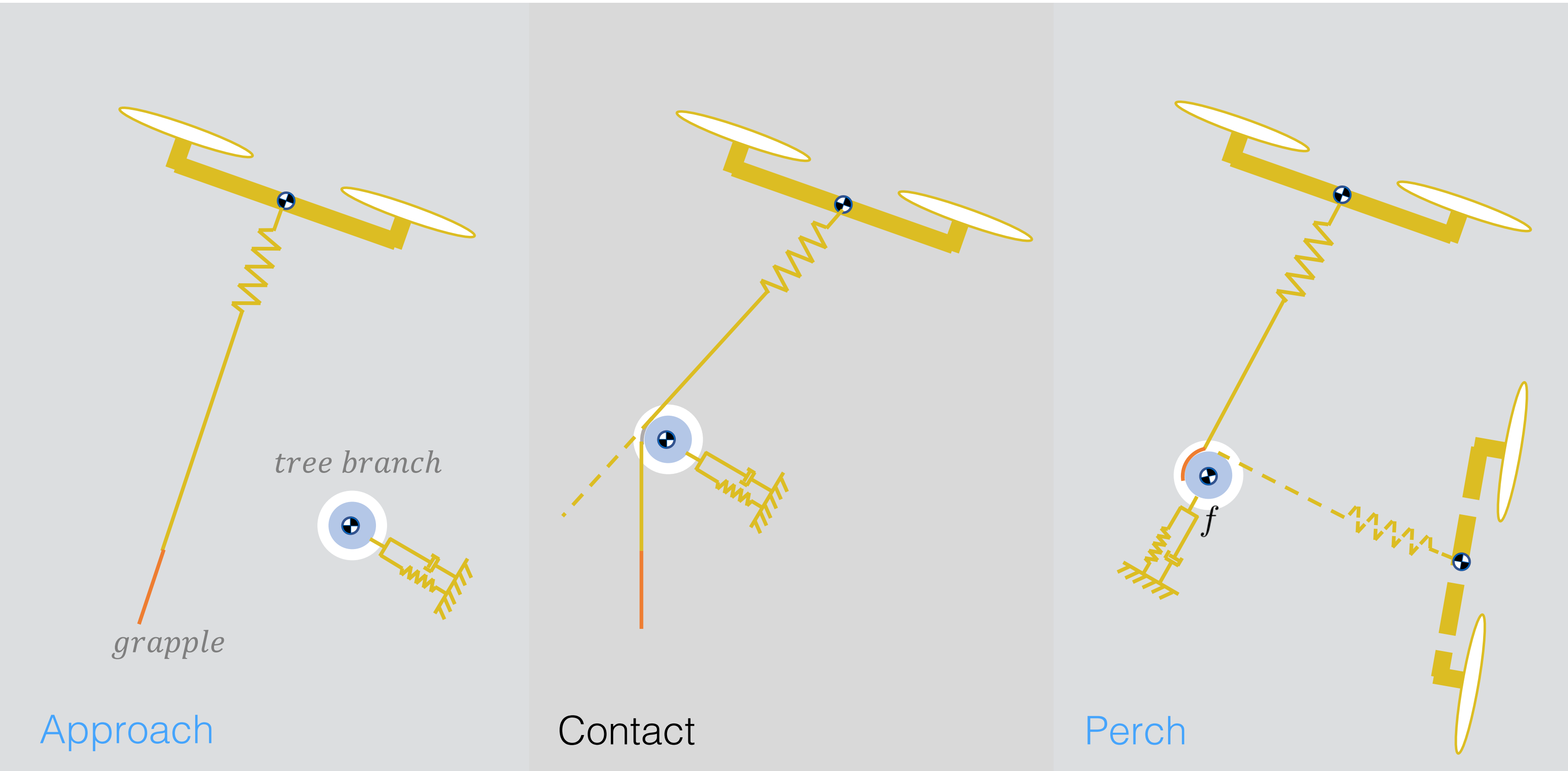


Tethered hovering thrust

- at 30deg: save 50% the energy
- at 10deg, save more than 80%

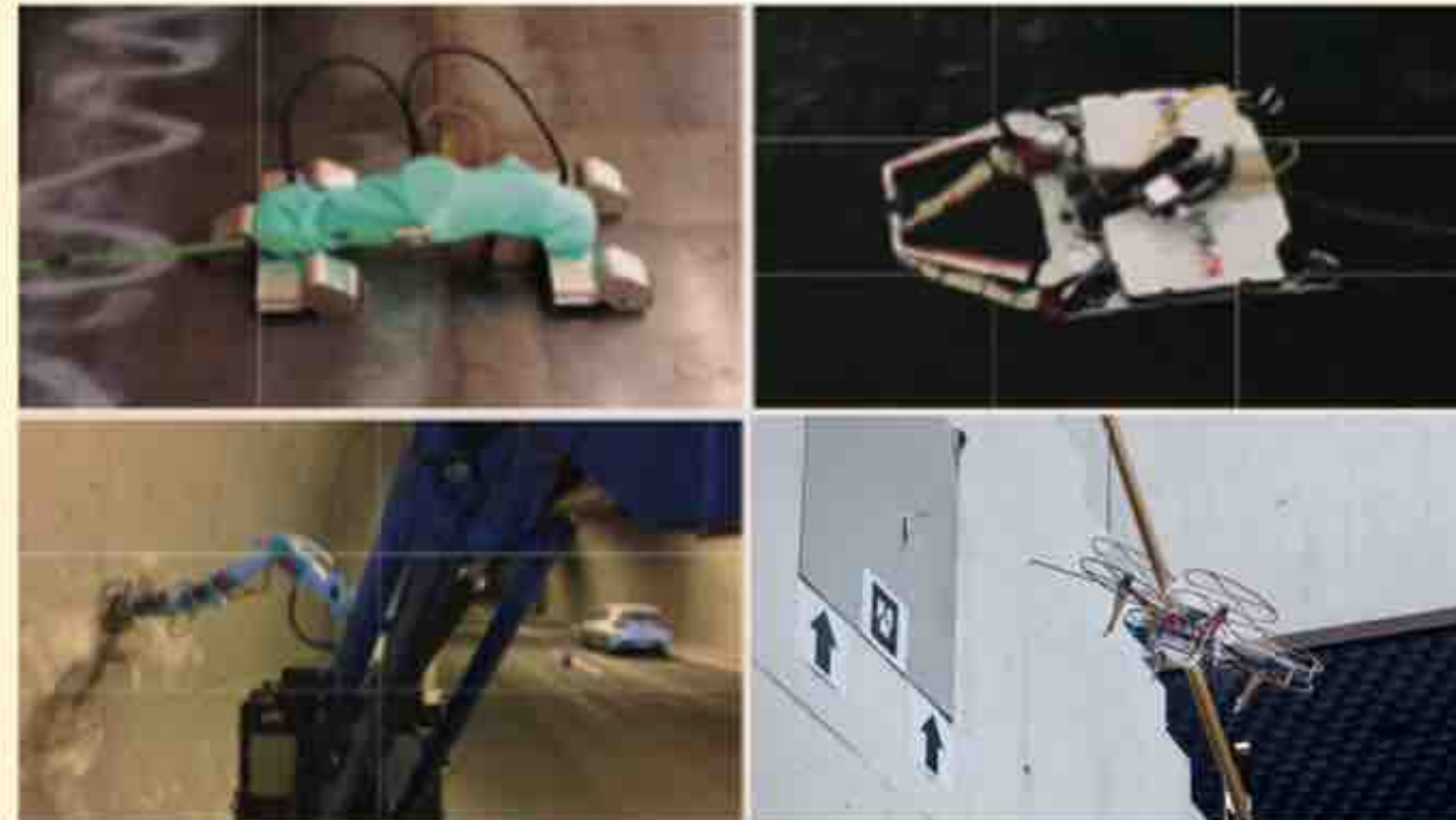


Autonomous Tensile Perching



Infrastructure Robotics

Methodologies, Robotic Systems and Applications

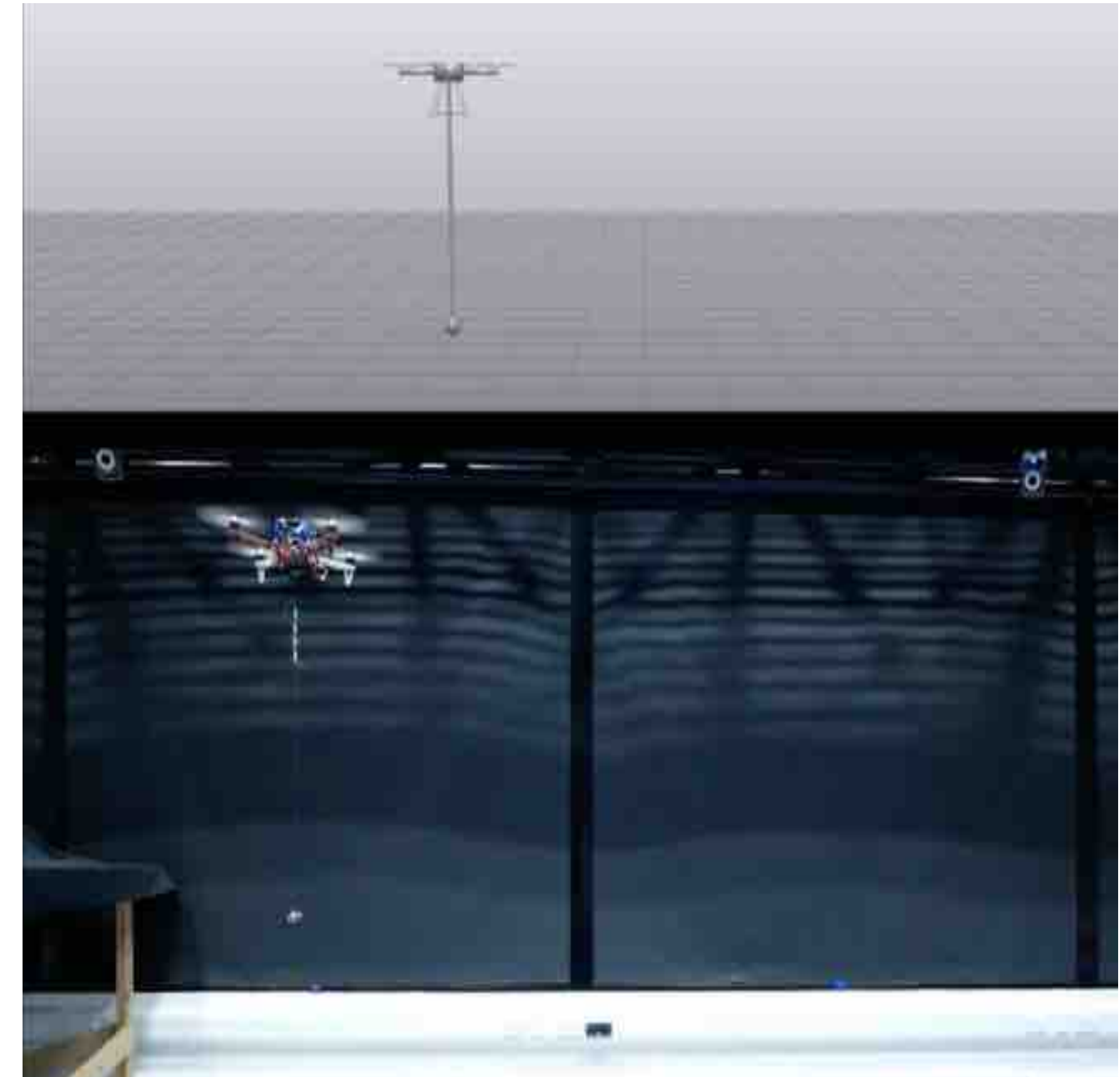
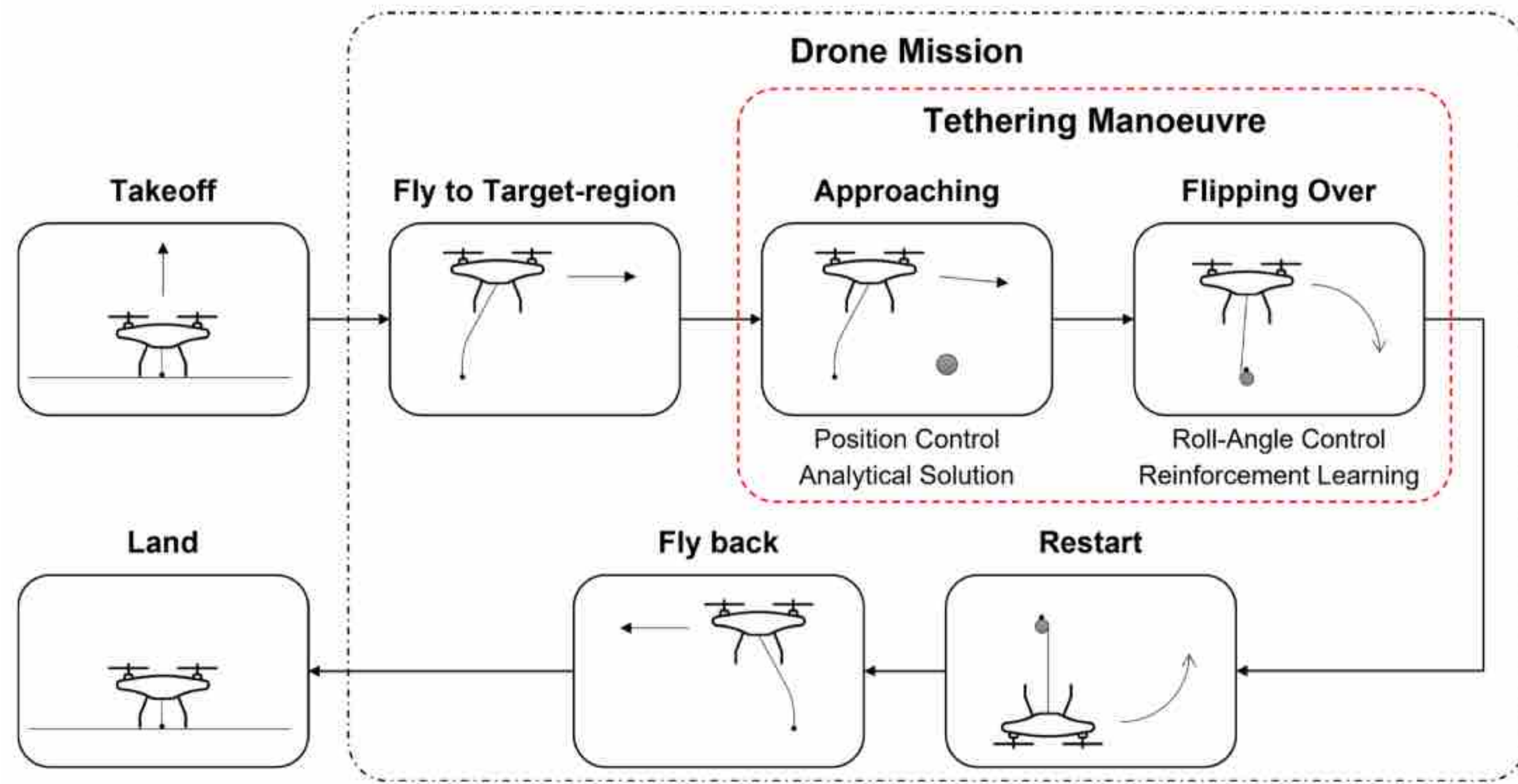


Edited by

Dikai Liu • Carlos Balaguer • Gamini Dissanayake

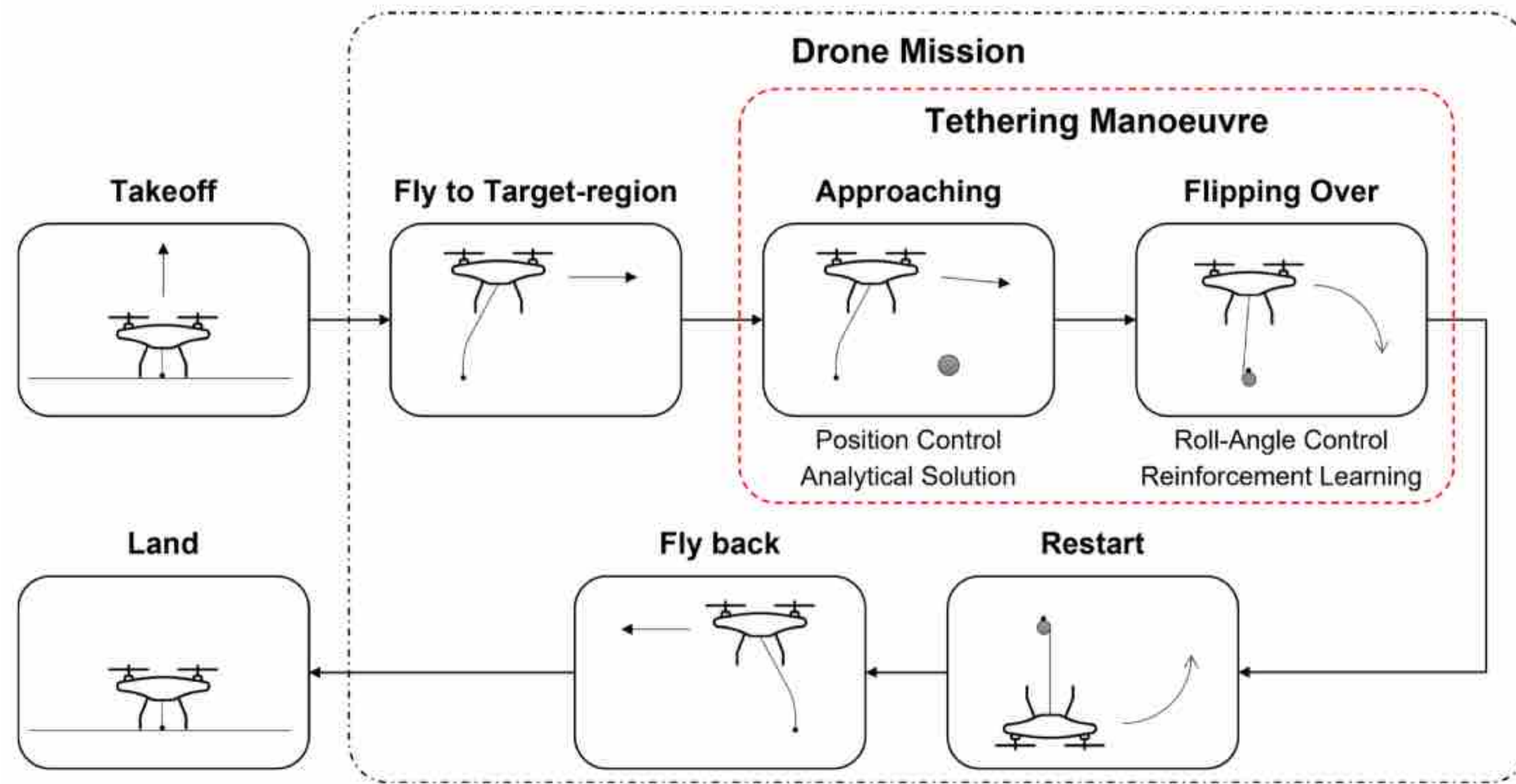
Mirko Kovac

Neural Nets for dynamic perching



Hauf, F., Kocer, B., Slatter, A., Nguyen, H-N., Pang, O., Clark, R., Johns, E., Kovac, M.
Learning Tethered Perching for Aerial Robots. *IEEE ICRA 2023*

Neural Nets for dynamic perching



Energy conservation for swinging

$$\frac{v^2}{2g} = \sqrt{L_2^2 + \left(\frac{d}{2}\right)^2} + L_1 \sin(\theta) + \frac{d}{2} \cos(\theta)$$

Reinforcement Learning scheme:

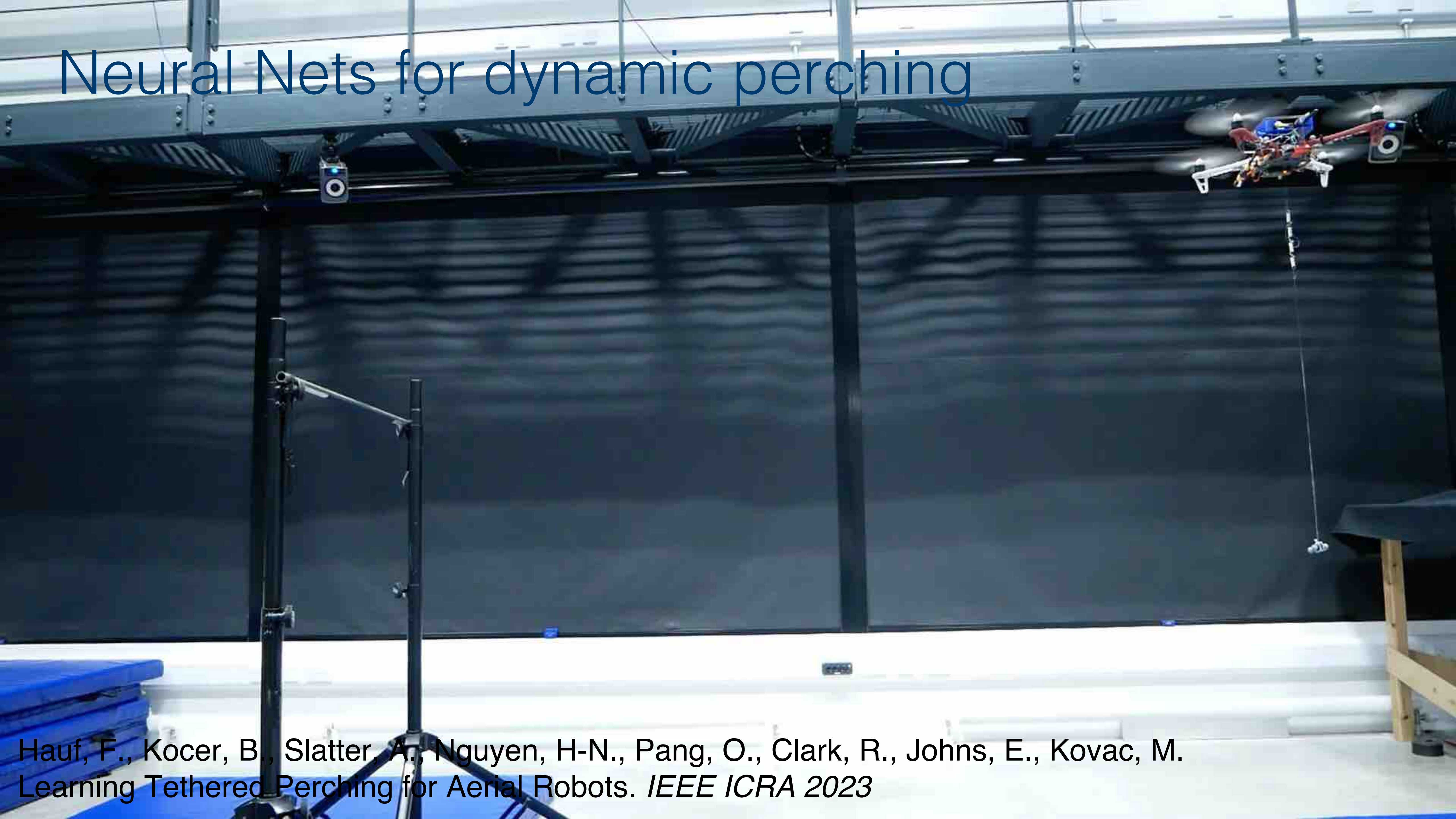
Reward 1: Function following baseline

Reward 2: Moving continuously and safely

Changing weights of reward functions

Evolved in Gazebo and tested in arena (21 flights)

Neural Nets for dynamic perching



Hauf, F., Kocer, B., Slatter, A., Nguyen, H-N., Pang, O., Clark, R., Johns, E., Kovac, M.
Learning Tethered Perching for Aerial Robots. *IEEE ICRA 2023*

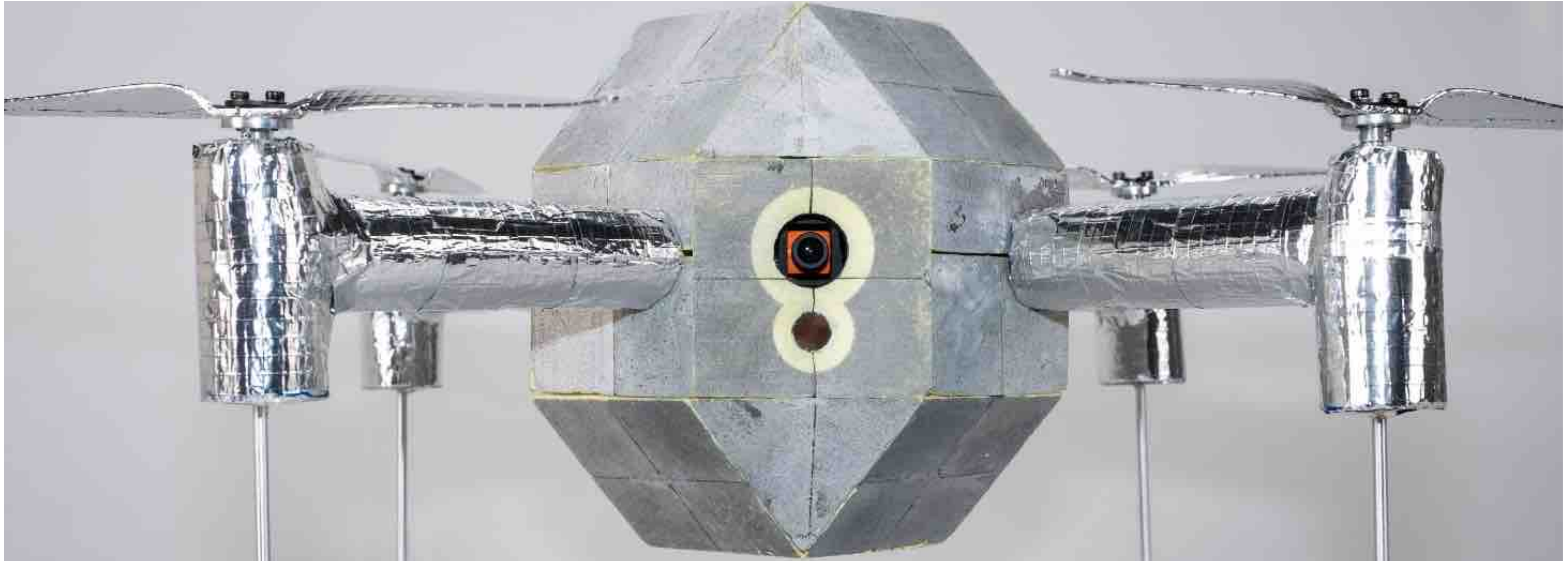
FIRE



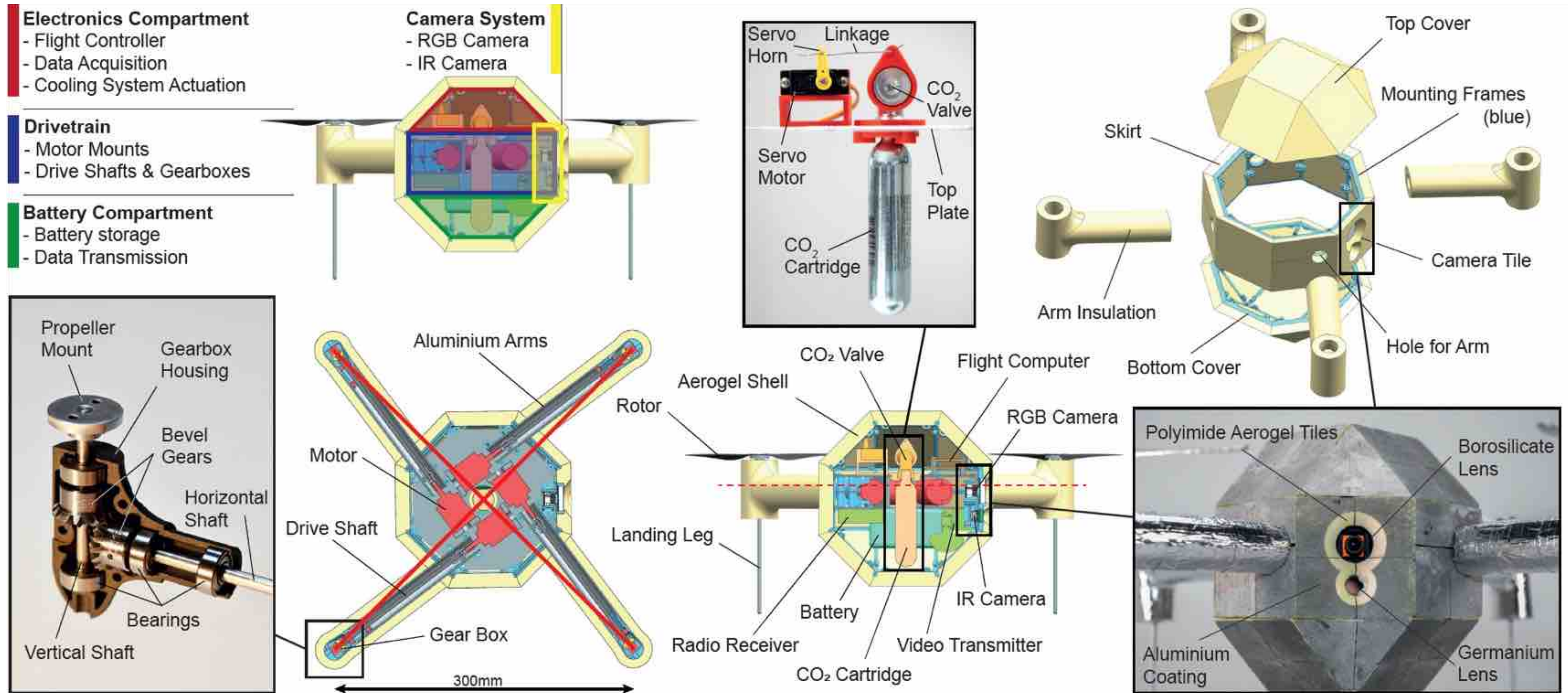
London Grenfell tower fire



FireDrone - Temperature agnostic aerogel drone



FireDrone - Temperature agnostic aerial robot



FireDrone Temperature agnostic aerial robot

104
**ADVANCED
INTELLIGENT
SYSTEMS**

Open Access

Häusermann, D., Bodry, S., Wiesemüller, F., Miriyev, A., Siegrist, S., Fu, F., Gaan, S., Koebel, M.M., Malfait, W.J., Zhao, S., Kovac, M., (2023) *Advanced Intelligent Systems* (cover)

WILEY-VCH

FireDrone

Temperature agnostic aerial robot



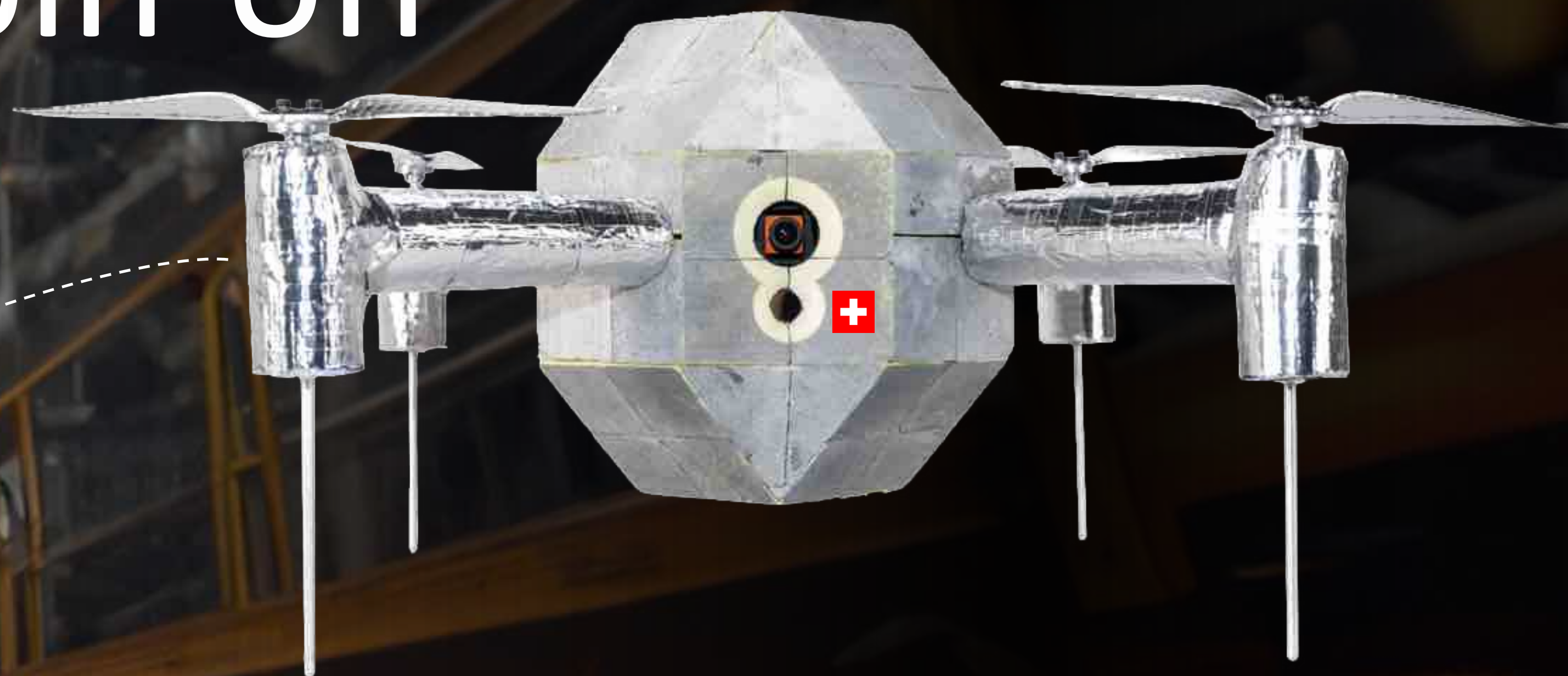
105
**ADVANCED
INTELLIGENT
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Häusermann, D., Bodry, S., Wiesemüller, F., Miriyev, A., Siegrist, S., Fu, F., Gaan, S., Koebel, M.M., Malfait, W.J., Zhao, S., Kovac, M., (2023) *Advanced Intelligent Systems* (cover)

FireDrone spin-off

robotic solutions for extreme environments



Create situational awareness,
pinpoint hazards and victims from a safe distance



SWISS 
ROBOTICS
DAY


STARTUP
CAMPUS
AWARD

VENTURE 
KICK

WISSENSCHAFT.
BEWEGEN
GEBERT RUF STIFTUNG



www.firedrone.ch



FAIR

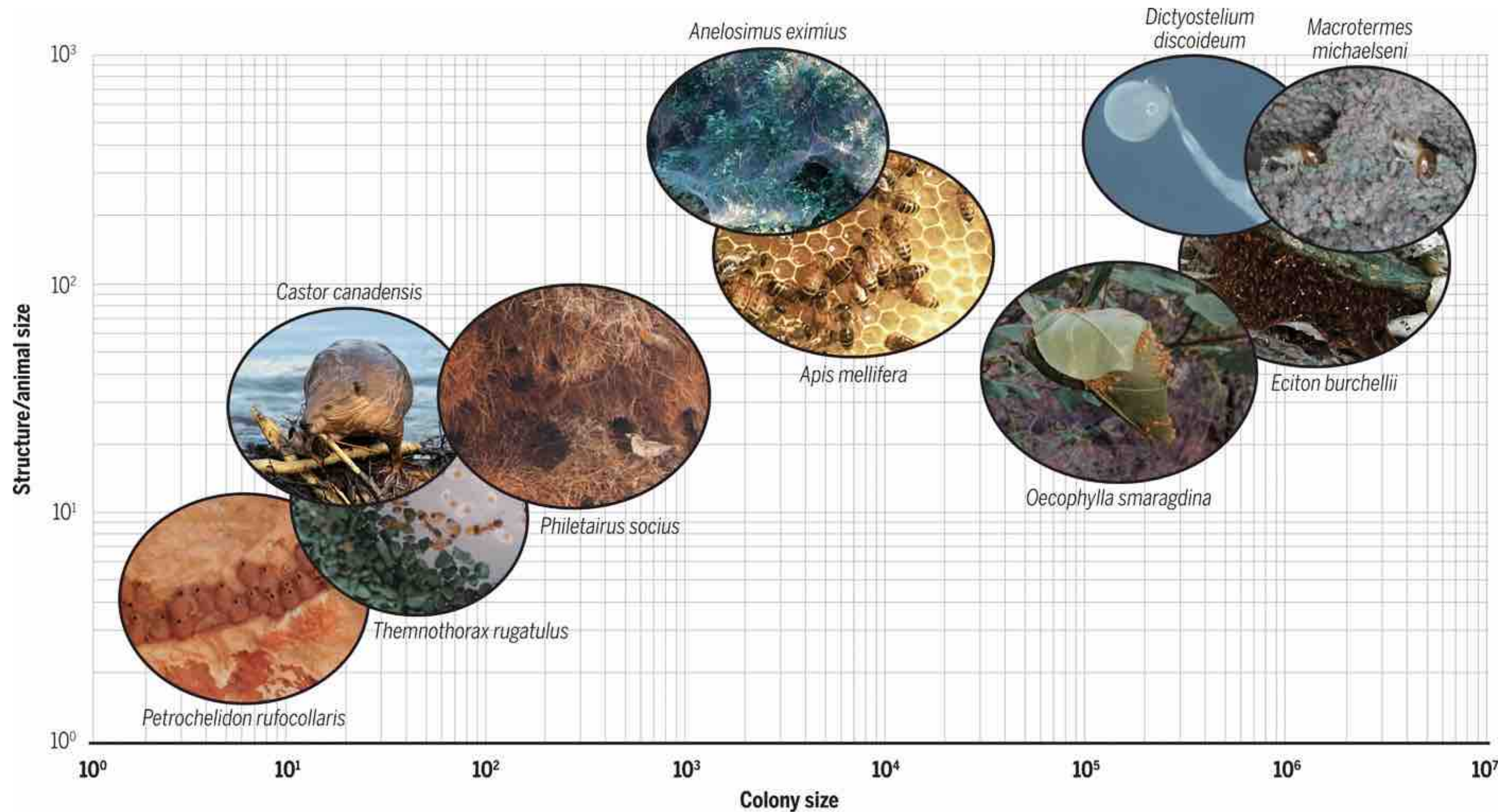
Petersen, Kovac, et al. *Science Robotics* (2019)

Kaya, Kovac et al. *Science Robotics* (2025)





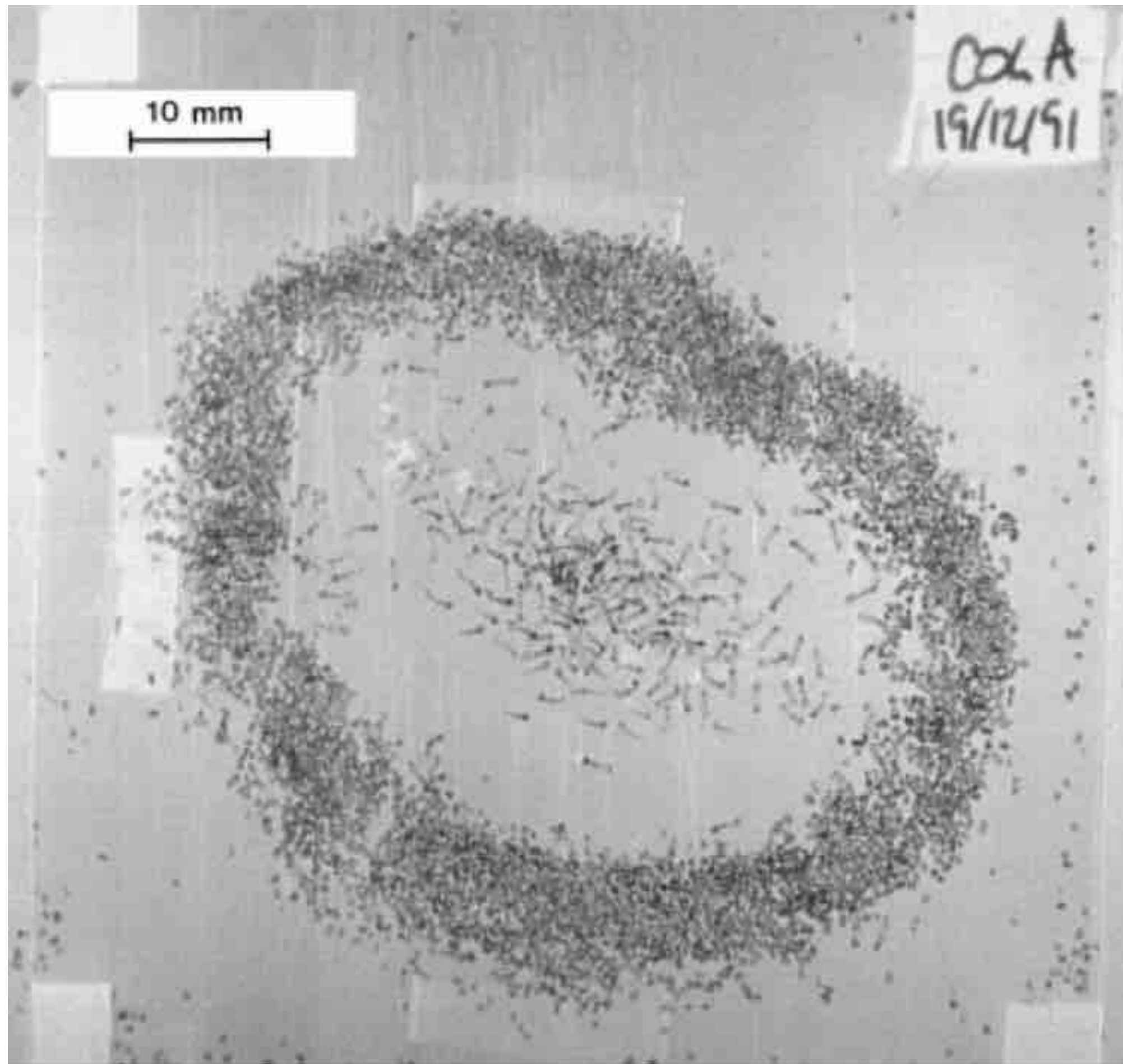
Construction in nature



K. H. Petersen, N. Napp, R. Stuart-Smith, D. Rus, M. Kovac,
Science Robotics (2019)

Bulldozer ants - use of templates

111



Franks, N. R., & Deneubourg, J. (1997). *Animal Behaviour*

Building process (external workers / internal workers)

1. External workers collect material and return to nest
2. Enter nest and drop material close to cluster of nest mates (carrying time is constant at 21sec after entry)
3. Drop material after direct contact with a cluster of internal workers or stones previously deposited. Release stone only after feeling resistance of stationary stones
4. External workers rarely pick up stones on the inside
5. Internal workers often pick up stones and bulldoze outwards
6. No evidence of pheromone or cement pheromone use
7. Cluster of adult workers around brood cluster (radial symmetry) serves as mechanical template for wall geometry
8. Template is local information and does not provide global knowledge of structure. How is nest entrance built?

K. H. Petersen, N. Napp, R. Stuart-Smith, D. Rus, M. Kovac,
Science Robotics (2019)

Bio-inspired construction principles

Construction coordination



Centralized control (12)



Communication (28)



Templated (8)



Emergent (23)

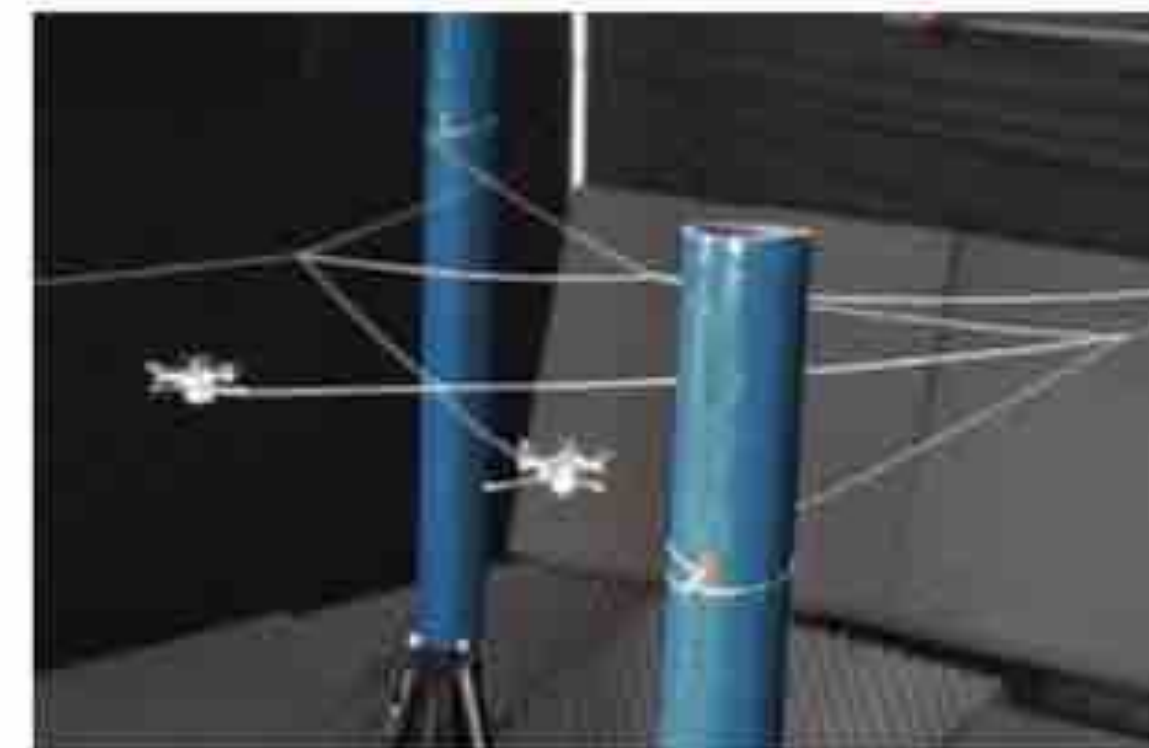
Building elements



Predefined (43)



Amorphous (68)



Continuous (32)

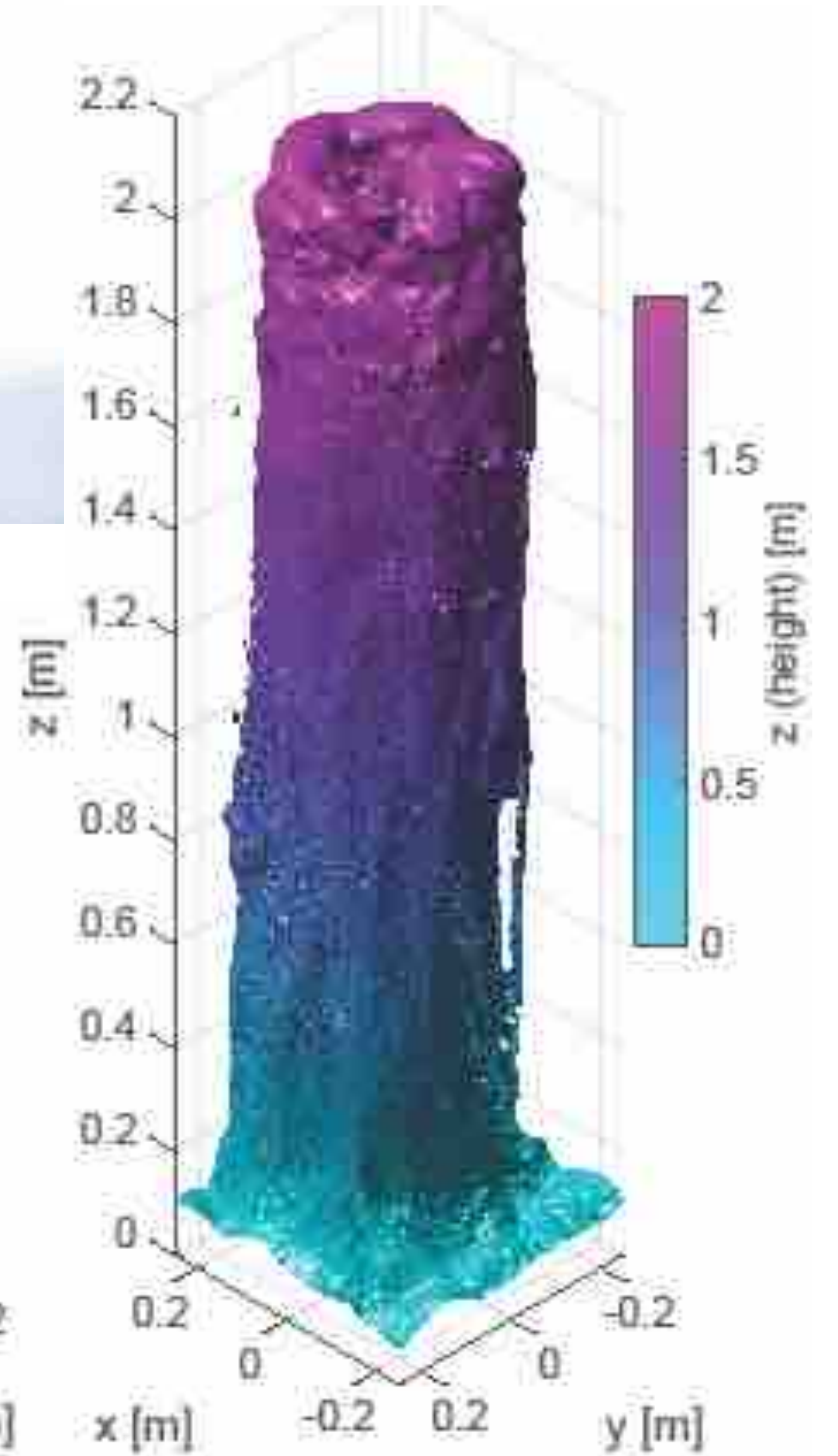
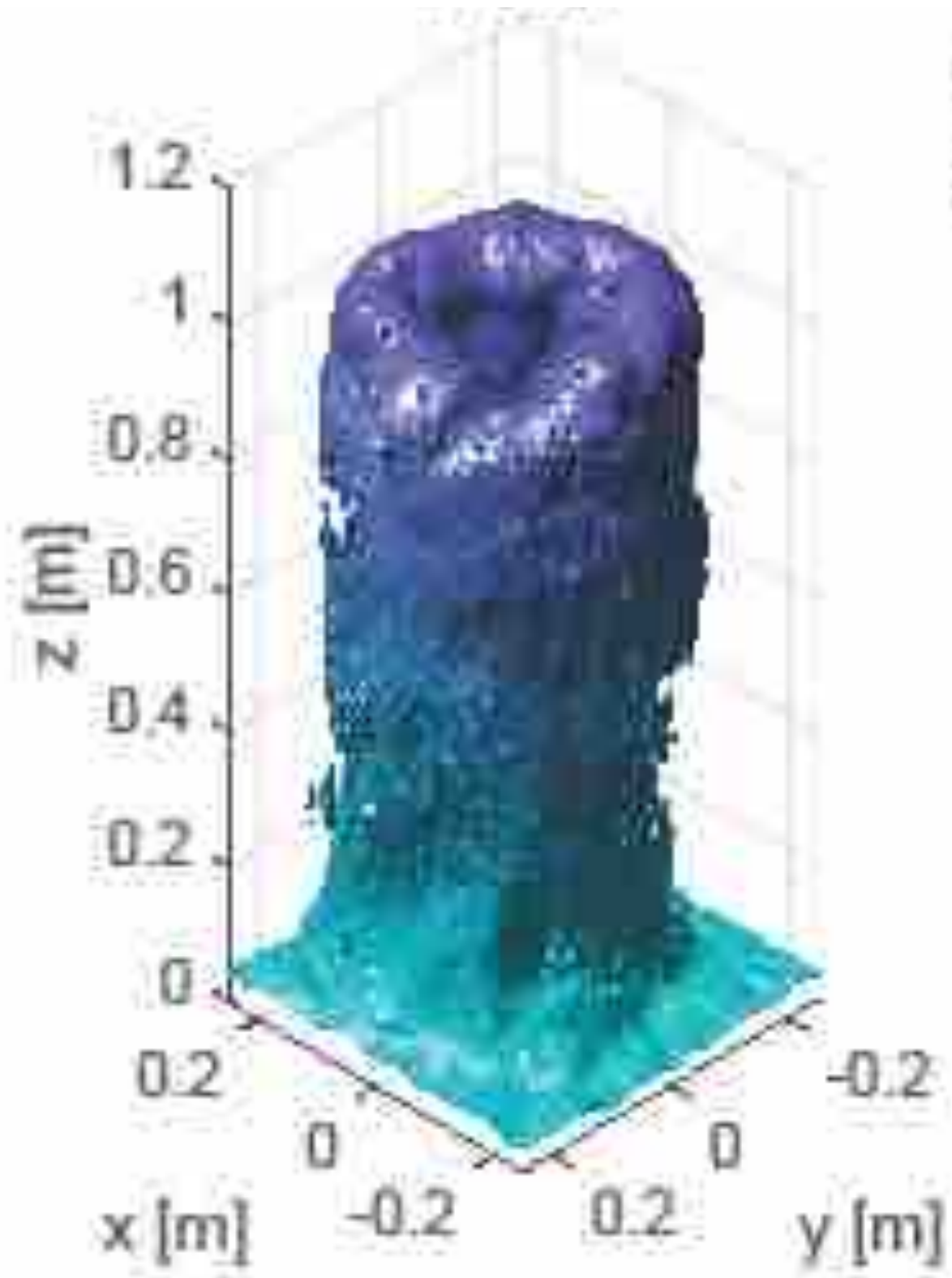


Arbitrary materials



Scan-drone

Build-drone



Multi-Agent Aerial-AM: Virtual Printing with Multiple Robots

Aerial Additive Manufacturing

nature



BUILDER DRONES

3D construction using
bee-inspired aerial robots

Zhang, K., Chermprayong, P., Xiao, F., Tzoumanikas, D., Dams, B., Kay, S., Kocer, B.B, Burns, A., Orr, L., Alhinai, T., Choi, C., Darekar, D.D., Li, W., Hirschmann, S., Soana, V., Ngah, S.A., Grillot, C., Sareh, S., Margheri, L., Pawar, V., Ball, R.J., Williams, C., Shepherd, P., Leutenegger, S., Stuart-Smith, R., Kovac, M., (2022)
Aerial Additive Manufacturing: 3D Printing with Multiple Autonomous Aerial Robots
Nature 2022 (cover article)

Aerial Additive Manufacturing

The international journal of science / 22 September 2022

nature

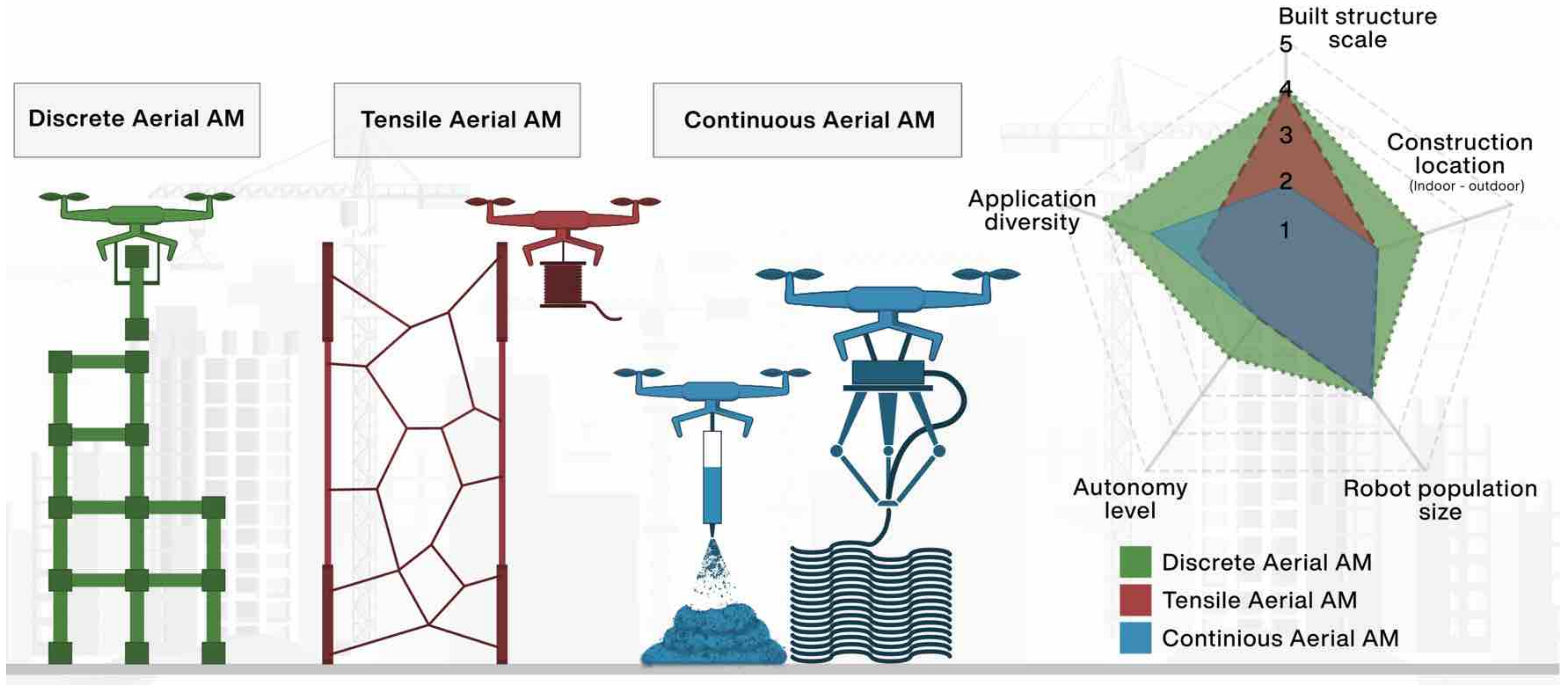


BUILDER DRONES

3D construction using
bee-inspired aerial robots

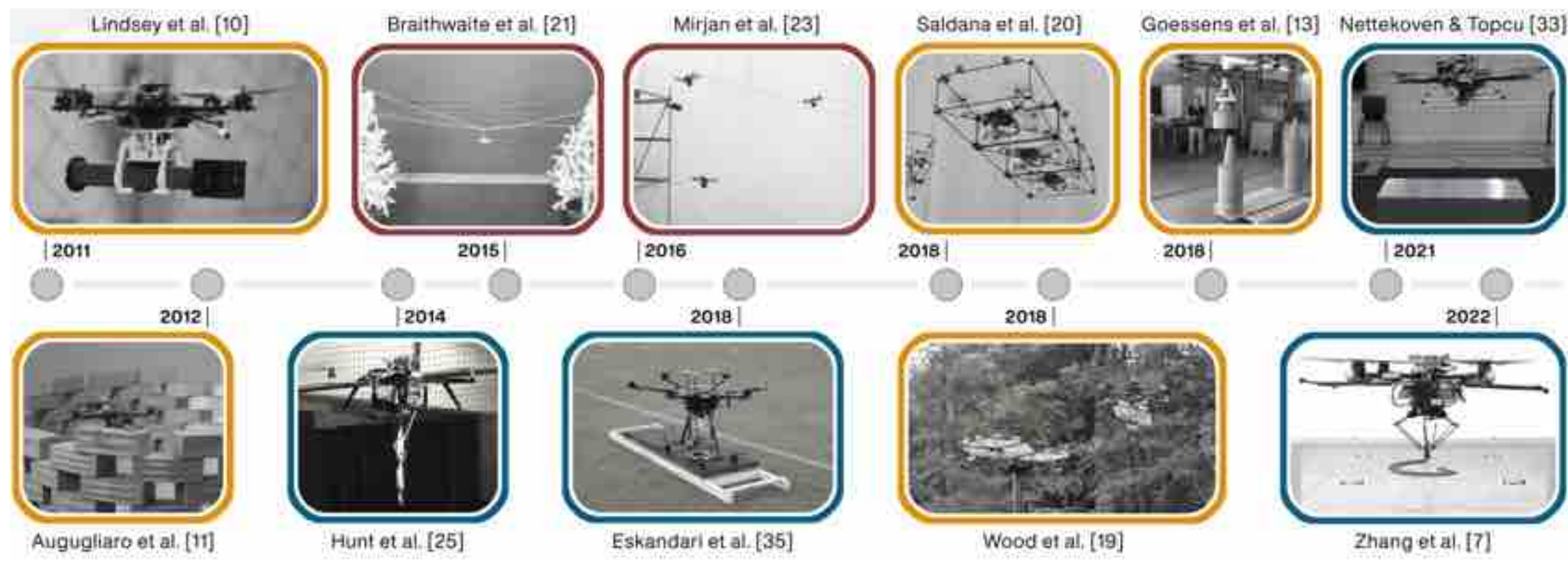
Zhang, K., Chermprayong, P., Xiao, F., Tzoumanikas, D., Dams, B., Kay, S., Kocer, B.B, Burns, A., Orr, L., Alhinai, T., Choi, C., Darekar, D.D., Li, W., Hirschmann, S., Soana, V., Ngah, S.A., Grillot, C., Sareh, S., Margheri, L., Pawar, V., Ball, R.J., Williams, C., Shepherd, P., Leutenegger, S., Stuart-Smith, R., Kovac, M., (2022) Aerial Additive Manufacturing: 3D Printing with Multiple Autonomous Aerial Robots *Nature* 2022 (cover article)

Aerial Additive Manufacturing - Methods

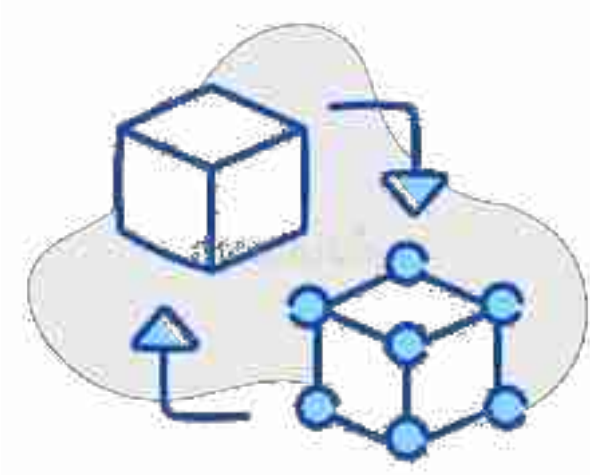


Kaya, Y. F., Orr, L., Kocer, B. B., Pawar, V., Stuart-Smith, R. and Kovac, M.
Science Robotics (2025)

Aerial Additive Manufacturing - Autonomy



Conceptual representation of existing AAMs, the radar chart analysis of them, and their chronological representation.



Kaya, Y. F., Orr, L., Kocer, B. B., Pawar, V., Stuart-Smith, R. and Kovac, M.
Science Robotics (2025)



Kaya, Y. F., Orr, L., Kovac, M., (in prep)

Sustainability Robotics




Aerial Robots as first responders





Aerial Robotics for wind blade inspection



Eco-robotics to protect natural environments



Aerial-aquatic robots to protect aquatic ecosystems



Aerial robotics for ageing infrastructure



Aerial Additive Manufacturing

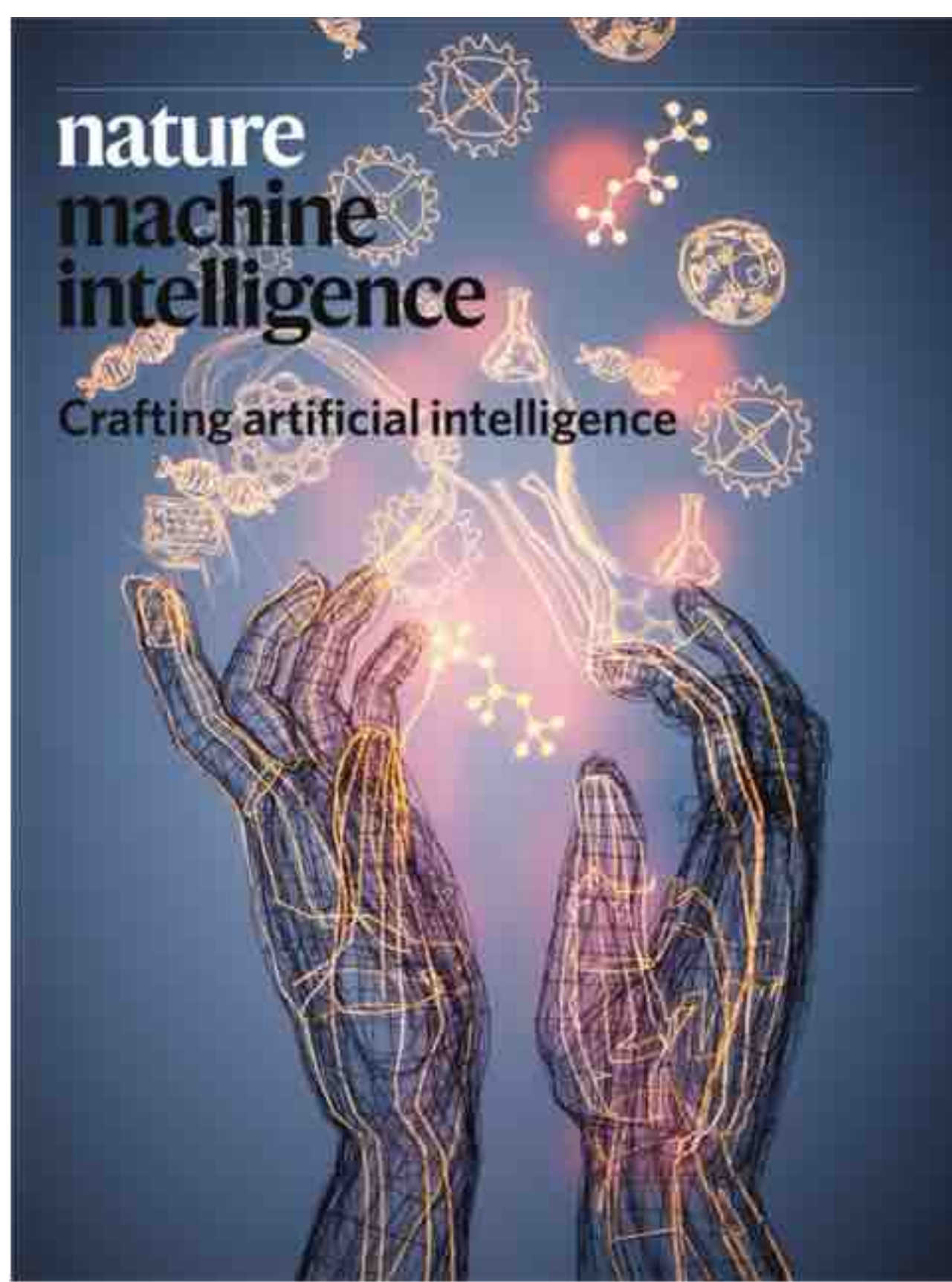


SCIENCE

TECHNOLOGY



Co-development Method: Physical Artificial Intelligence

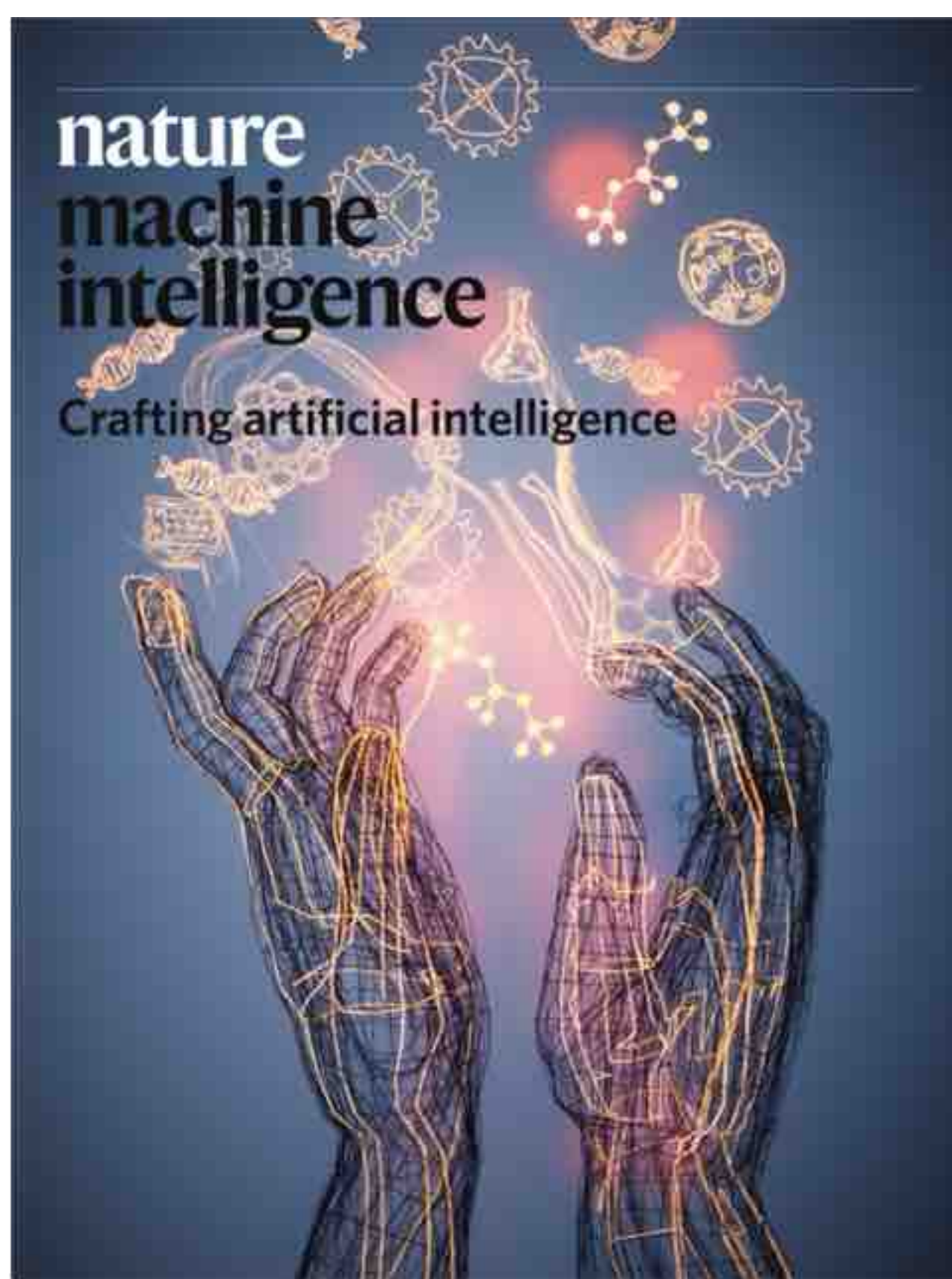


Miriyev, Kovac, Skills for Physical Artificial Intelligence,
Nature Machine Intelligence, 2020 (cover)

Kovac, The Bioinspiration Design Paradigm: A Perspective for Soft Robotics,
Soft Robotics, 2014

Kovac, Learning from nature how to land aerial robots,
Science, 2016

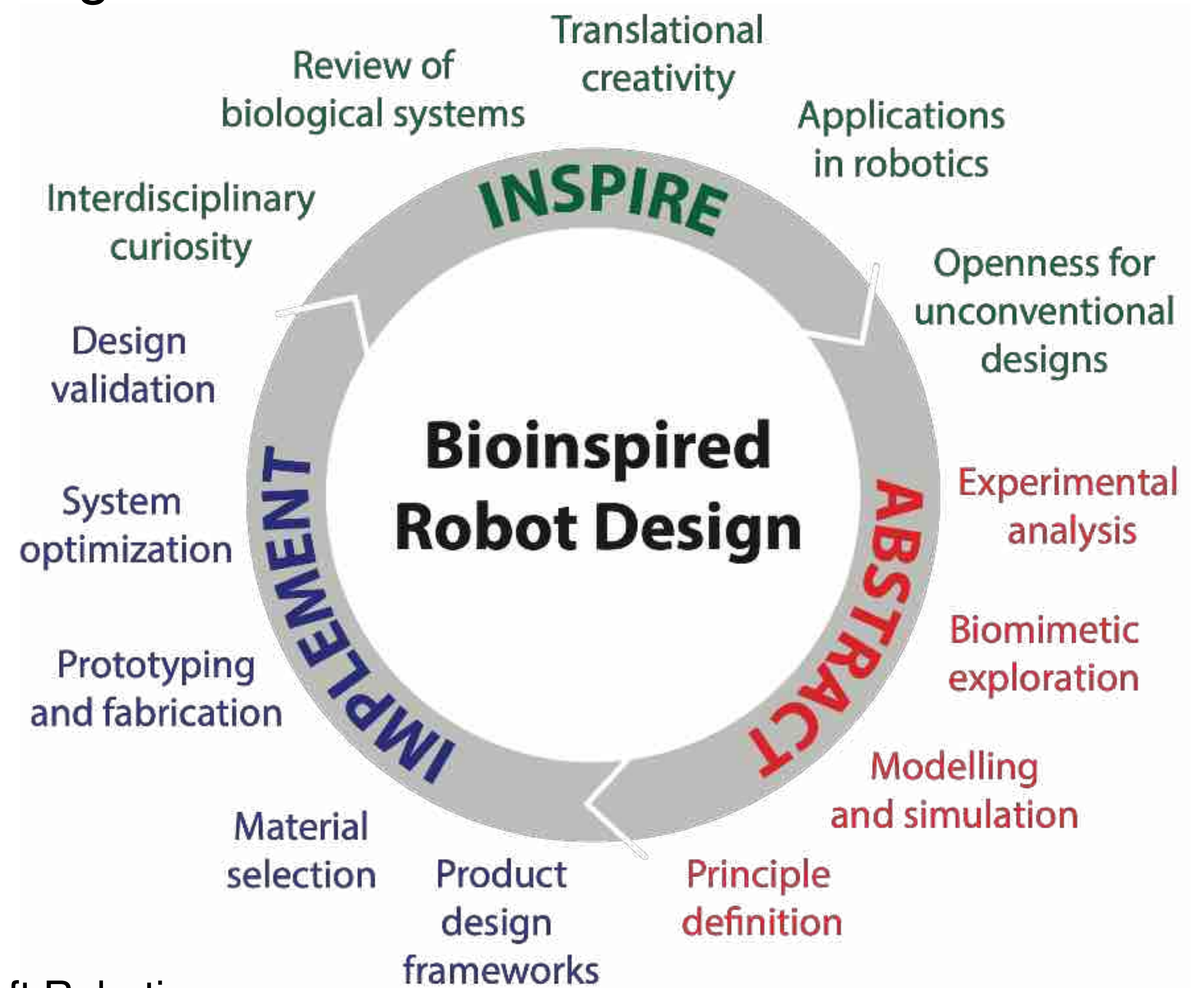
Co-development Method: Physical Artificial Intelligence



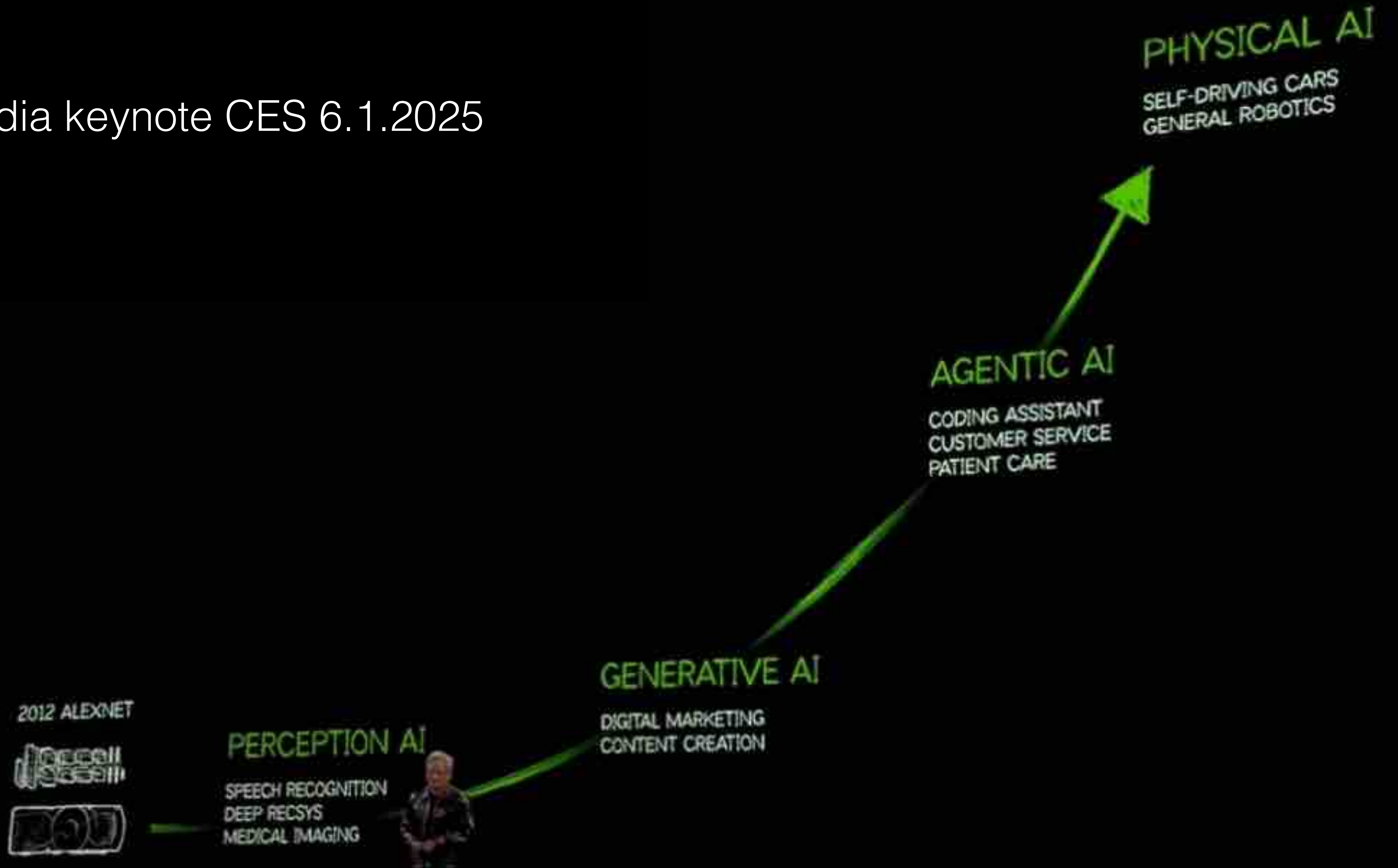
Miriyev, Kovac, Skills for Physical Artificial Intelligence, *Nature Machine Intelligence*, 2020 (cover)

Kovac, The Bioinspiration Design Paradigm: A Perspective for Soft Robotics, *Soft Robotics*, 2014

Kovac, Learning from nature how to land aerial robots, *Science*, 2016



Nvidia keynote CES 6.1.2025



Multi-terrain flight arena in South Kensington



Air/ground/water test areas

- 12m long, 10m wide 5.7m high
- integrated workshops, meeting rooms and student spaces

UK's most advanced drone lab to be built at Imperial College London

£1.25m Brahmil Vasudevan aerial robotics lab will allow development and testing of next-generation flying robots

● **Rise of the drones: how unmanned aircraft took off - video**



📷 The new facility in South Kensington will place the UK at the forefront of drone research.

Photograph: Jean Pierre Muller/AFP/Getty Images

Samuel Gibbs

Thu 6 Nov 2014 06:00 GMT





Indoor Facilities

Gap for a transitional research facility



Outdoor Facilities



Indoor Facilities

Gap for a transitional research facility

Outdoor Facilities

8 DECENT WORK AND ECONOMIC GROWTH



9 INDUSTRY, INNOVATION AND INFRASTRUCTURE



11 SUSTAINABLE CITIES AND COMMUNITIES



12 RESPONSIBLE CONSUMPTION AND PRODUCTION



Empa EPFL
Laboratory of Sustainability Robotics



13 CLIMATE ACTION



14 LIFE BELOW WATER



15 LIFE ON LAND



17 PARTNERSHIPS FOR THE GOALS

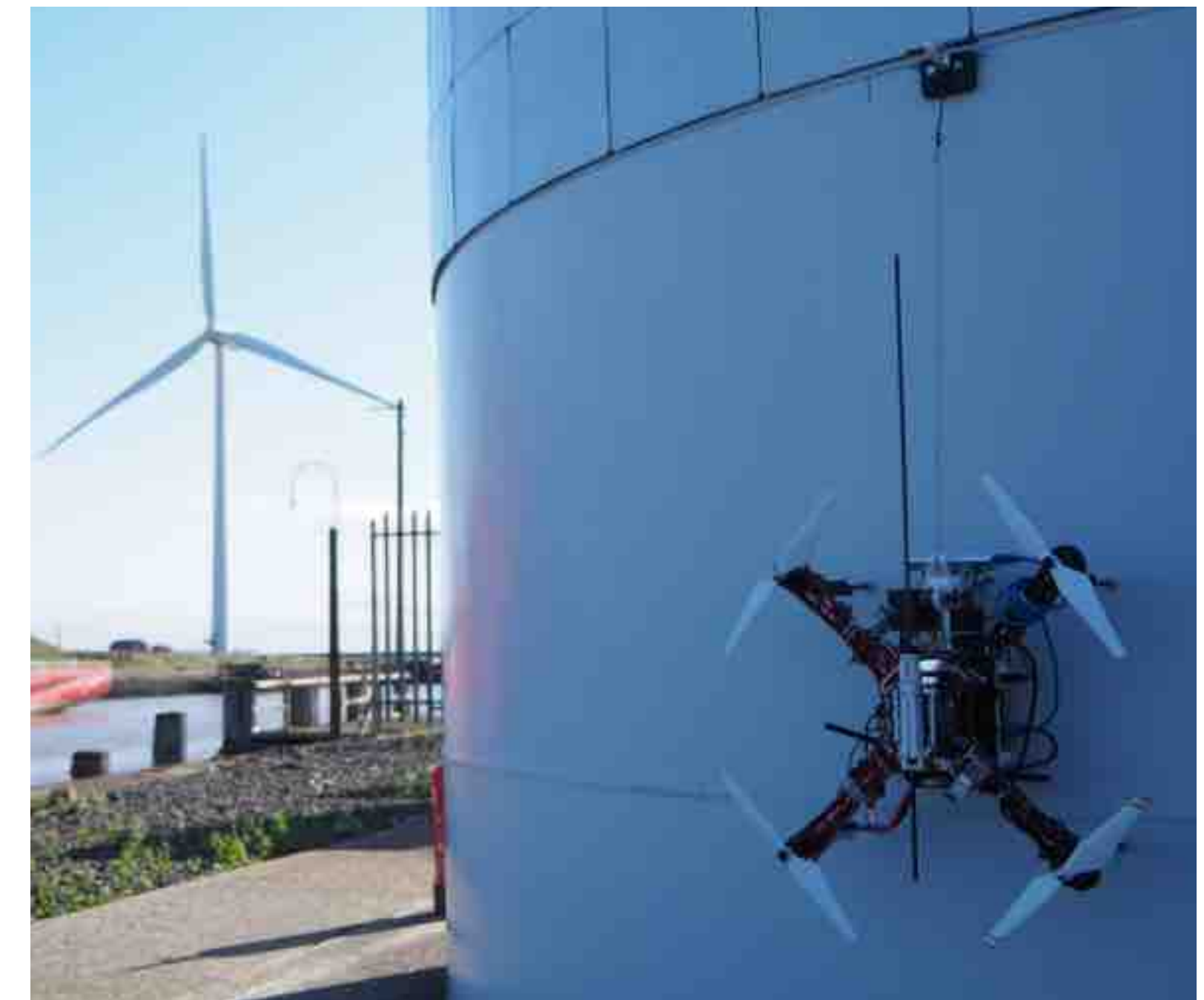


NEST Next Evolution of Sustainable Infrastructure

Infrastructure Robotics Facade

131

- Building interface for logistics
- Drone based Non Destructive Evaluation
- Autonomous recharging



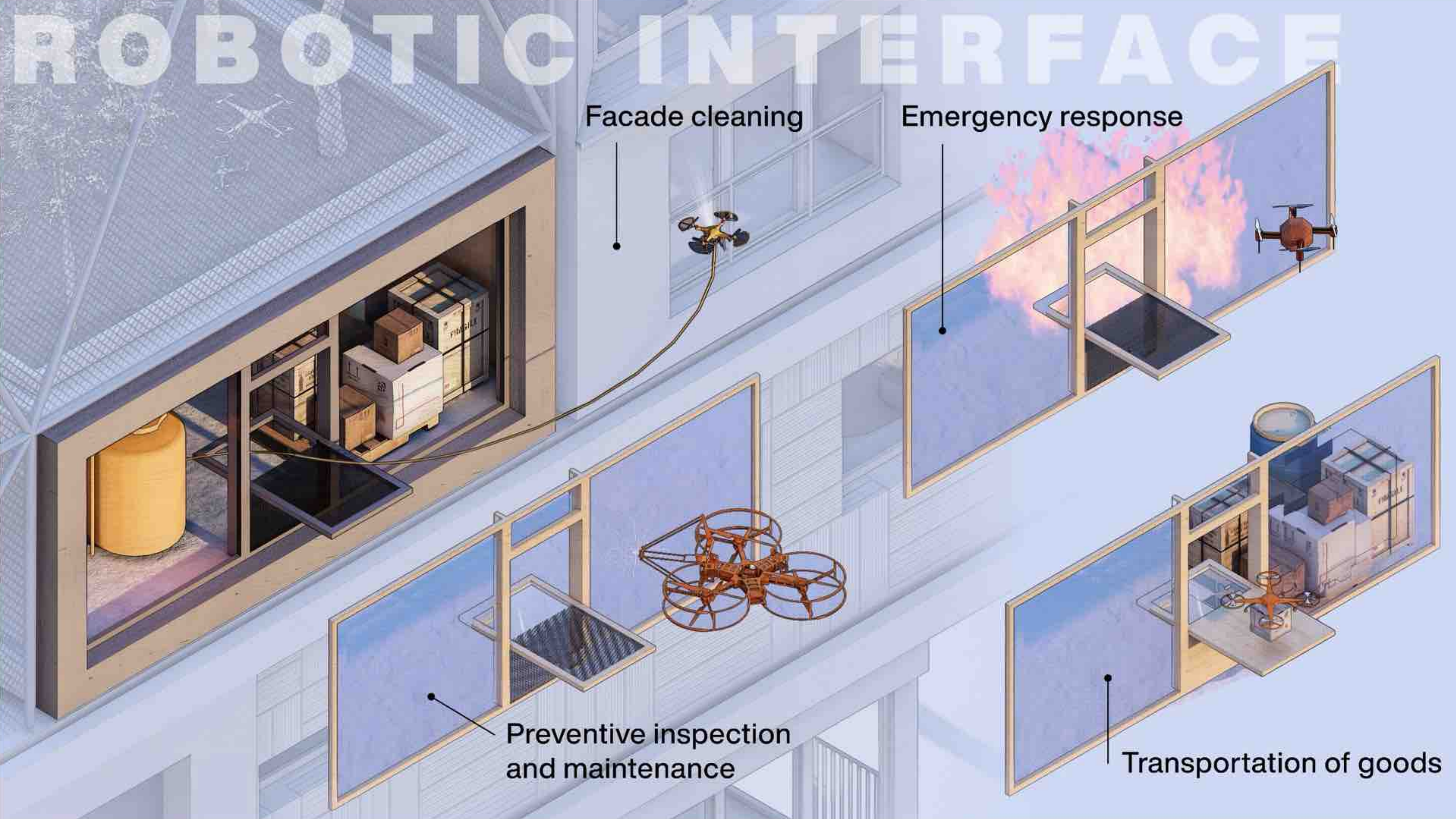
ROBOTIC INTERFACE

Facade cleaning

Emergency response

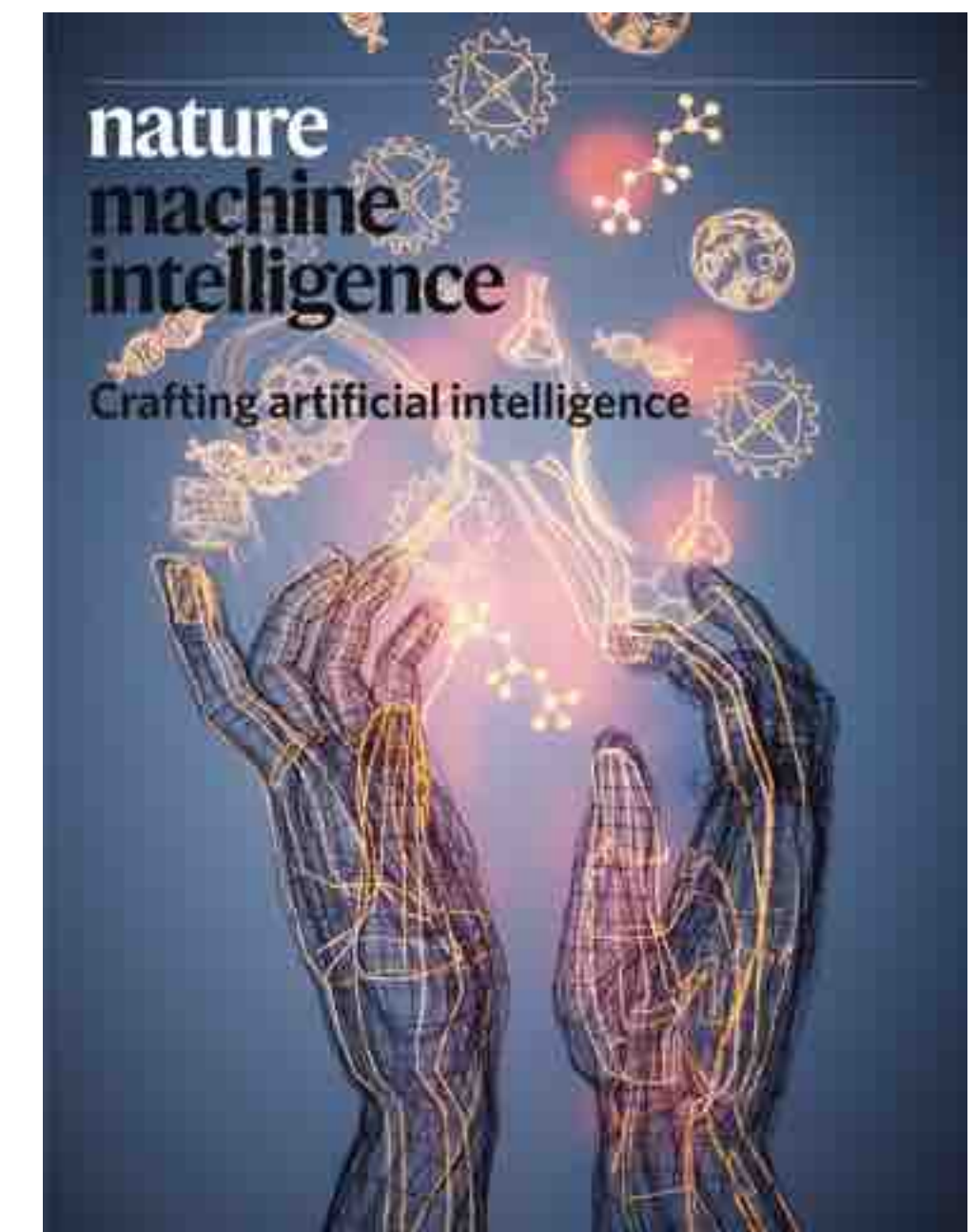
Preventive inspection and maintenance

Transportation of goods



Biosphere for environmental sensing

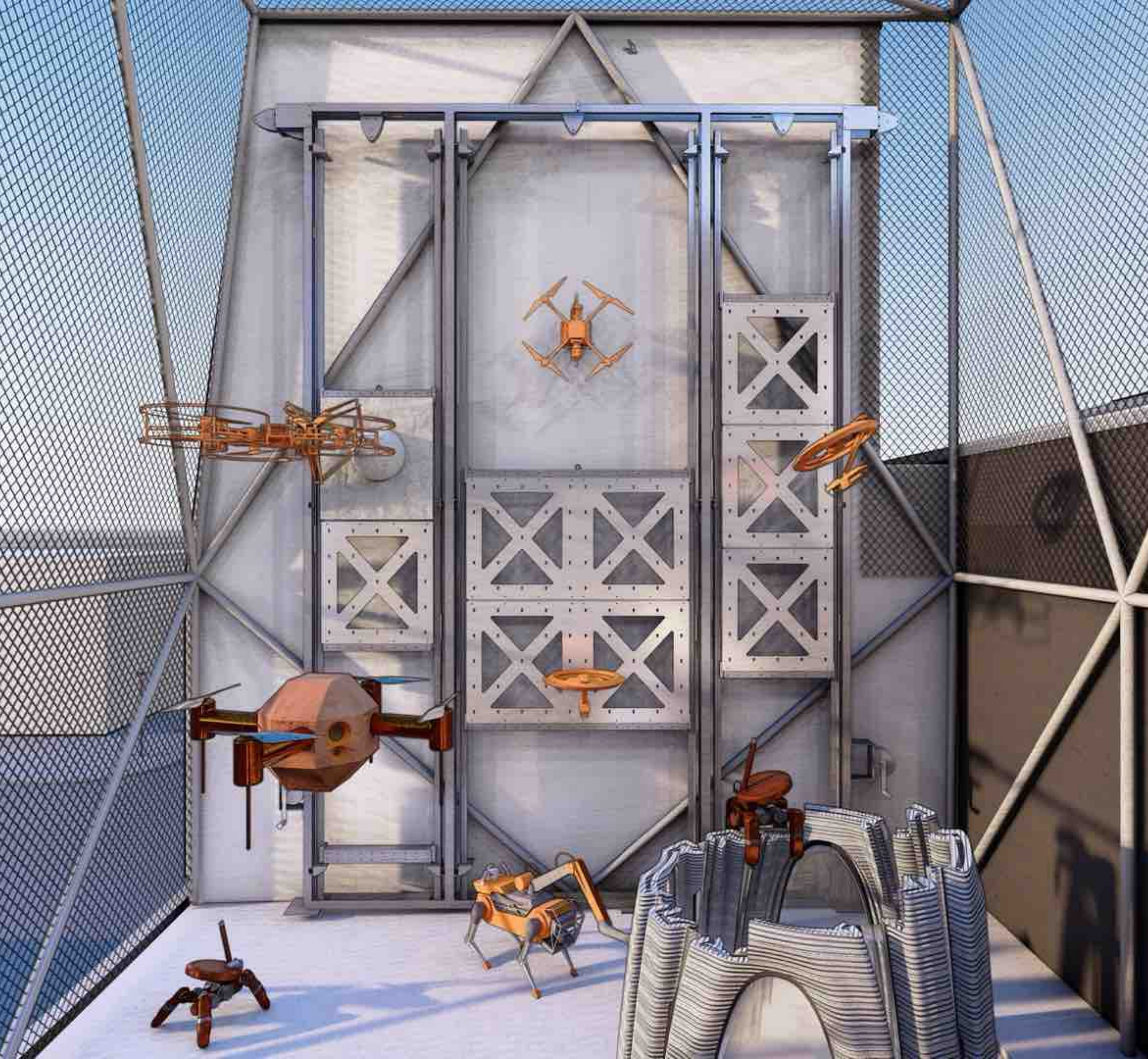
- Transient robots made from bio-polymers
- Long term biodegradability in real-life setting.
- Sustainable circular economy, growing robot structures



ARTIFICIAL BIOSPHERE



Multi-modal robots



Aerial Additive Manufacturing

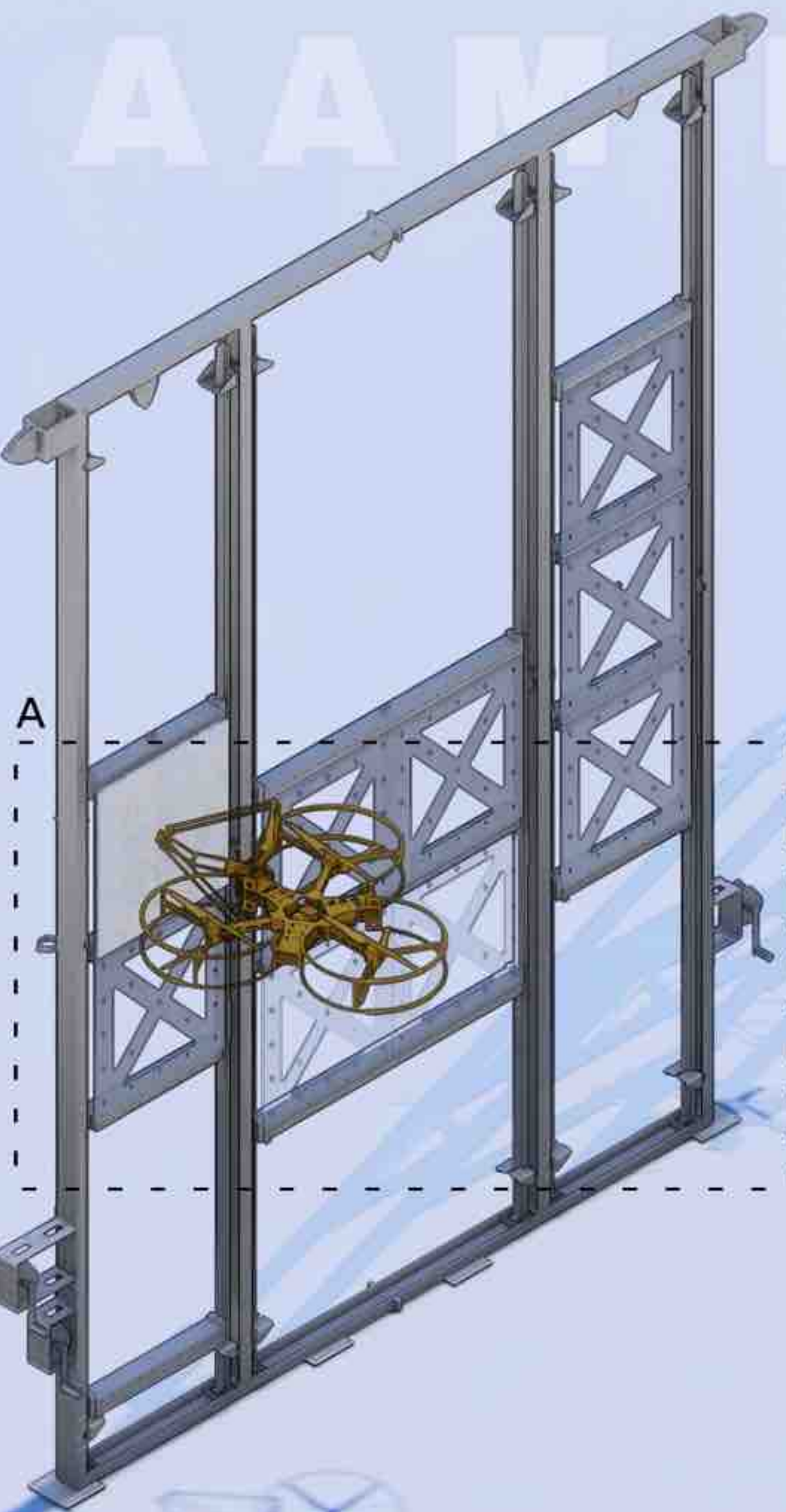
135

- Inspection and repair tasks
- Construction at height
- Modular characteristic
- Safe outdoor flight area



A A M F A C A D E

Manual cranes

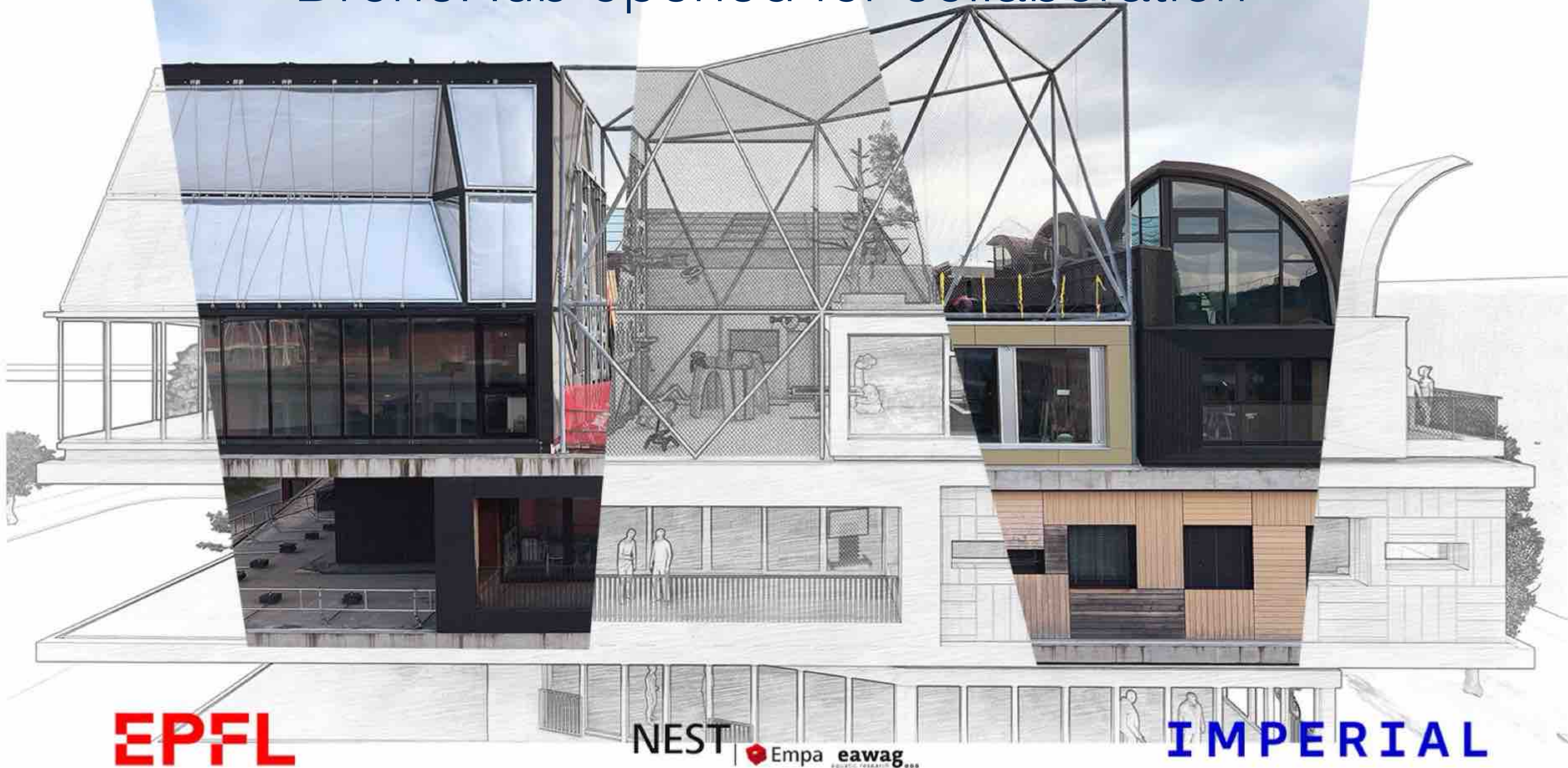


Aluminium back plates

Horizontal mounting bars

Breaking mechanisms

DroneHub opened for collaboration



EPFL

NEST | Empa eawag

IMPERIAL



Aquatic research platform in lake Geneva



LéXPLORE

eawag
aquatic research

EPFL

 **UNIVERSITÉ
DE GENÈVE**

Unil
UNIL | Université de Lausanne

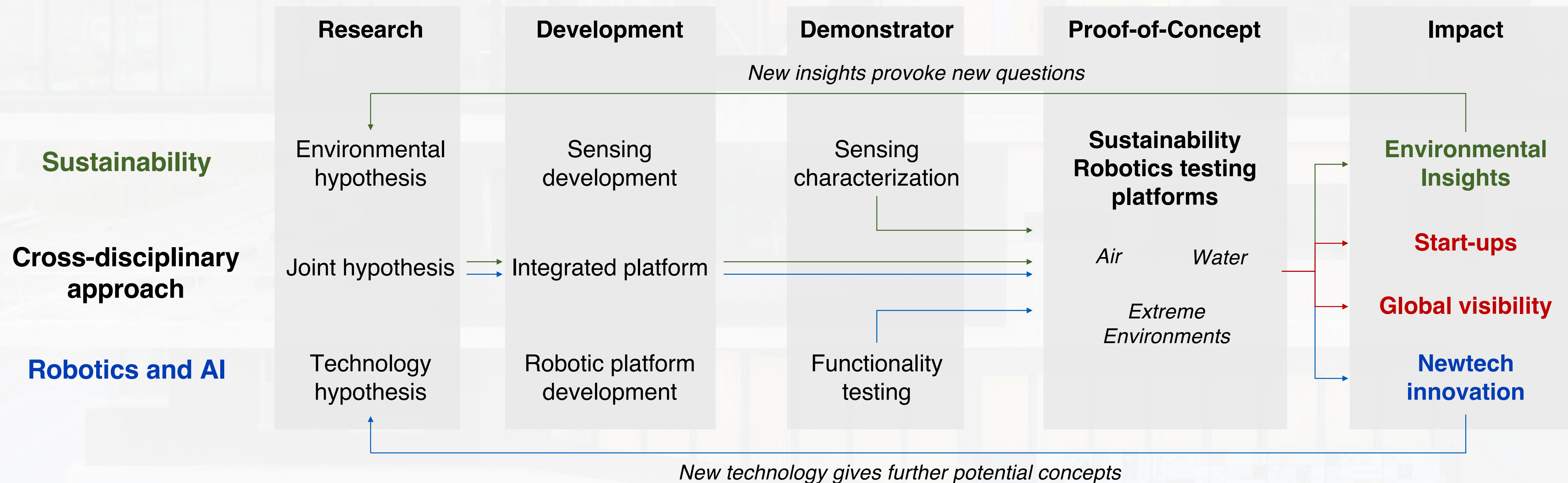
CARTEL
INRAE 

Global Competence Centre for Sustainability Robotics

Vision

A cross-disciplinary hub promoting the collaborative and beneficiary use of physical AI systems towards ecological measurement and the UN sustainability goals.

Innovation pathway for Sustainability Robotics



Global Competence Centre for Sustainability Robotics

Development arenas

Indoor Arena



DroneHub

Flight
Arena



Deployment within Switzerland

Controlled Outdoor Arena

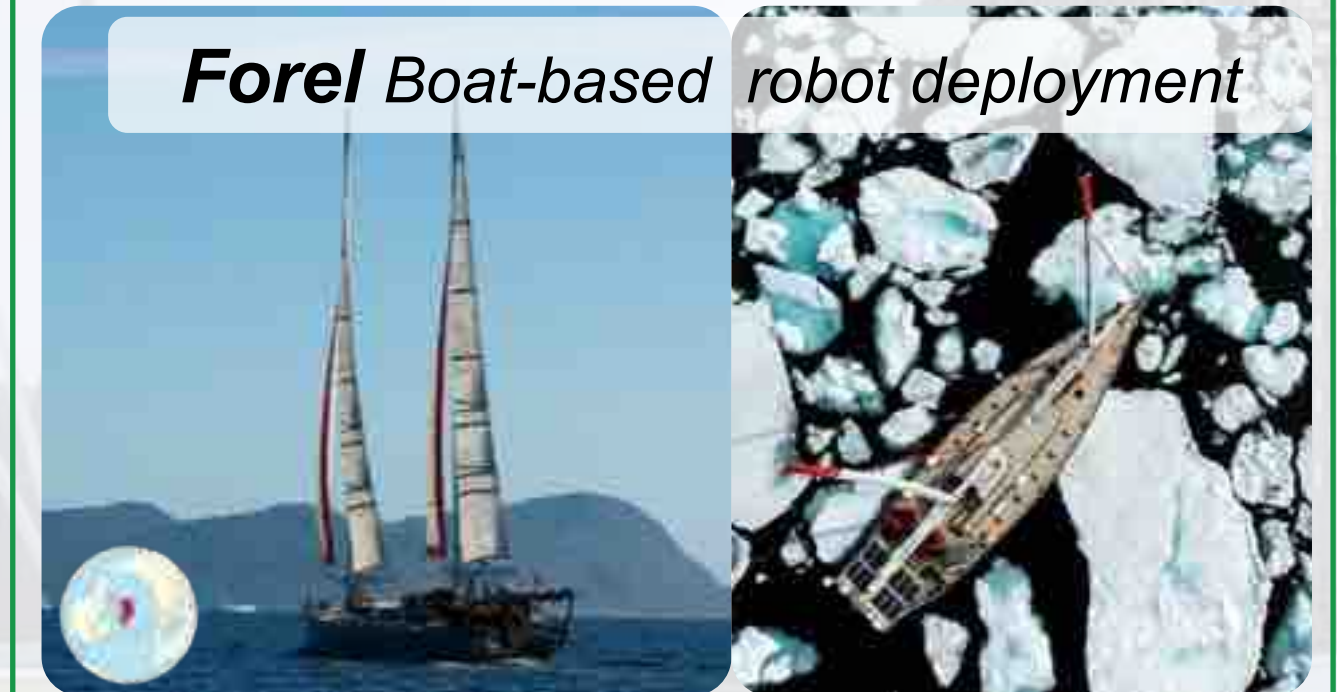


Lac Léman

LéXPLORE

Deployment globally

Greenland



Forel Boat-based robot deployment

The Arctic and Antarctica

Infrastructure

Partners



University of
Zurich ^{UZH}

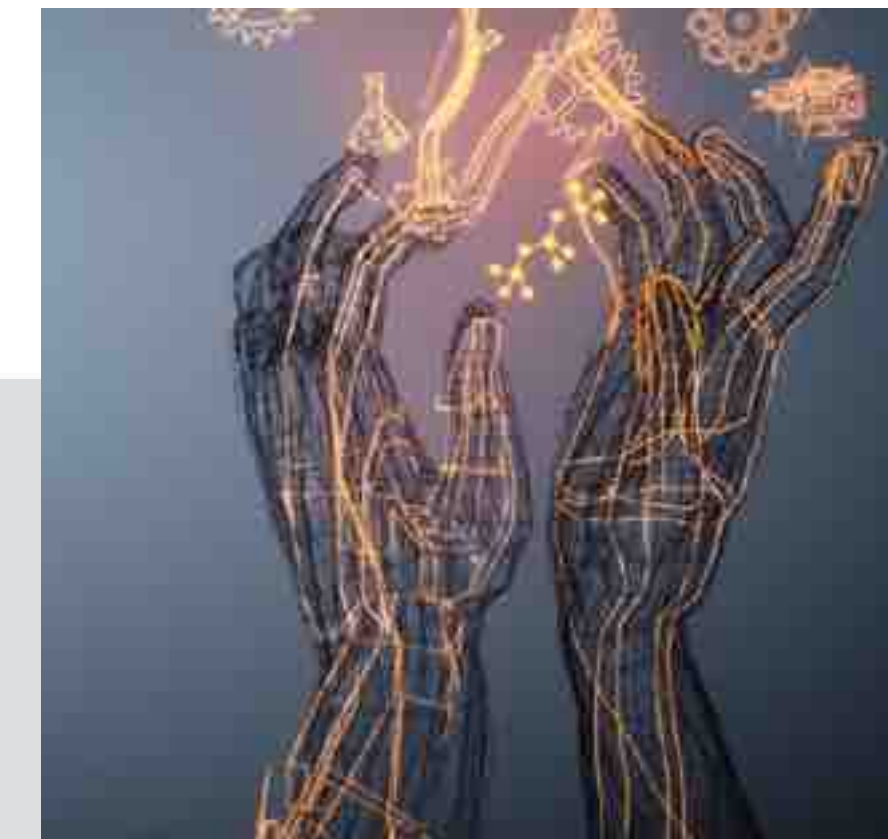
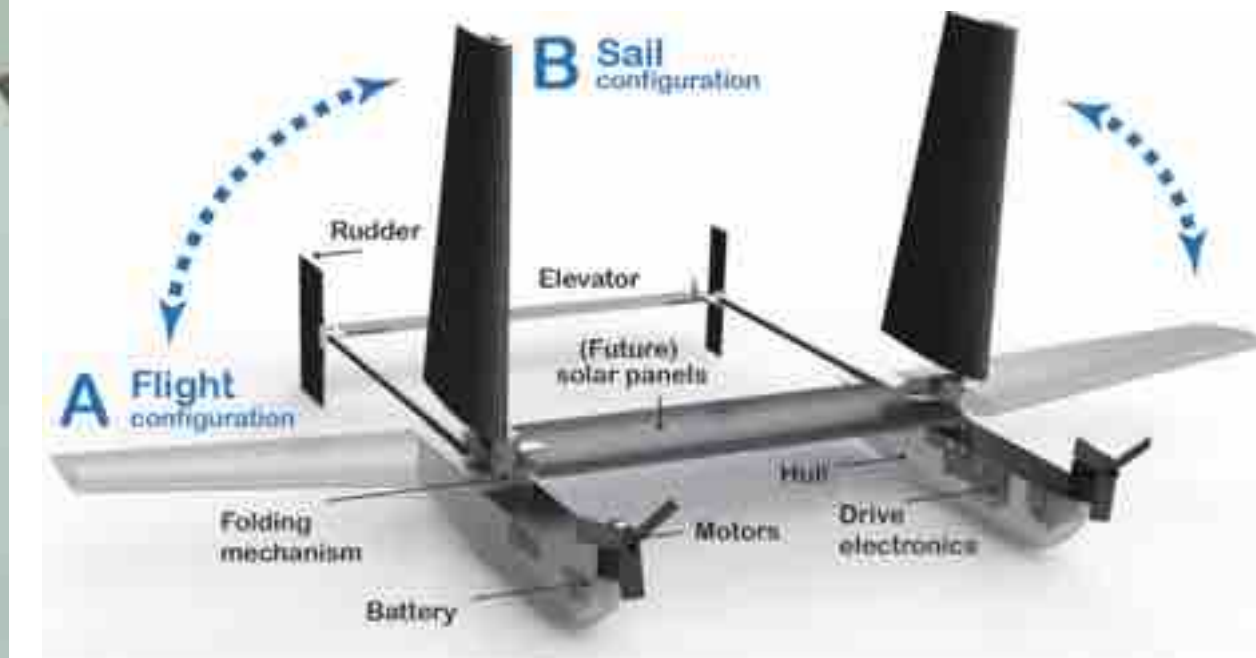
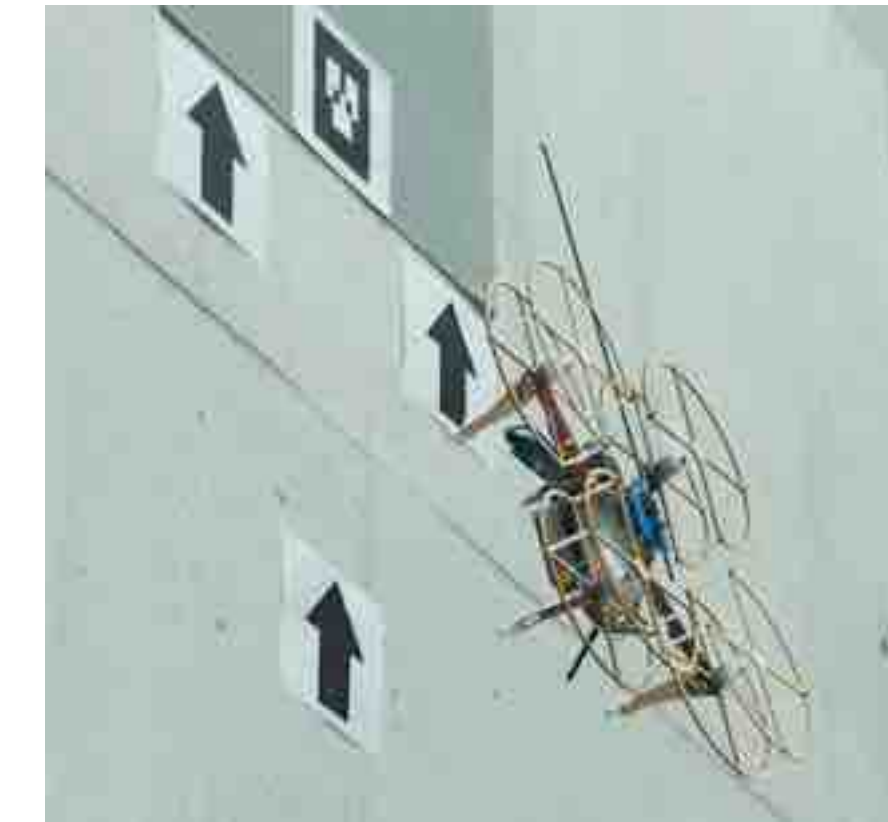
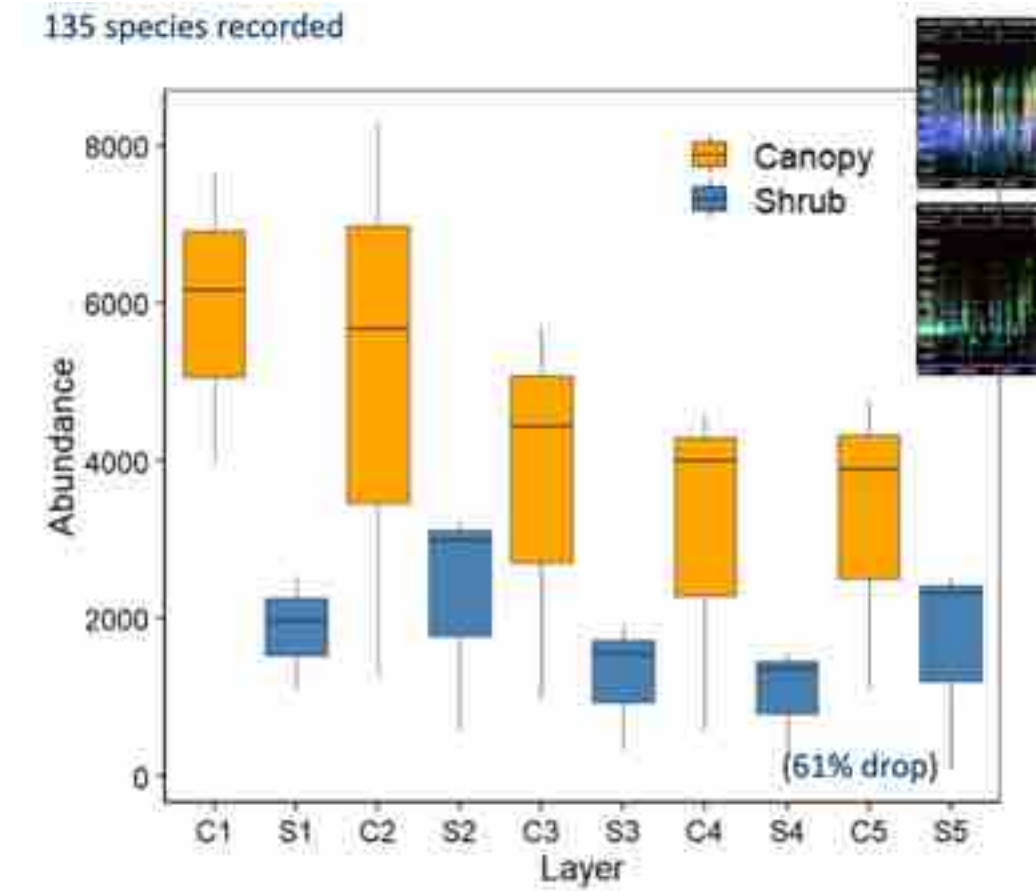


eawag
aquatic research



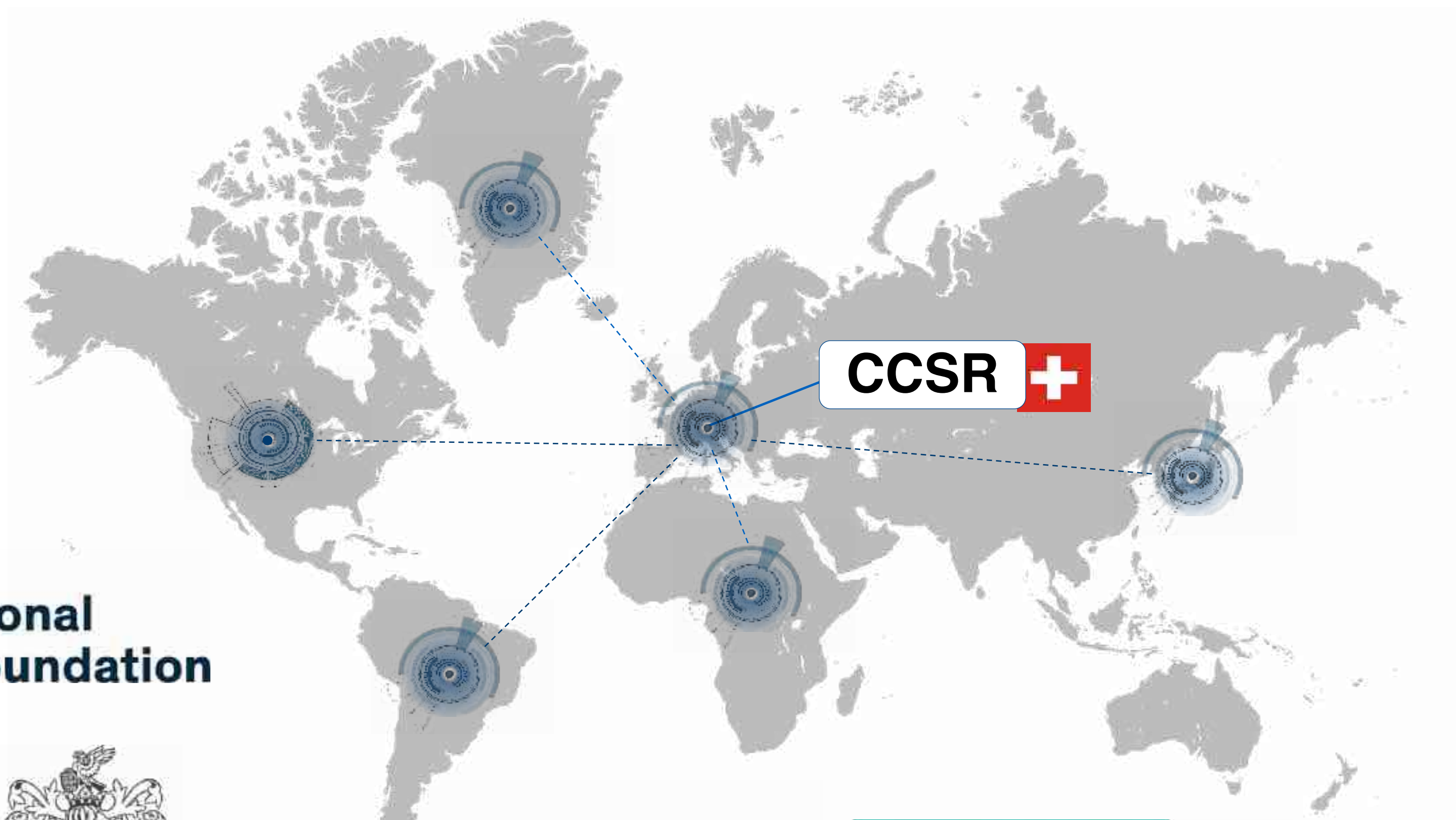
Sustainability Robotics

- ✓ Robotics - Materials - Environments
- ✓ Bio-inspired methods can increase robustness and multi-terrain capabilities
- ✓ Physical AI: Co-evolution of disciplines for lifelike robots
- ✓ DroneHub: Physical AI testbeds for future robotics



Let's continue the conversation

Explore collaborations, discover our projects, and meet the team.



Illustration/visualisation credit: Yusuf Fukan Kaya, Robert Stuart-Smith, Raphael Zufferey, Jose Pereira, Aerial Robotics Lab, Laboratory of Sustainability Robotics, AI LLMs

PROFESSORIAL
LAB
ALUMNI

Raphael Zufferey, Asst. Prof. MIT
Salua Hamaza, Asst.Prof. TU Delft
Sophie Armanini, Senior Lecturer (Assoc. Prof.) Imperial
Basaran Bahadir Kocer, Asst.Prof. (Lecturer) U. of Bristol
Pooya Sareh, Asst.Prof. (Lecturer) U. Liverpool
Sina Sareh, Assoc.Prof. (Reader) Royal College of Arts

Sukho Song, Asst. Prof. DGIST South Korea
Ketao Zhang, Senior Lecturer (Assoc. Prof.) Queen-Mary Uni.
Rob Siddall, Asst.Prof. (Lecturer) University Surrey
Aslan Miriyev, Sen. Lecturer (Assoc. Prof.) B. G. Uni of the Negev
Pisak Chermprayong, Asst.Prof. (Lecturer) Burapha Uni.
Yunus Govedeli Asst.Prof. (Lecturer) Salford Uni.

Appendix

Call for Papers



npj Robotics is an **open-access journal** that publishes high-quality research papers, representing **substantial advances in the field**. Artificial intelligence fuels many of these advances and will reach its full potential when developed in synergy with a robot's body, environment, and application.

npj Robotics aims at stimulating the publication of research that adopts a **holistic stance**, taking the physical nature of robots and their relation and interaction with the world as a departure point.

EXAMPLE TOPICS

- **Physical AI**
- **Embodied intelligence**
- **Bio-inspired learning methods**
- **Bio-inspired AI**
- **Bio-hybrid systems**
- **Soft robotics**
- **Micro- and nano-robotics**
- **Novel sensors and actuators**

npj nature partner
journals

Shinrin-yoku (森林浴) – Forest Bathing

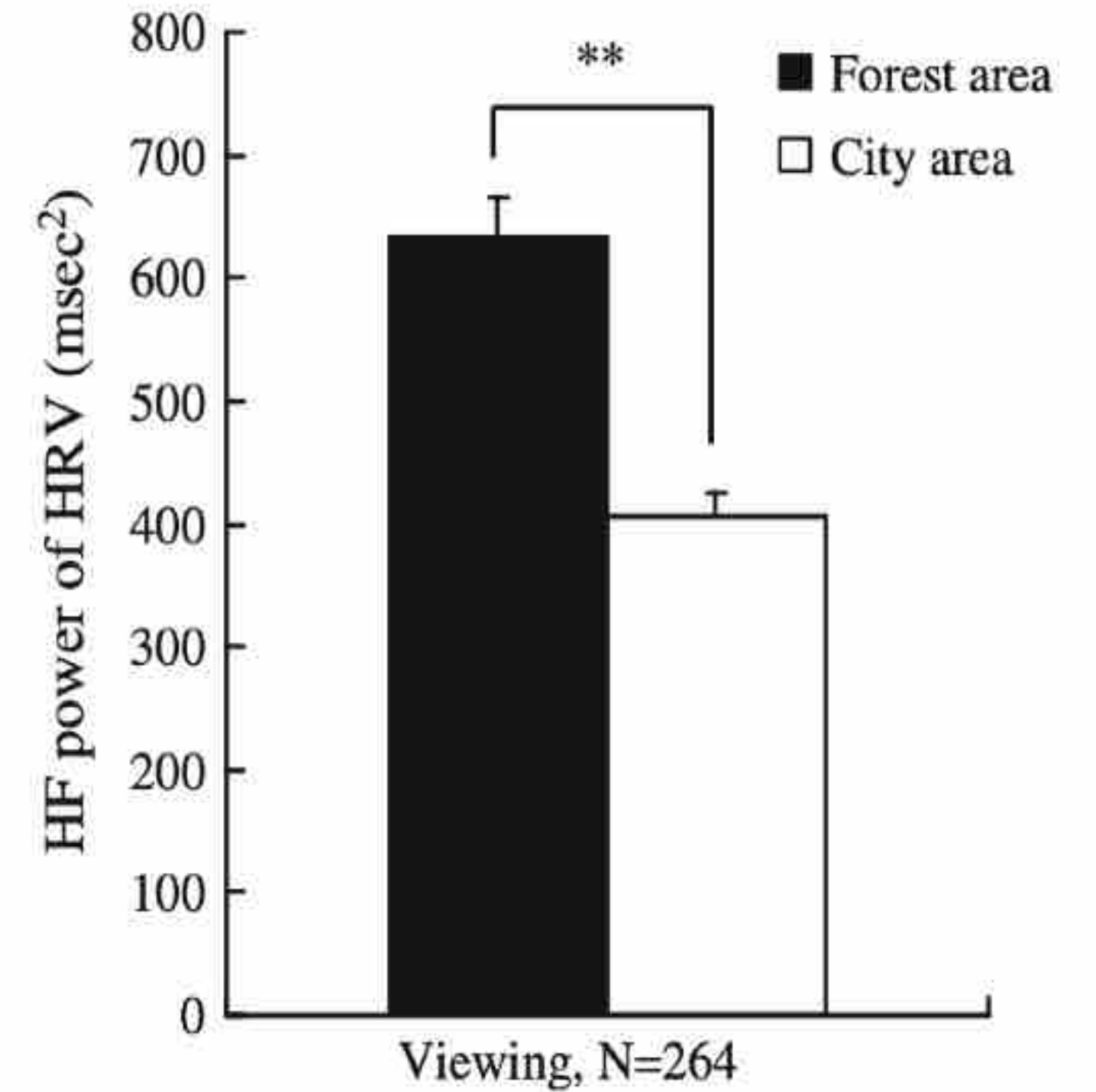
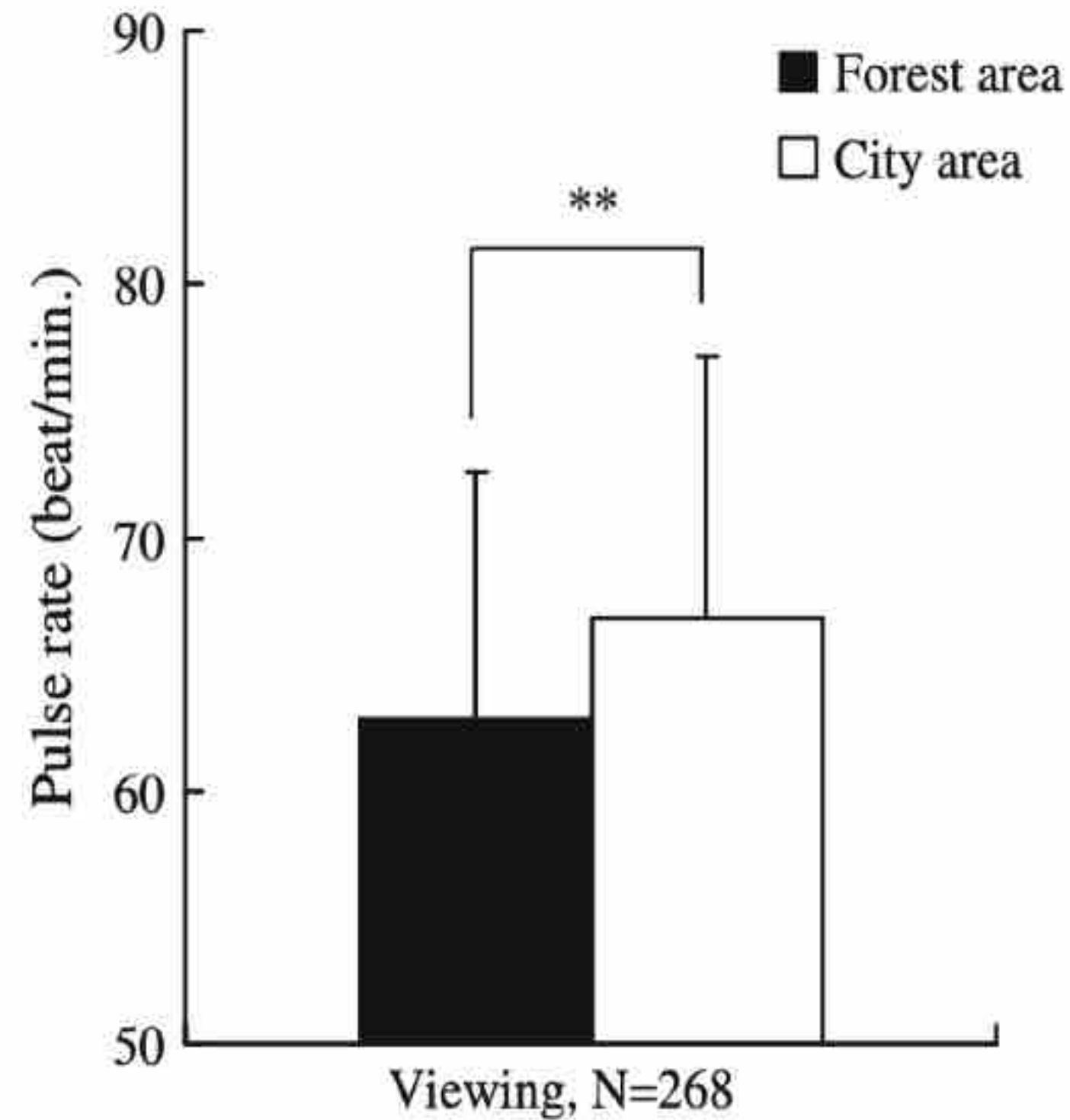
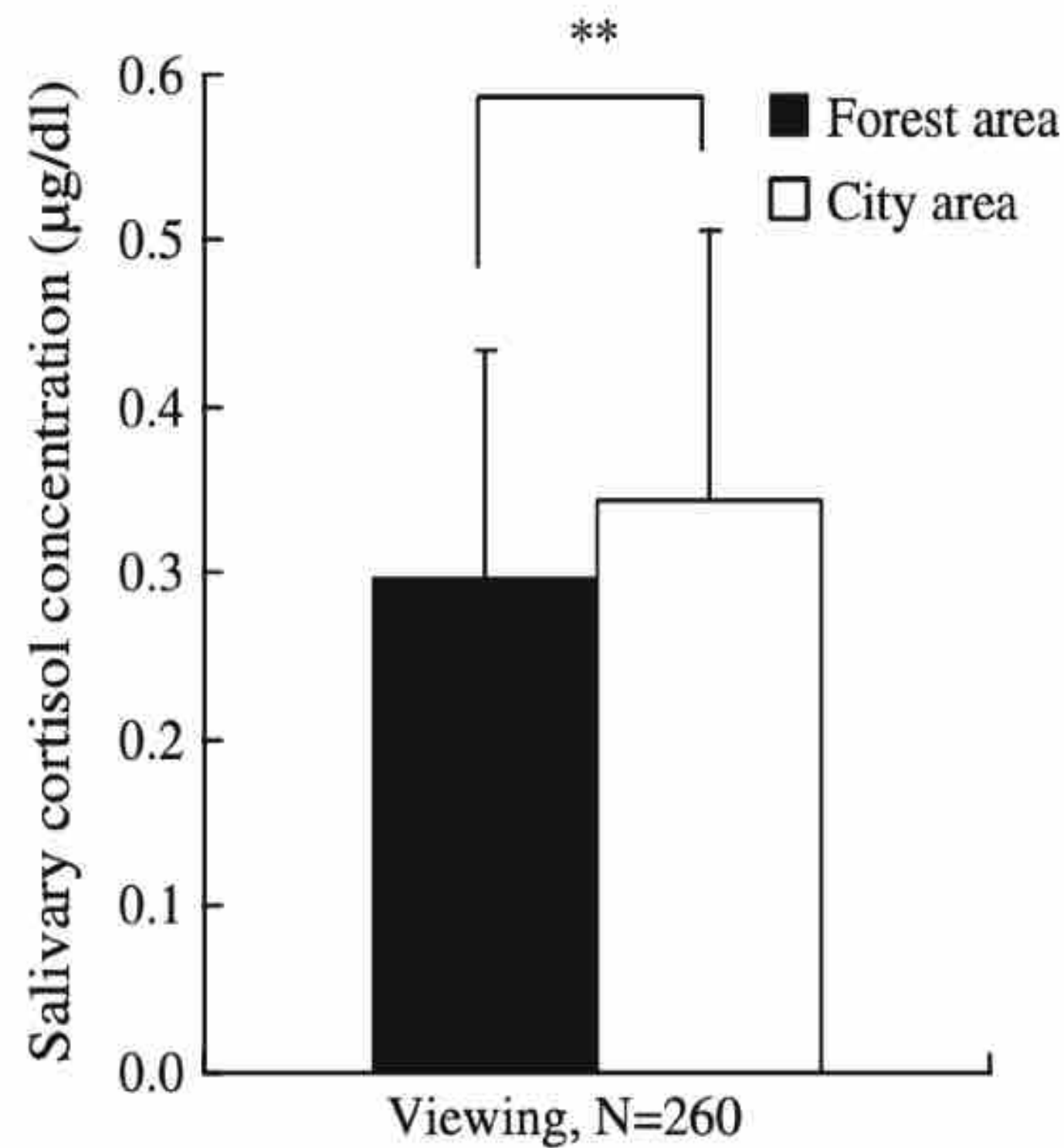
**...making contact with and taking in
the atmosphere of the forest...**

- as defined by the Japanese Ministry of Agriculture, Forestry, and Fisheries in 1982

Benefits

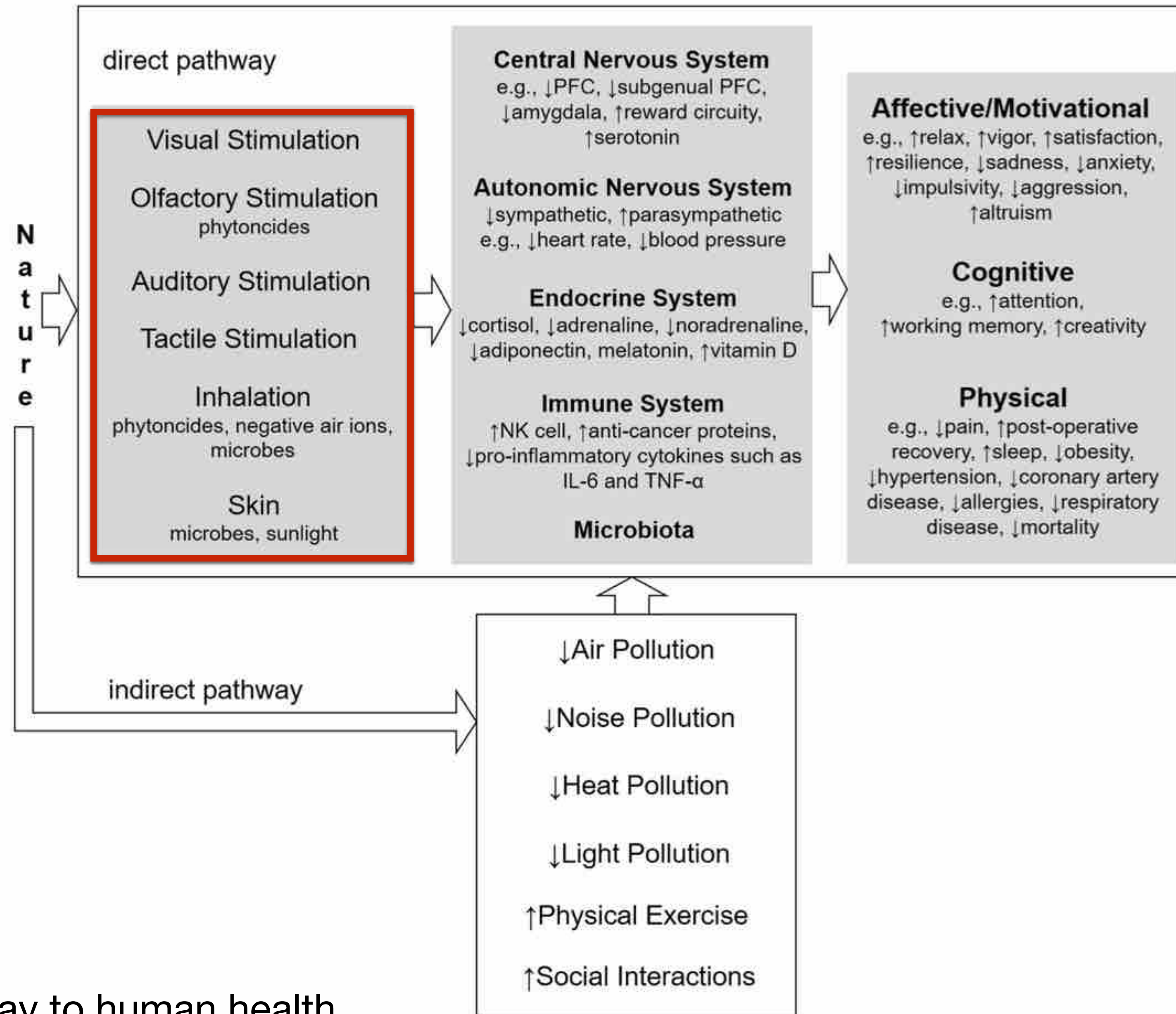
- Reduced stress
- Improved mood
- Enhanced relaxation
- Boosted immune system
- Increased focus
- Lowered blood pressure
- Decreased anxiety
- Improved sleep
- Increased energy levels
- Enhanced creativity
- Reduced inflammation
- Improved mental clarity
- Lowered heart rate
- Better cardiovascular health
- Improved overall well-being

Shinrin-yoku – Health Benefits



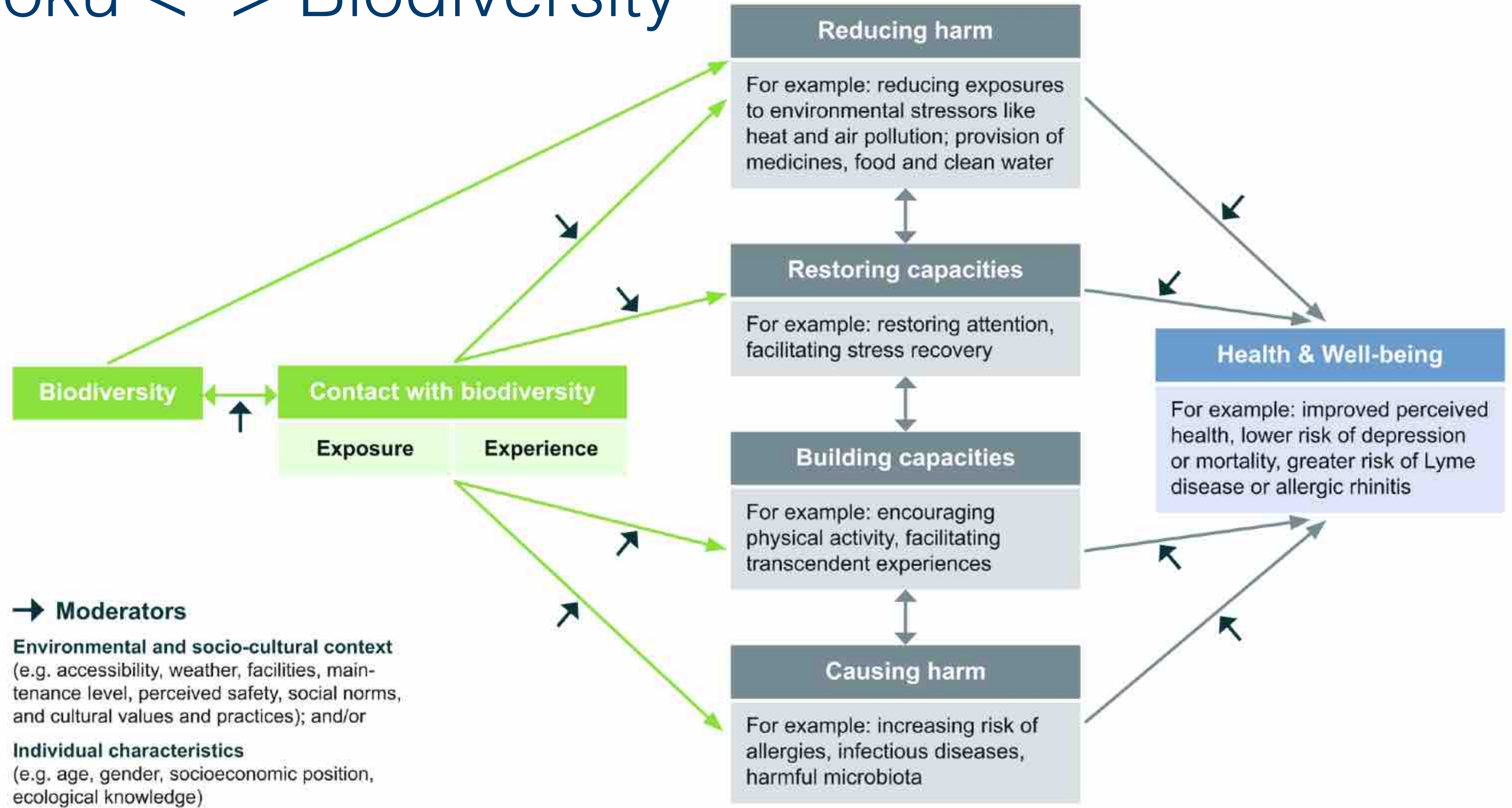
Bum Jin Park, Yuko Tsunetsugu, Tamami Kasetani, Takahide Kagawa,
Yoshifumi Miyazaki *Environ Health Prev Med* (2010)

Shinrin-yoku



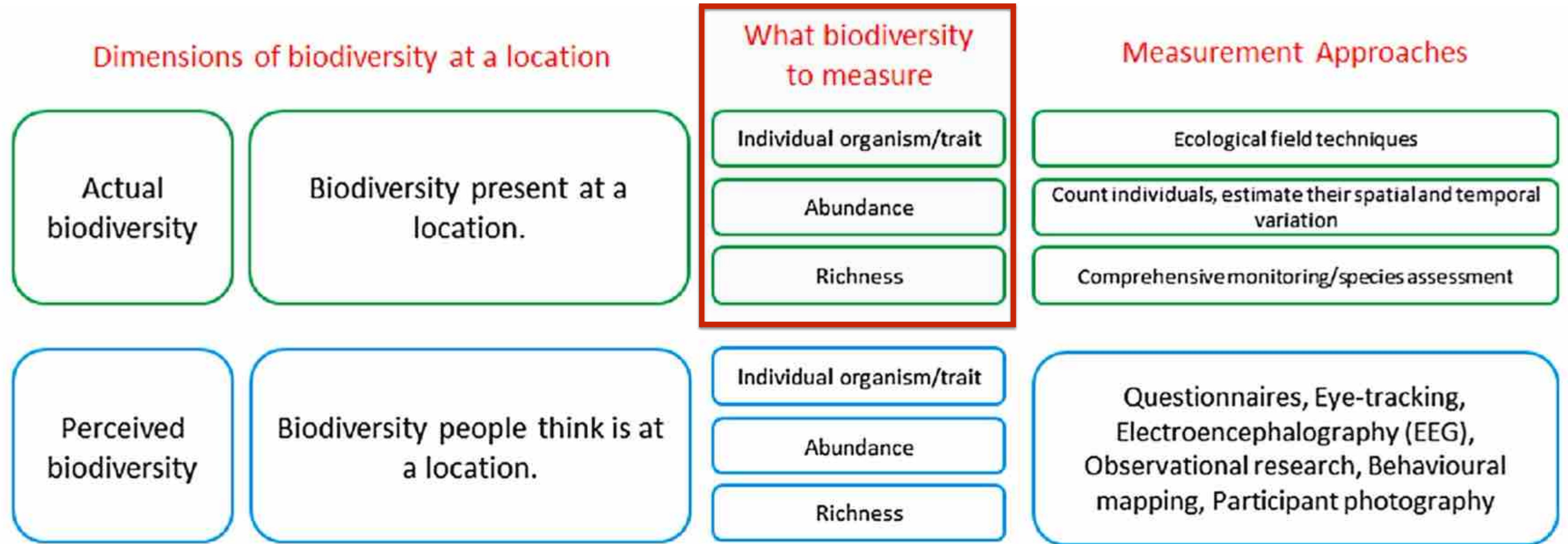
Chen et al. Nature's pathway to human health
International Handbook of Forest Therapy (2019)

Shinrin-yoku \leftrightarrow Biodiversity



Craig et al. Natural environments, nature relatedness and the ecological theater: connecting satellites and sequencing to shinrin-yoku
Journal of Physiological Anthropology (2016)

Shinrin-yoku <—> Biodiversity



Craig et al. Natural environments, nature relatedness and the ecological theater: connecting satellites and sequencing to shinrin-yoku
Journal of Physiological Anthropology (2016)