

Sustainability Robotics



Illustration: Jose Pereja

Prof. Mirko Kovac



Laboratory of Sustainability Robotics

IMPERIAL

Aerial Robotics Laboratory

Robotics innovation global trends

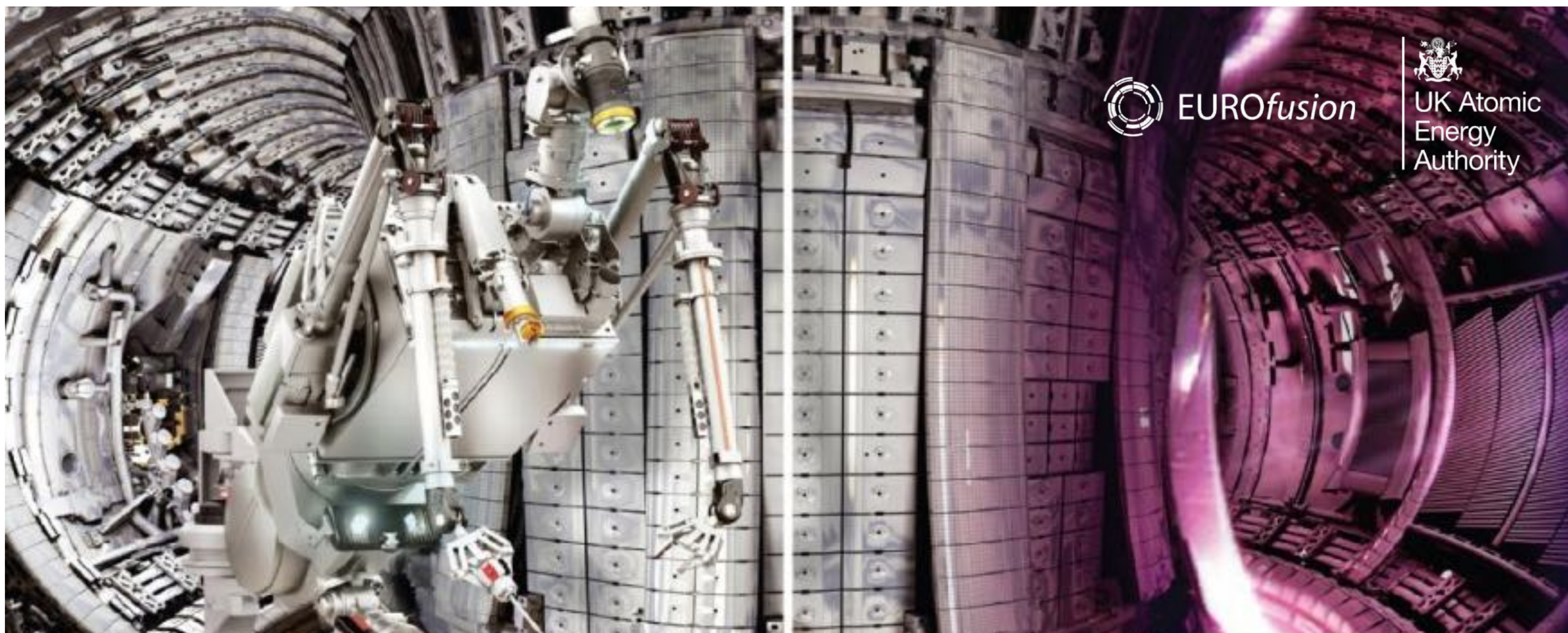
2



Da Vinci robotic surgery system (Intuitive Surgical)

Robotics innovation global trends

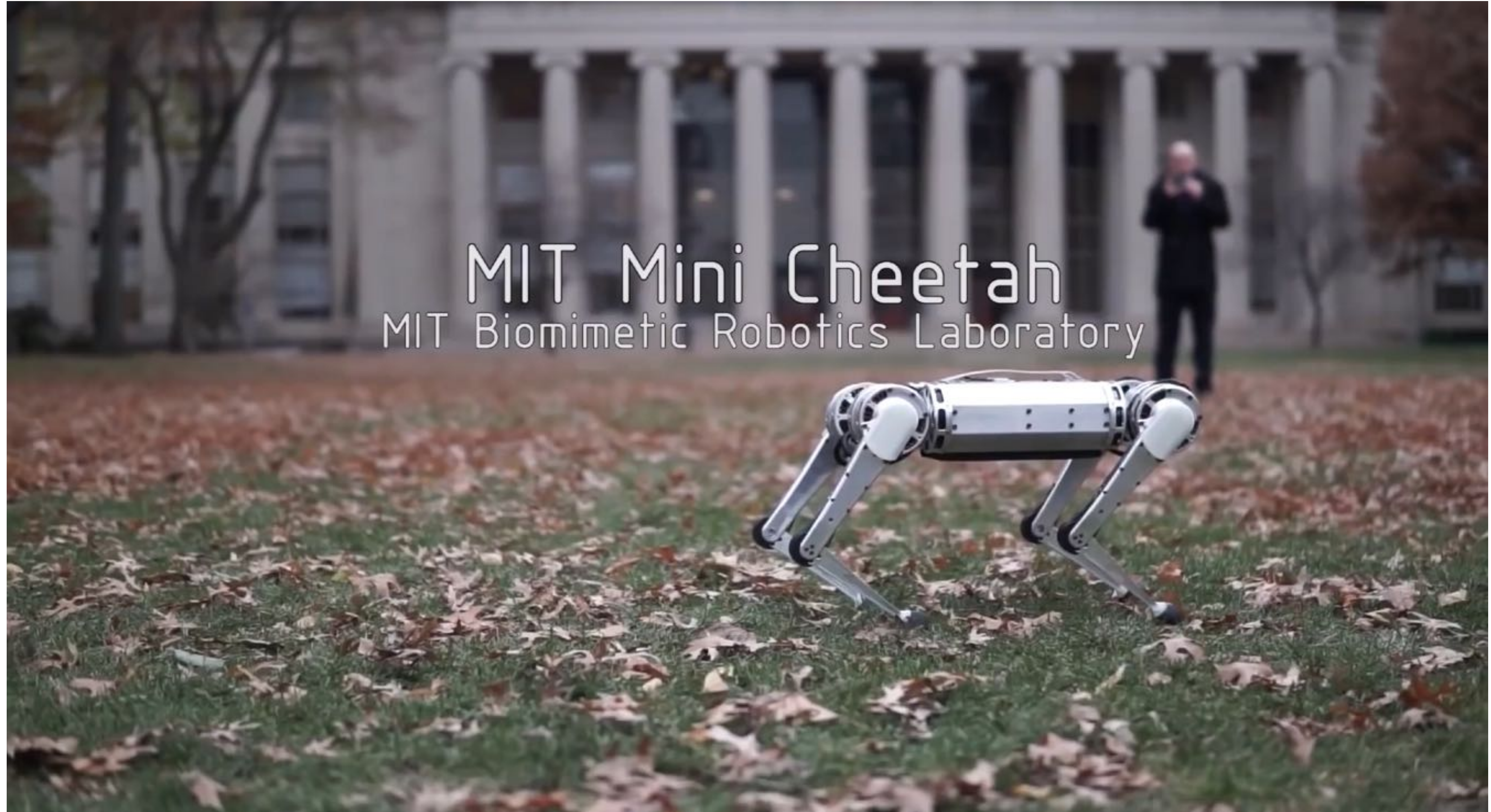
3



Remote Applications in Challenging Environments (RACE) in Culham Oxford

Robotics innovation global trends

4



MIT Cheetah robot (Prof. Sang-bae Kim)

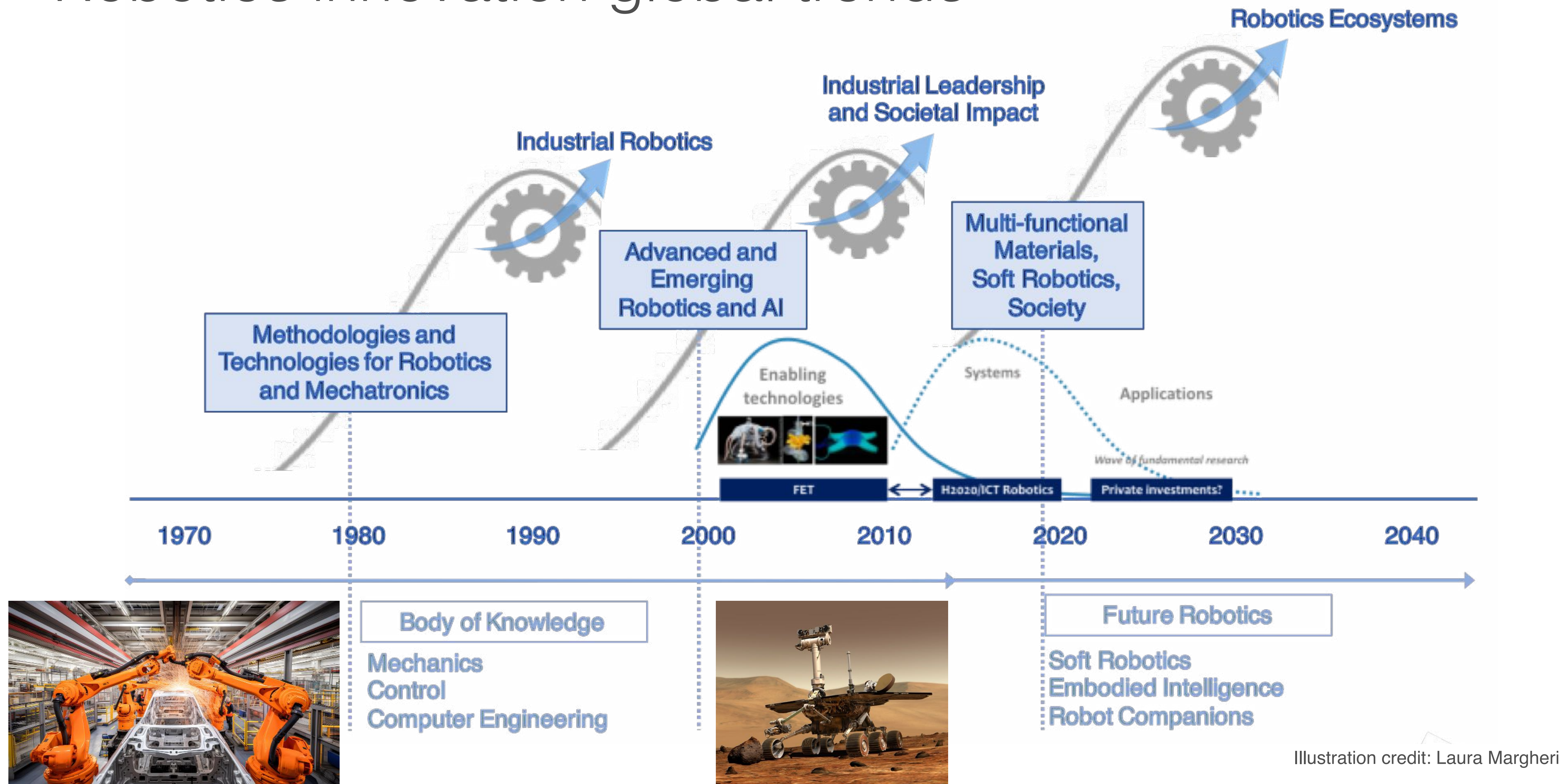
Robotics innovation global trends

5



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

Robotics innovation global trends



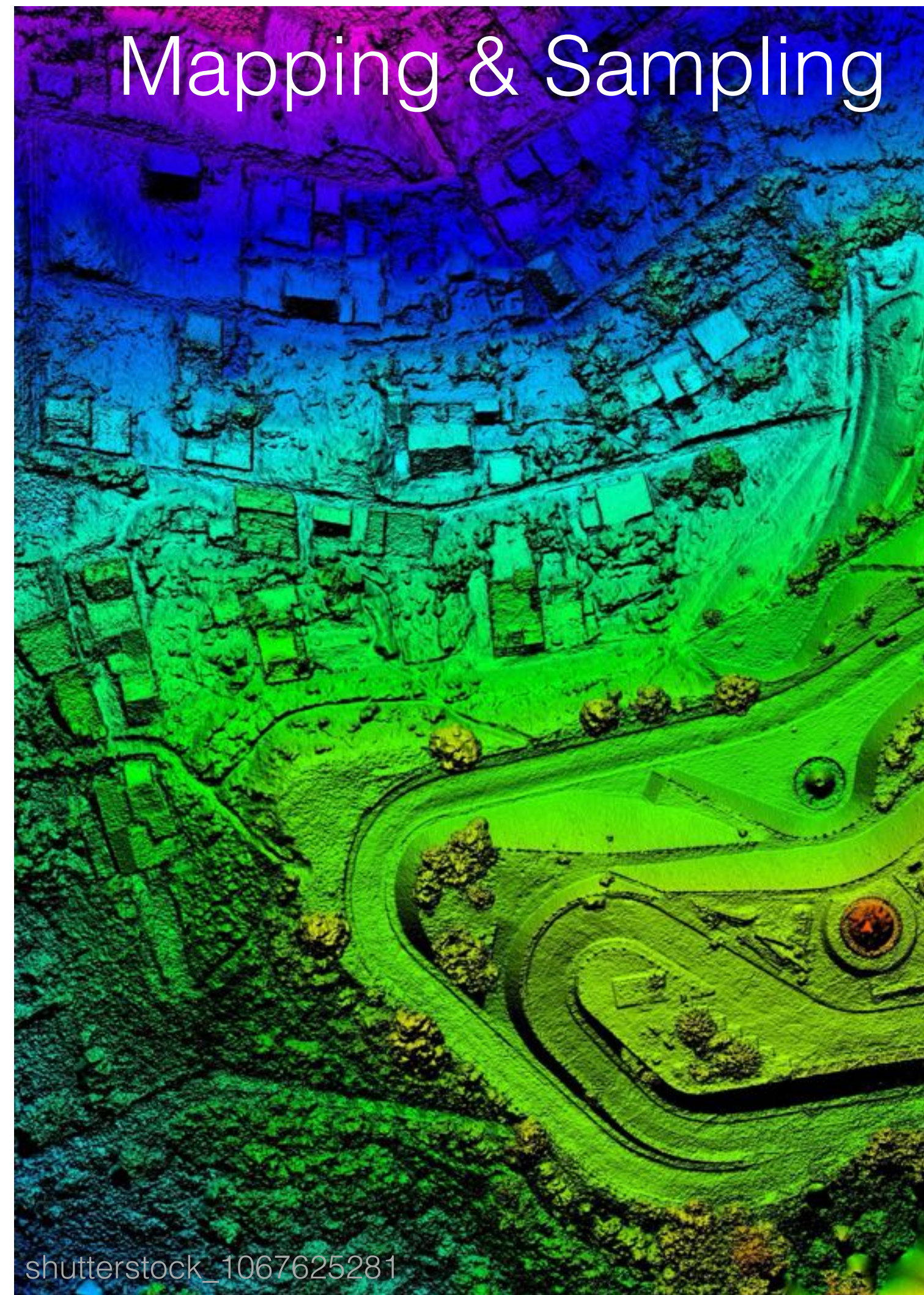


Aerial Robotics based value chain - today

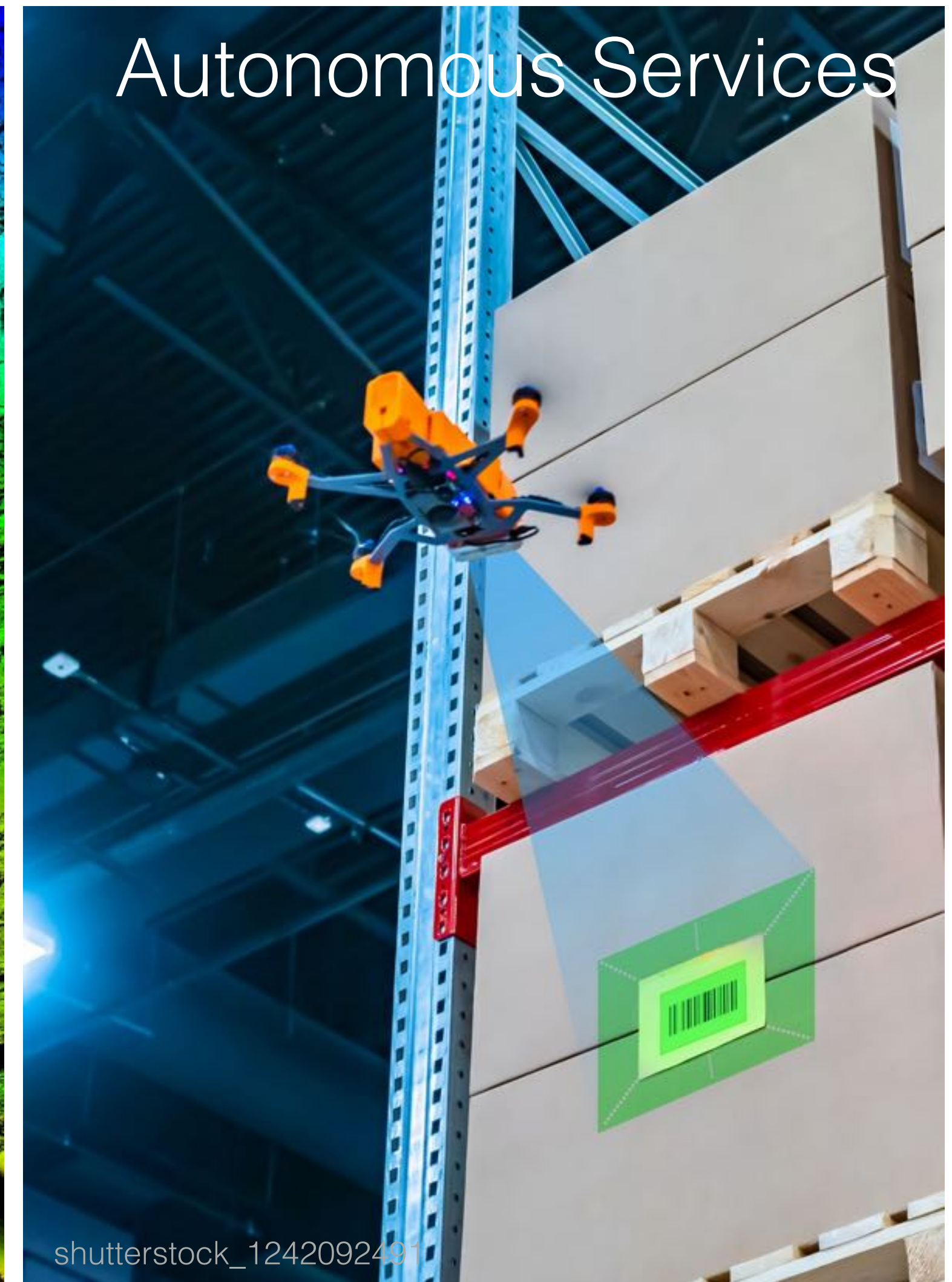
Imaging & Photography



Mapping & Sampling



Autonomous Services



Drones for physical interaction & manipulation



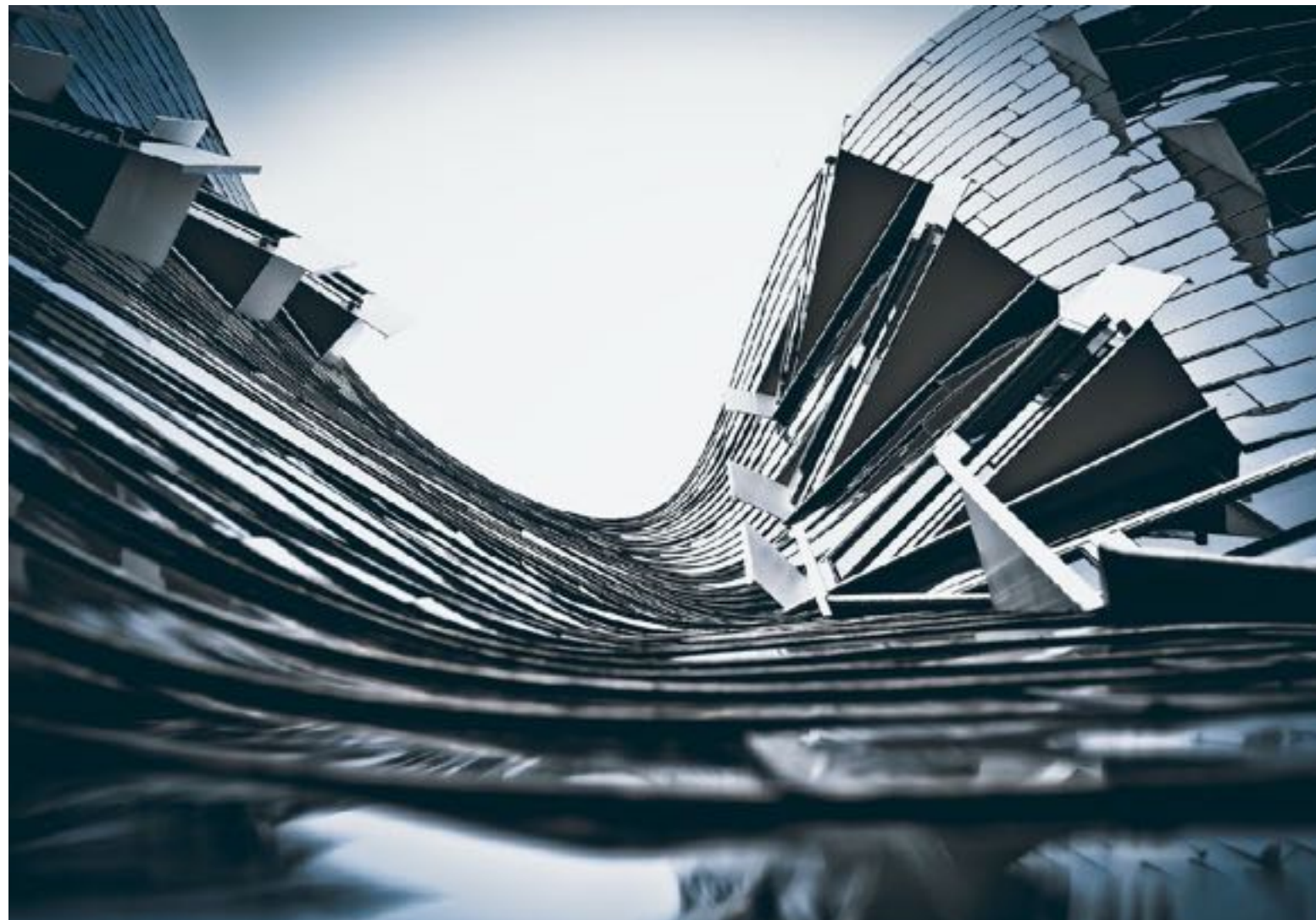
Built environment



Off-shore infrastructure



Environmental health



Construction



Mining/tunnel infrastructure

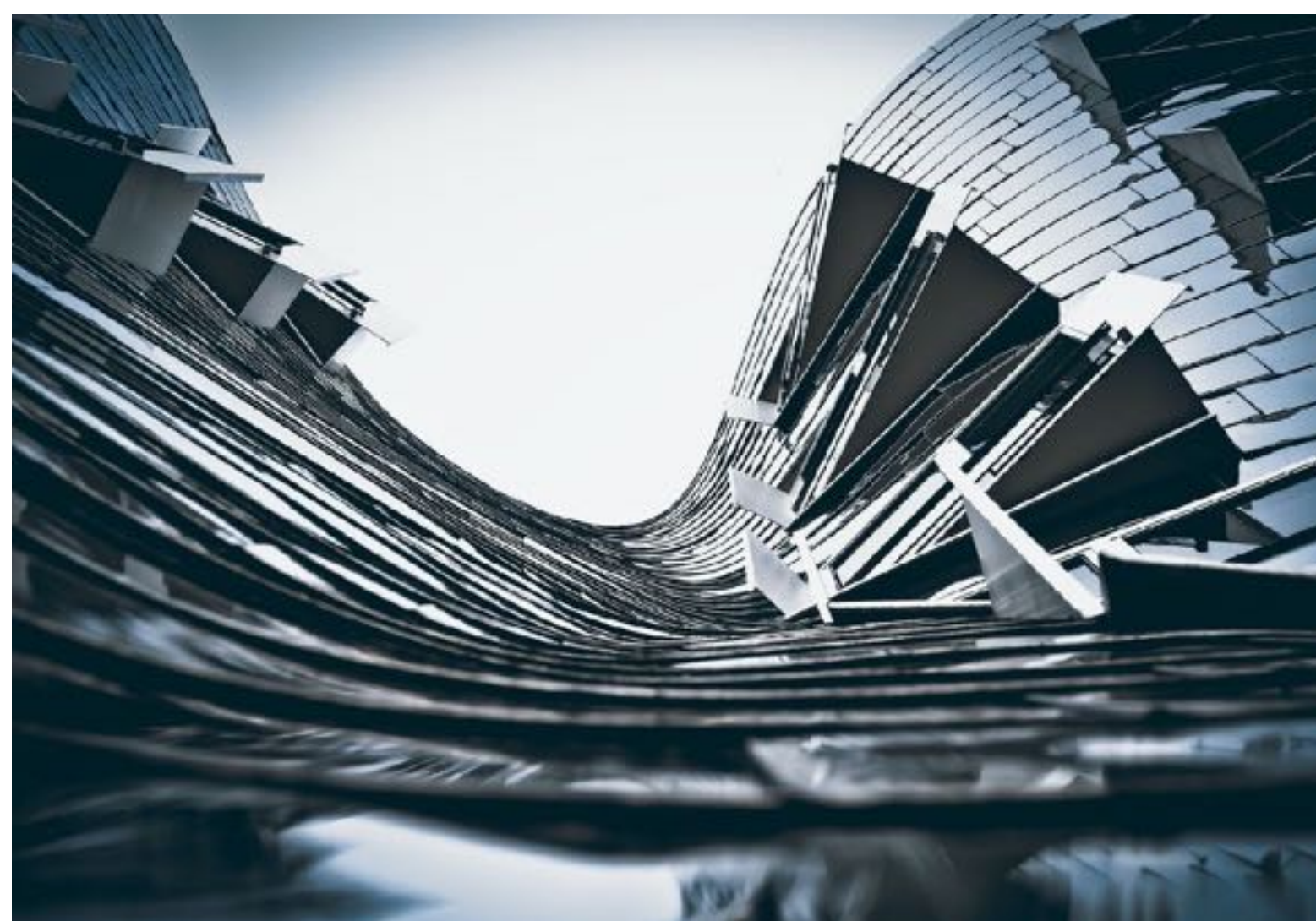


Extreme temperature regions

Drones for physical interaction & manipulation

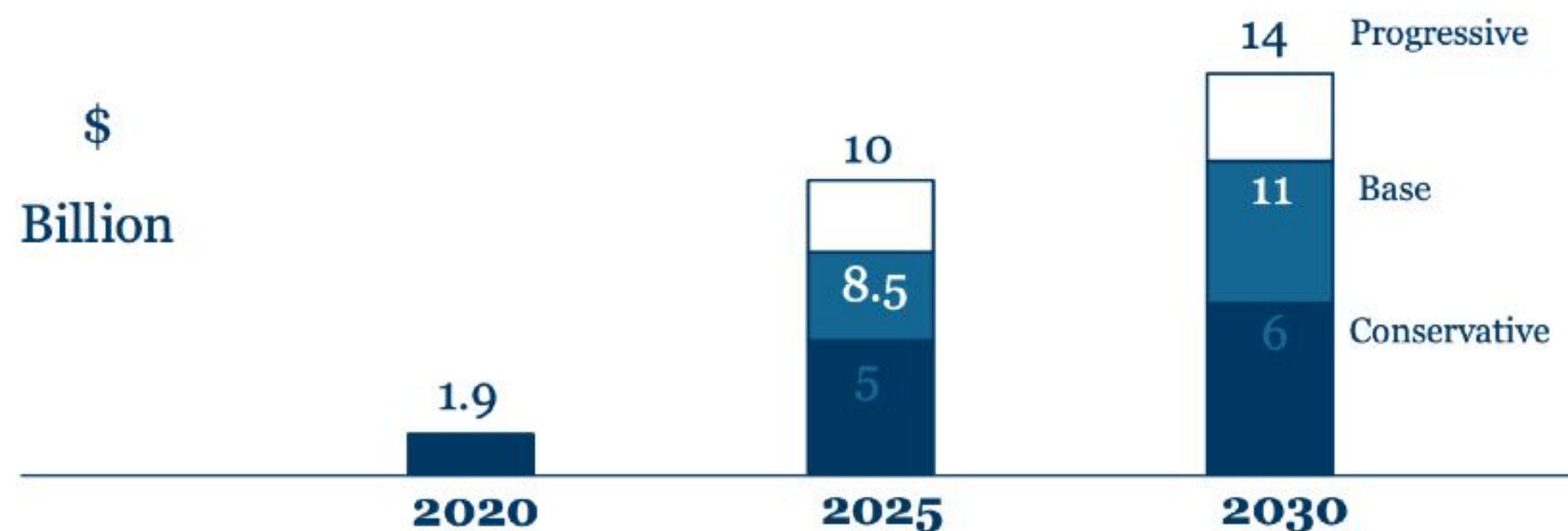


Built environment

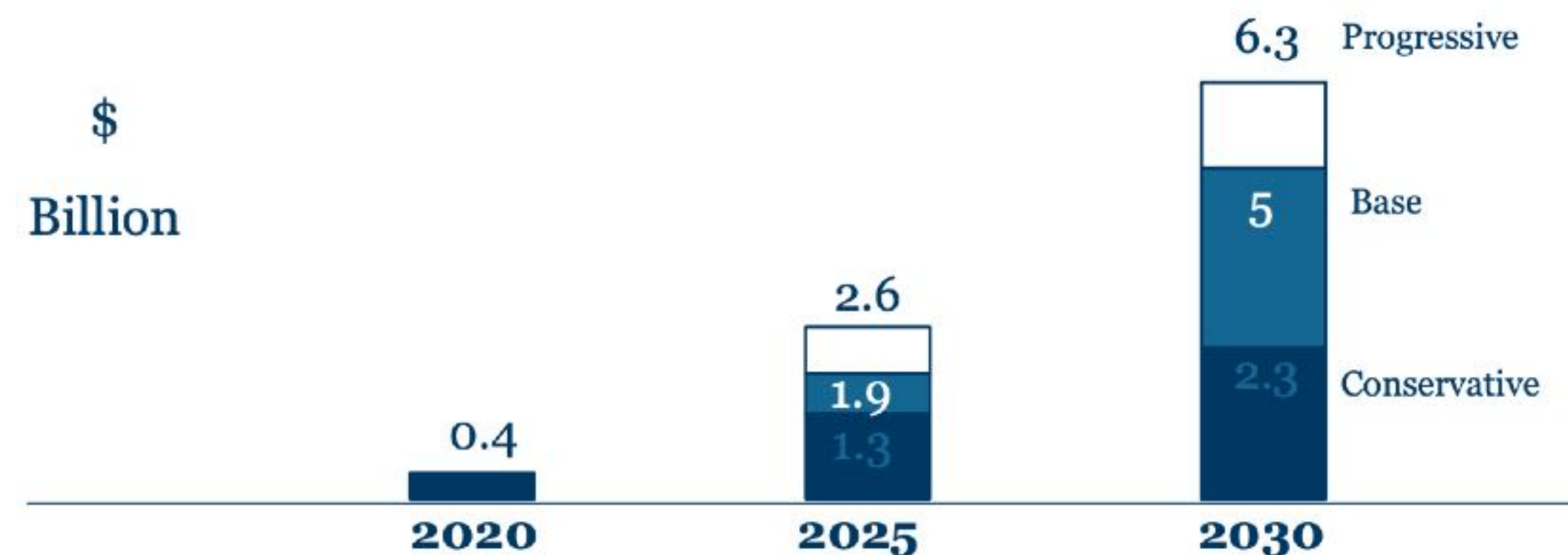


Construction

Market Size



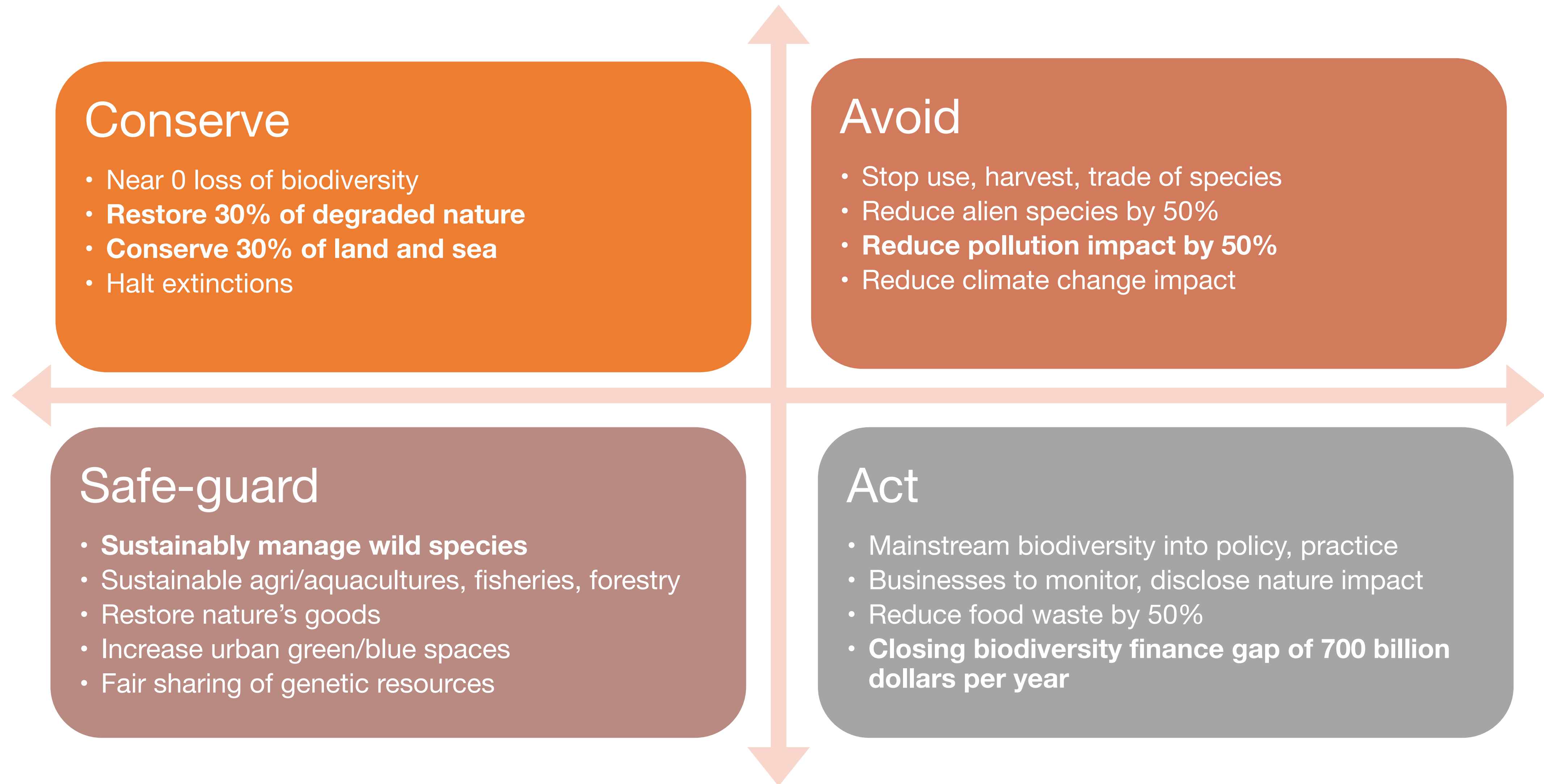
Market Size





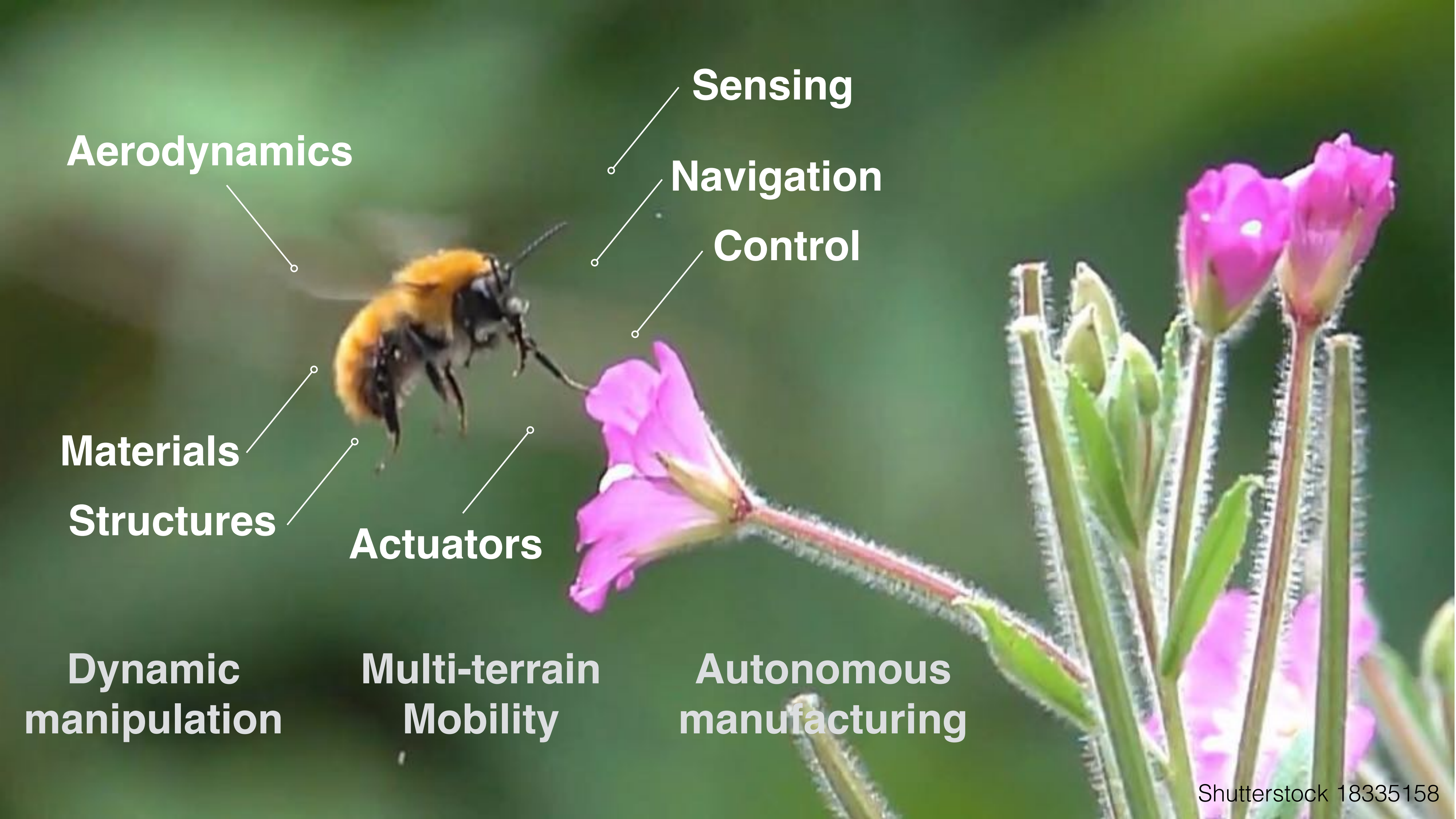
The Paris moment for biodiversity

Kunming Montreal Agreement Framework (COP 2022)





Thomas Creedy, Honduras, 2013



Aerodynamics

Sensing

Navigation

Control

Materials

Structures

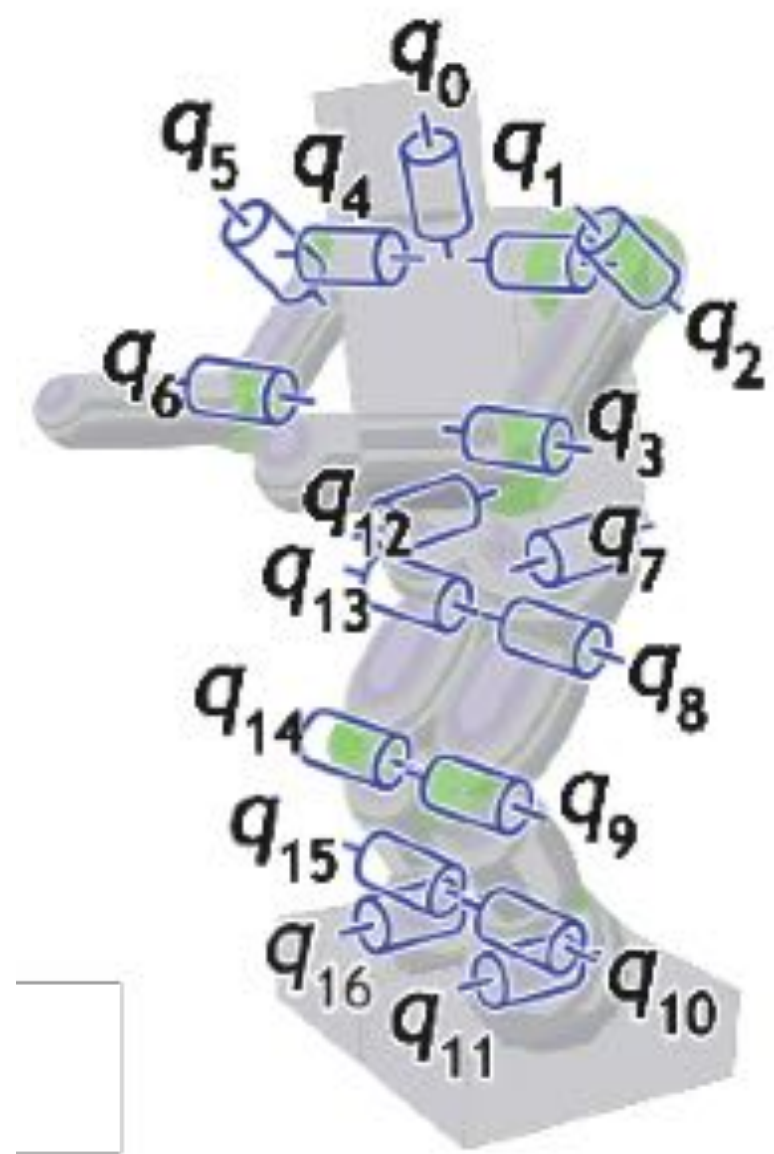
Actuators

**Dynamic
manipulation**

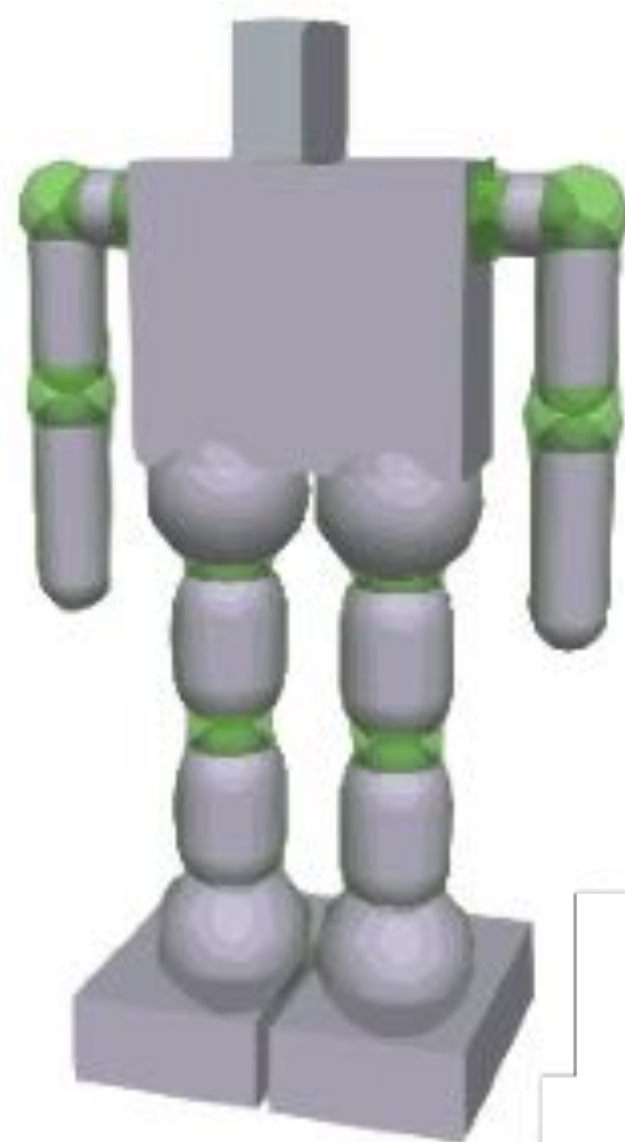
**Multi-terrain
Mobility**

**Autonomous
manufacturing**

Robotics and AI (the classical paradigm)



Yamaguchi et al (2013) AR



Yamaguchi et al (2013) AR



Buschmann et al (2009) JP



Kim, J. et al (2015) FSJ

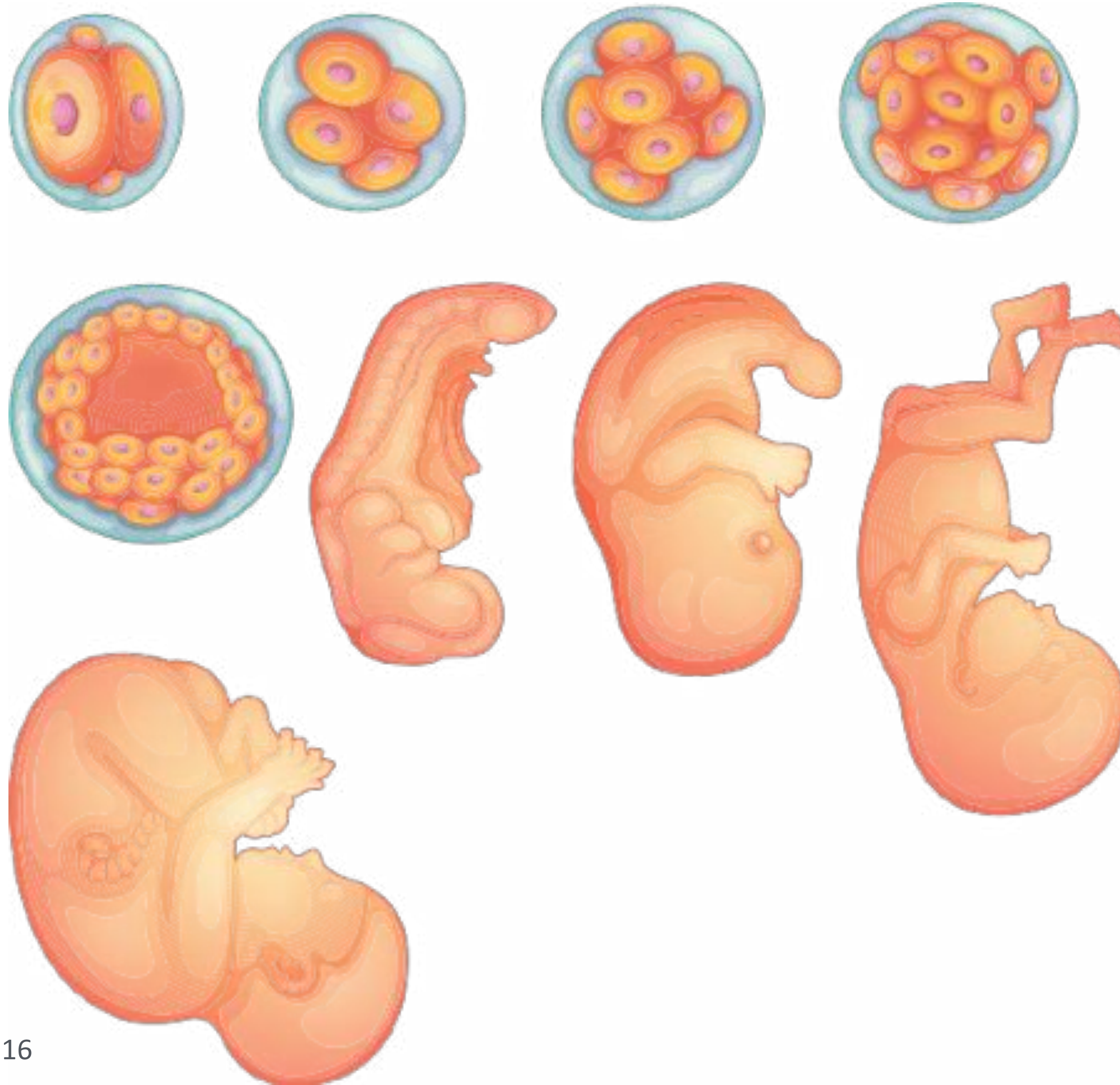


Image credit: IEEE Spectrum, 2015, Darpa Robotics Challenge
(<https://www.youtube.com/watch?v=g0TaYhjpOfo>)



Linear development with discrete components and development steps

Development in nature (the biological paradigm)



Circular and simultaneous co-evolution and adaptation of materials, sensors, actuators and controllers



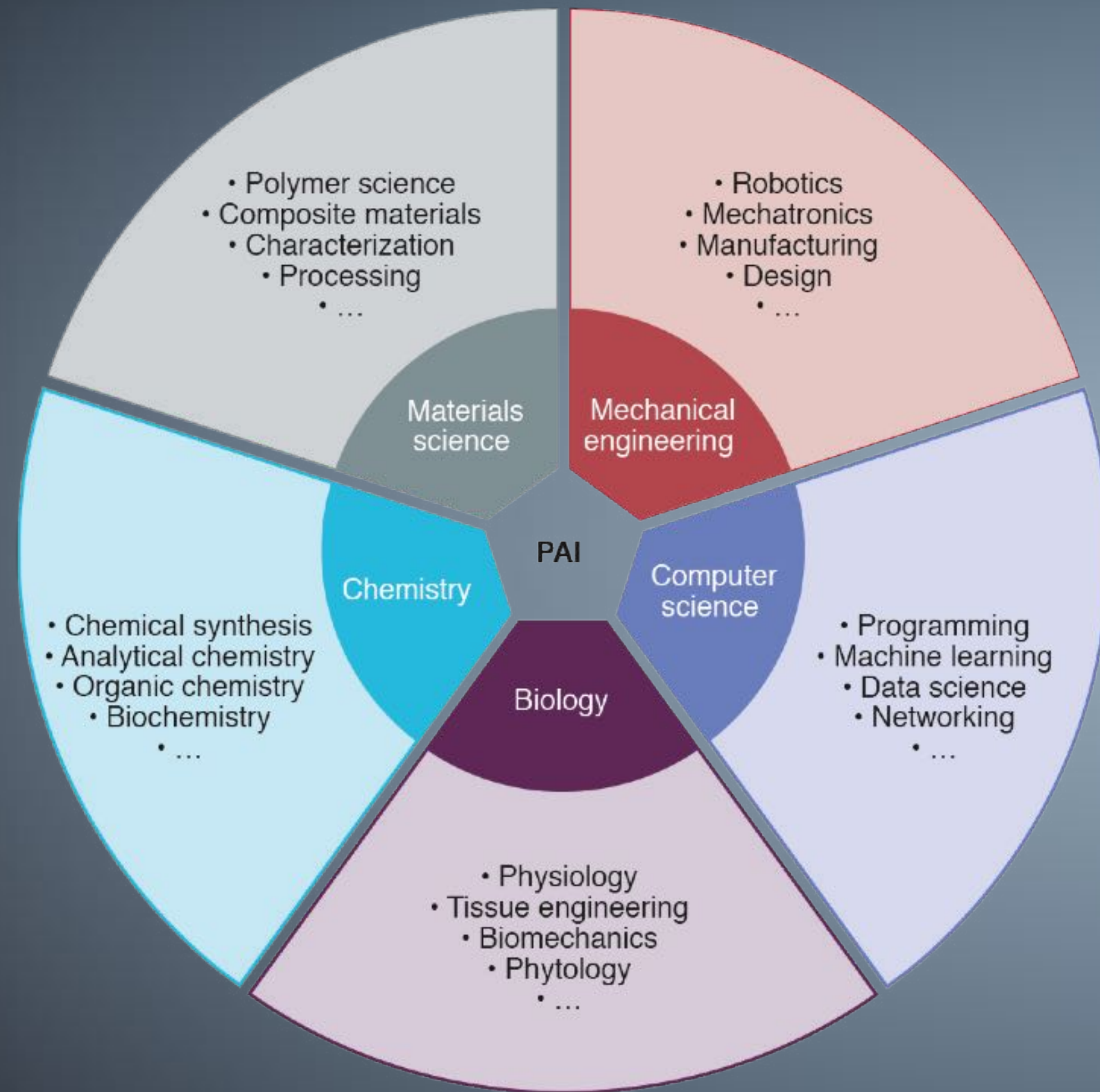
Physical Artificial Intelligence

**nature
machine
intelligence**

Crafting artificial intelligence



Physical Artificial Intelligence



**nature
machine
intelligence**

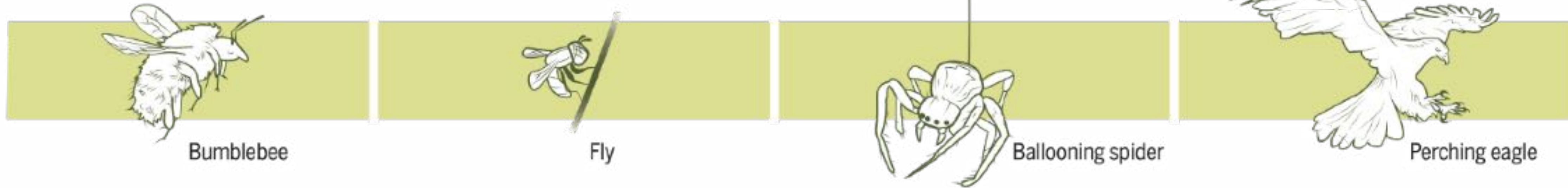
Crafting artificial intelligence



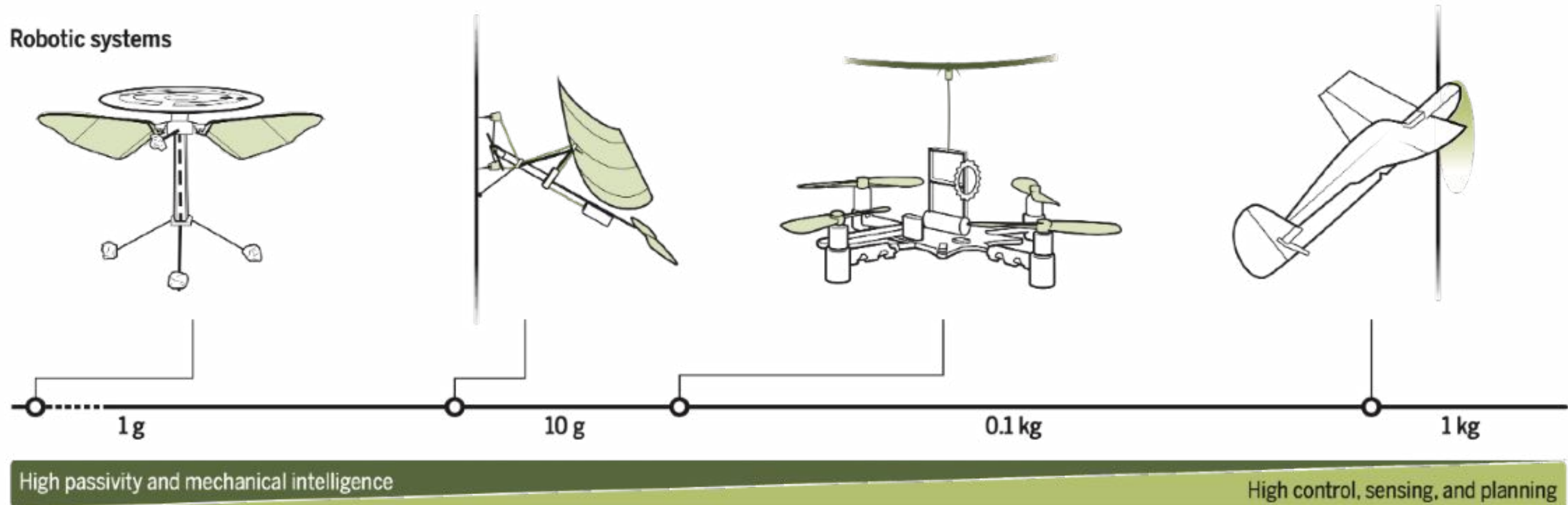
A. Miriyev, M. Kovac, Skills for Physical Artificial Intelligence,
Nature Machine Intelligence, 2020 (cover)

Lifelike aerial capability

Comparable biological systems



Robotic systems



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



1 NO
POVERTY



2 ZERO
HUNGER



3 GOOD HEALTH
AND WELL-BEING



4 QUALITY
EDUCATION



5 GENDER
EQUALITY



6 CLEAN WATER
AND SANITATION



7 AFFORDABLE AND
CLEAN ENERGY



8 DECENT WORK AND
ECONOMIC GROWTH



9 INDUSTRY, INNOVATION
AND INFRASTRUCTURE



10 REDUCED
INEQUALITIES



11 SUSTAINABLE CITIES
AND COMMUNITIES



12 RESPONSIBLE
CONSUMPTION
AND PRODUCTION



13 CLIMATE
ACTION



14 LIFE
BELOW WATER



15 LIFE
ON LAND



16 PEACE, JUSTICE
AND STRONG
INSTITUTIONS



17 PARTNERSHIPS
FOR THE GOALS



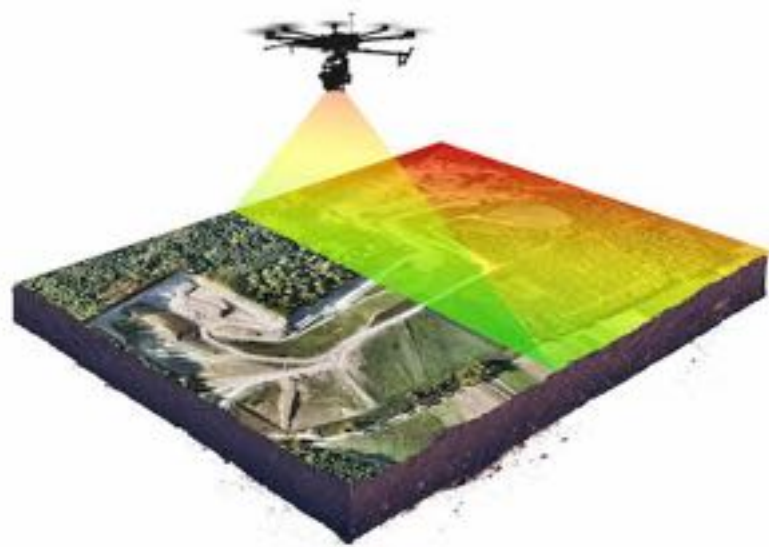
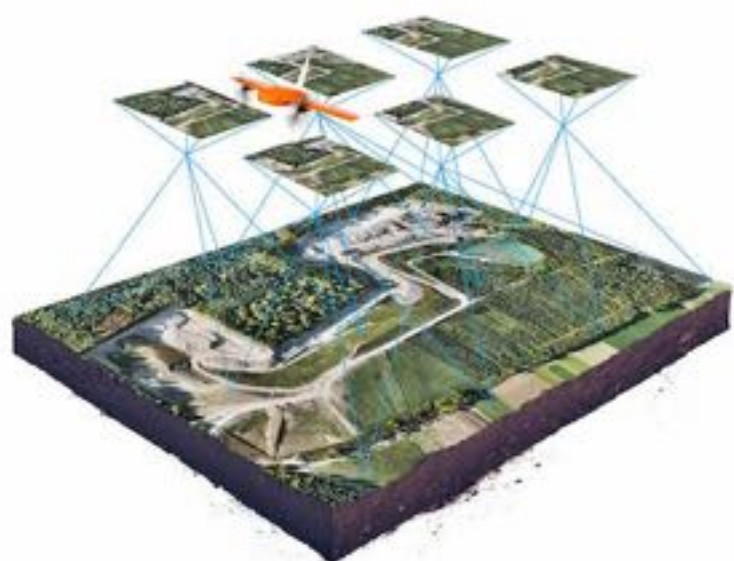
Mentimeter

Environmental sensing technologies today

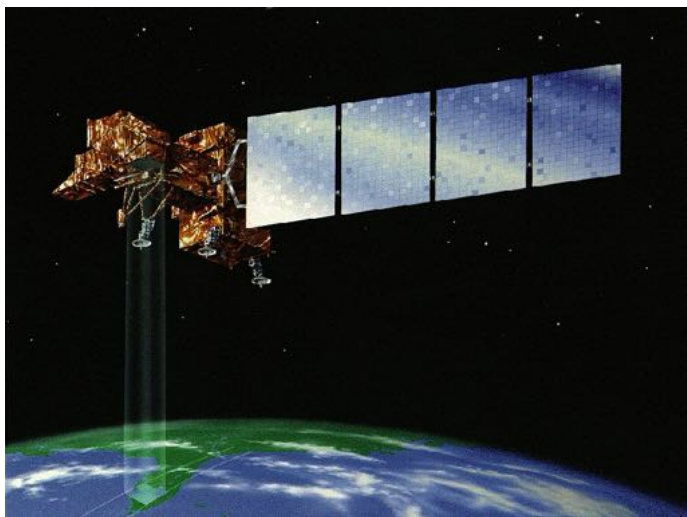
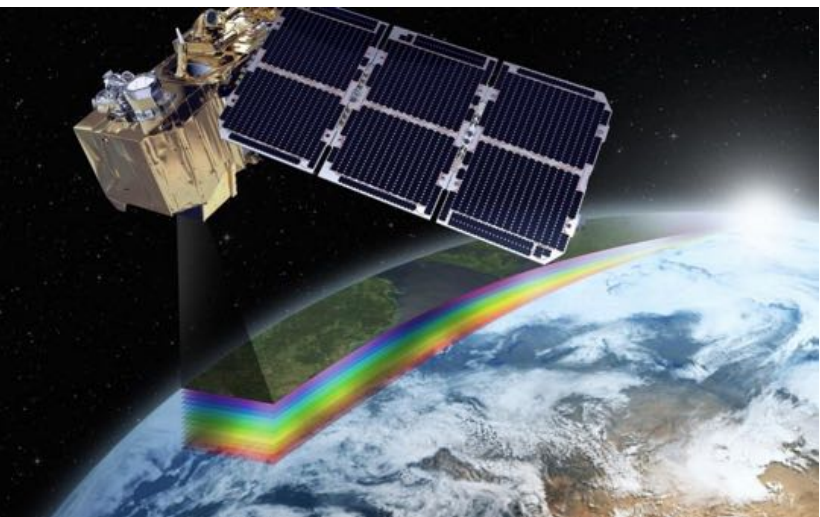
Air



EPFL Helikite, Tethered Balloon, 2021



Wingtra, Drone Photogrammetry, 2021



NASA, Land Remote Sensing, 2017

Land



Treetec, Sensor Installation

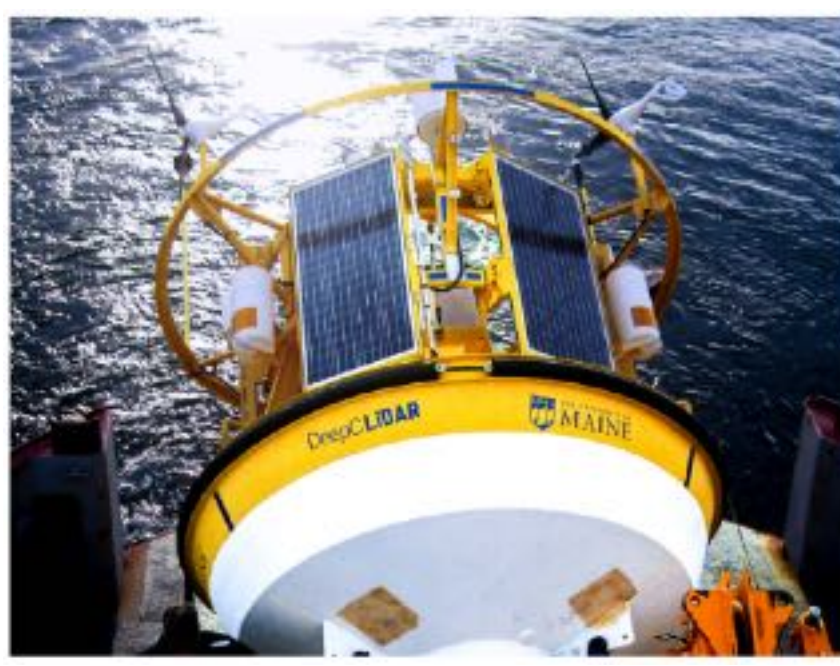


Hylio, Crop Spraying Drone, 2018



Soil Sampling Robots, Amrita - 2019; Momaro 2017

Water



DeepCLiDAR, Floating Buoys, 2016



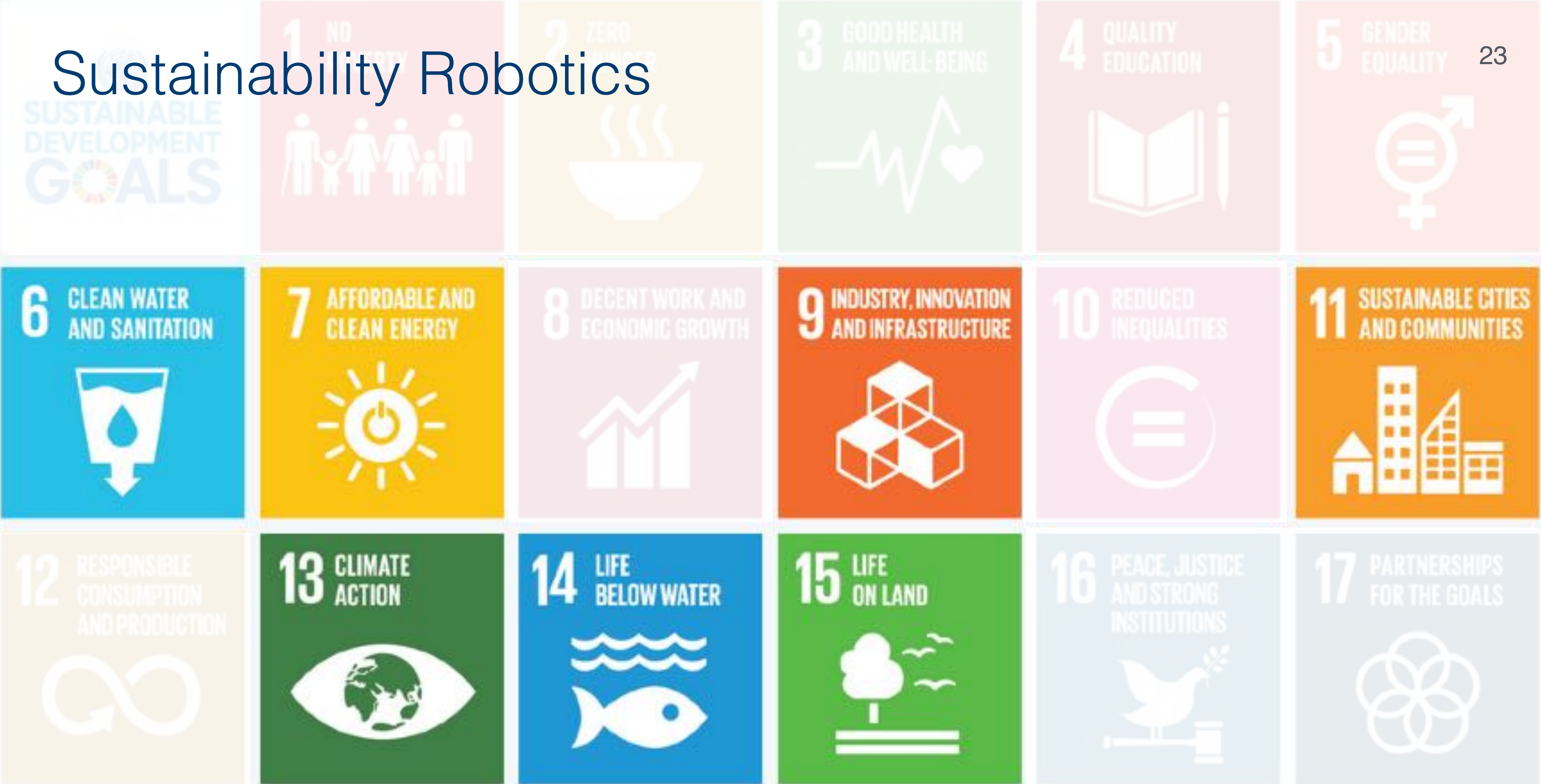
ASpire, Sailing Platform, 2017



Autonomous surface vehicle: Buscamos-Vigia, 2021

Sustainability Robotics

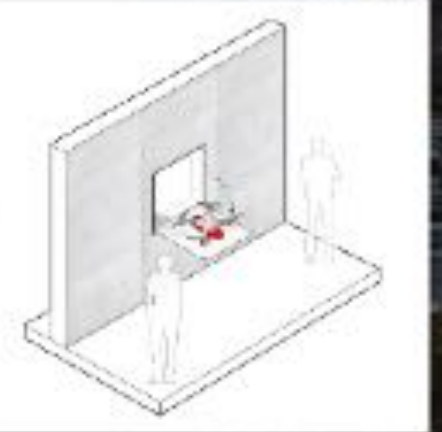
23



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





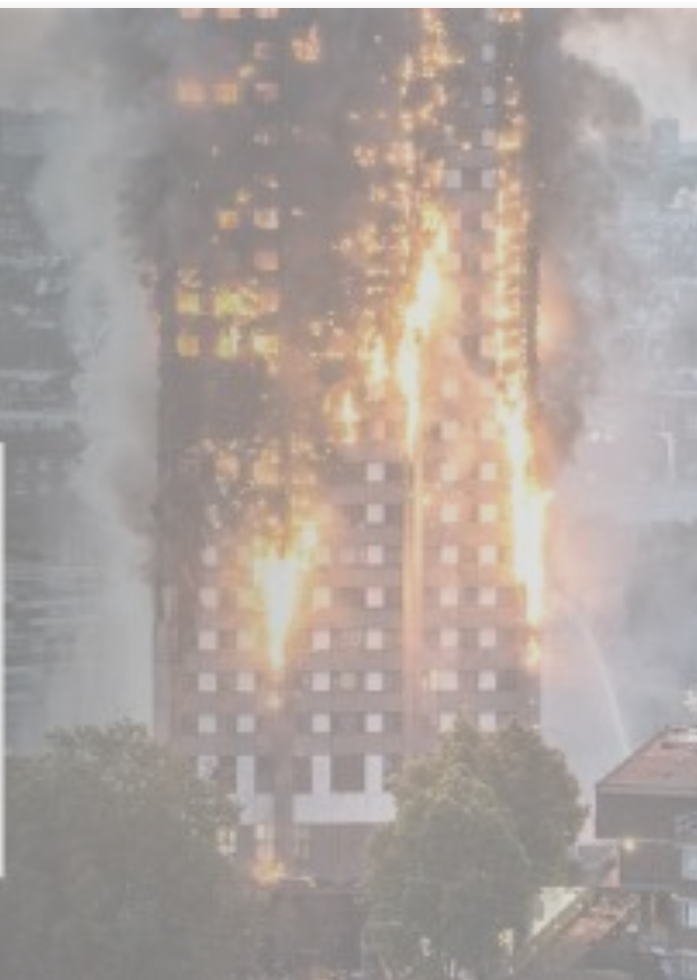
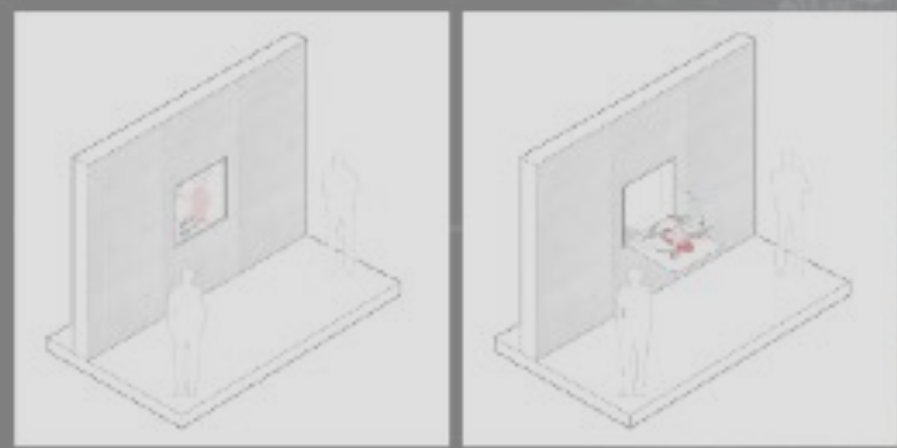
Aerial Additive Manufacturing



Sustainability Robotics

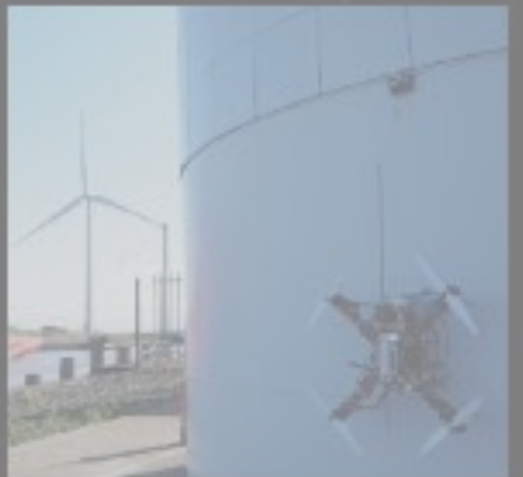


Aerial Robots as first responders





Aerial Robotics for wind blade inspection



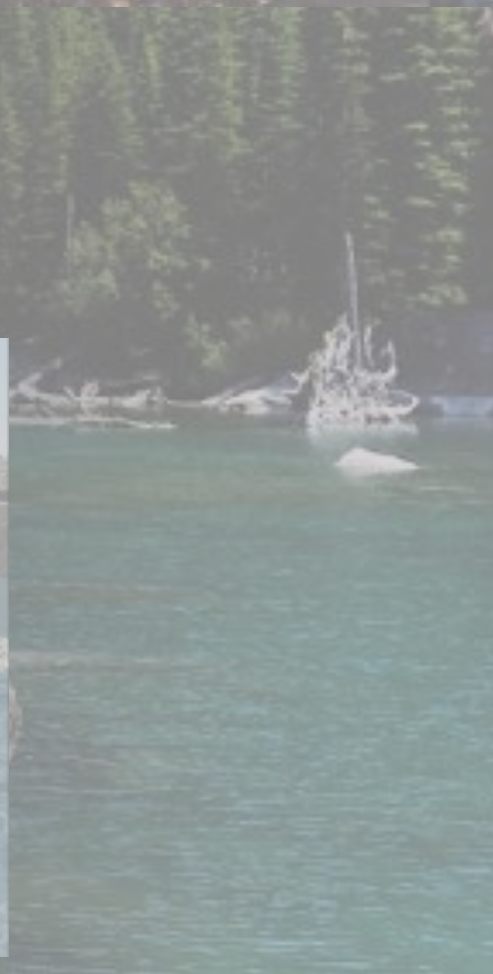


Eco-robotics to protect natural environments





Aerial-aquatic robots to protect aquatic ecosystems





Aerial robotics for ageing infrastructure

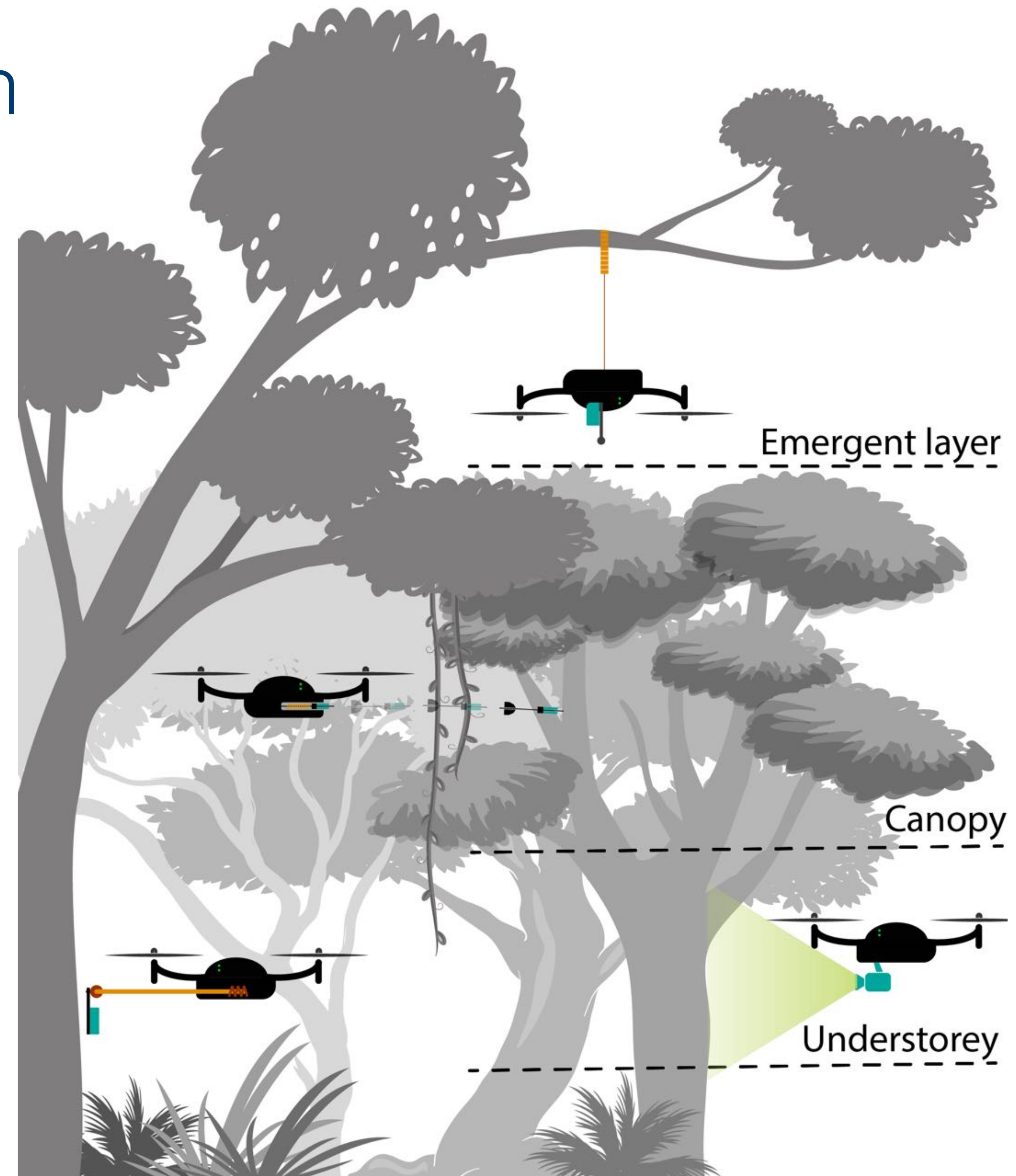




Aerial Additive Manufacturing

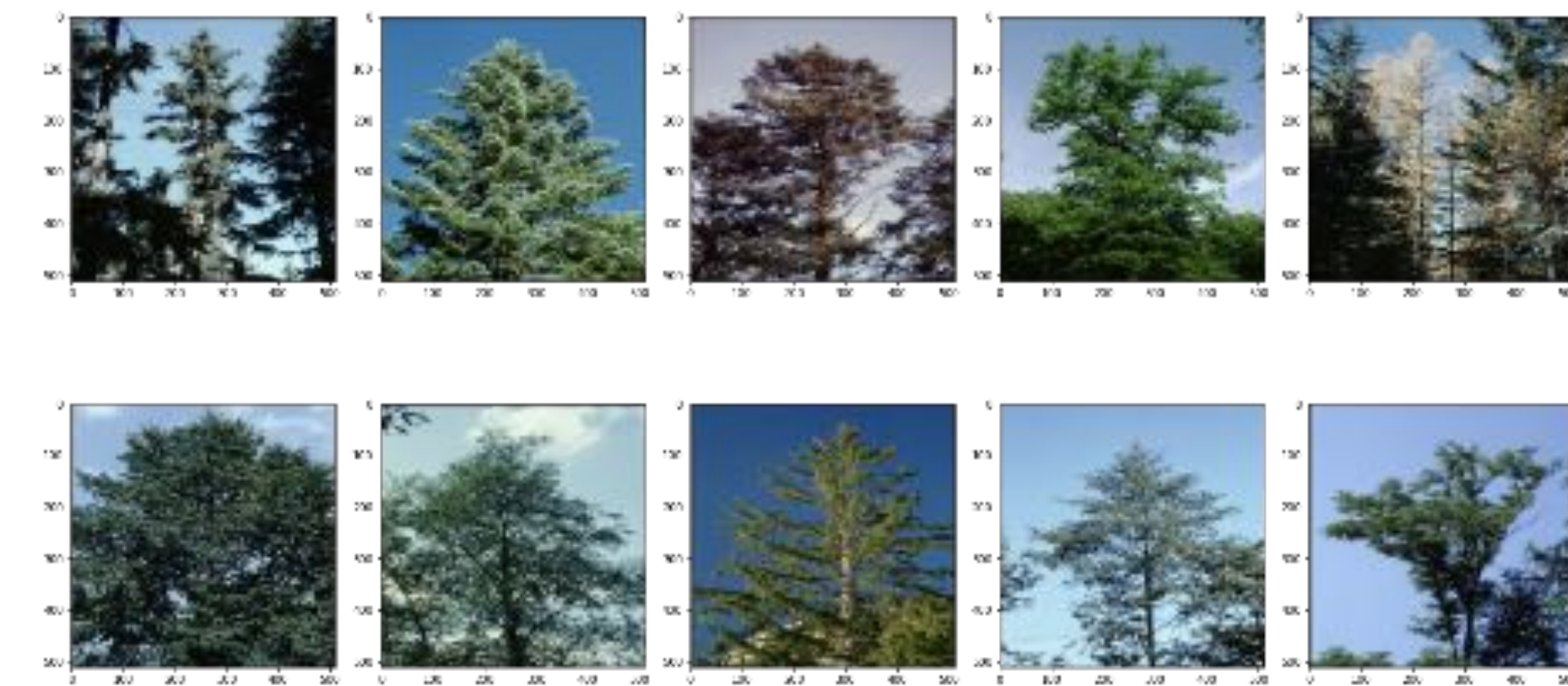


Need for autonomous sensin

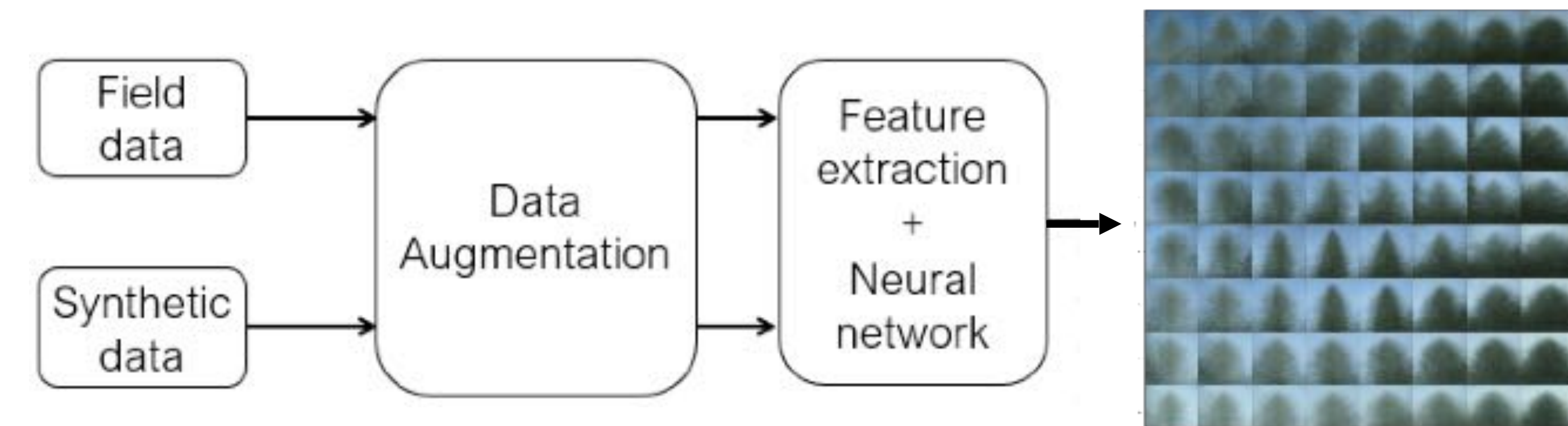
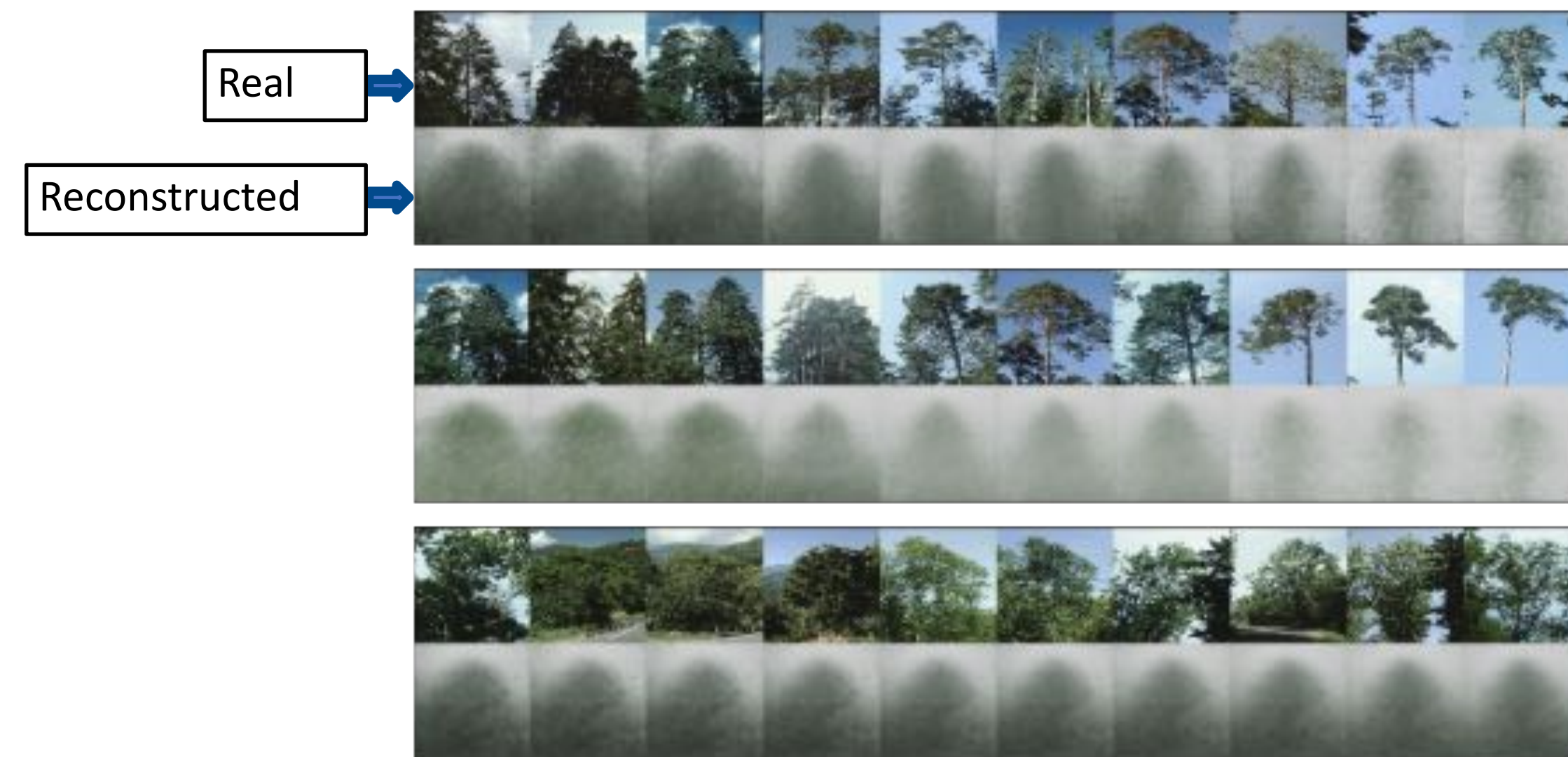


Autonomous crown loss estimation

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WSL tree dataset



Density map (estimated)

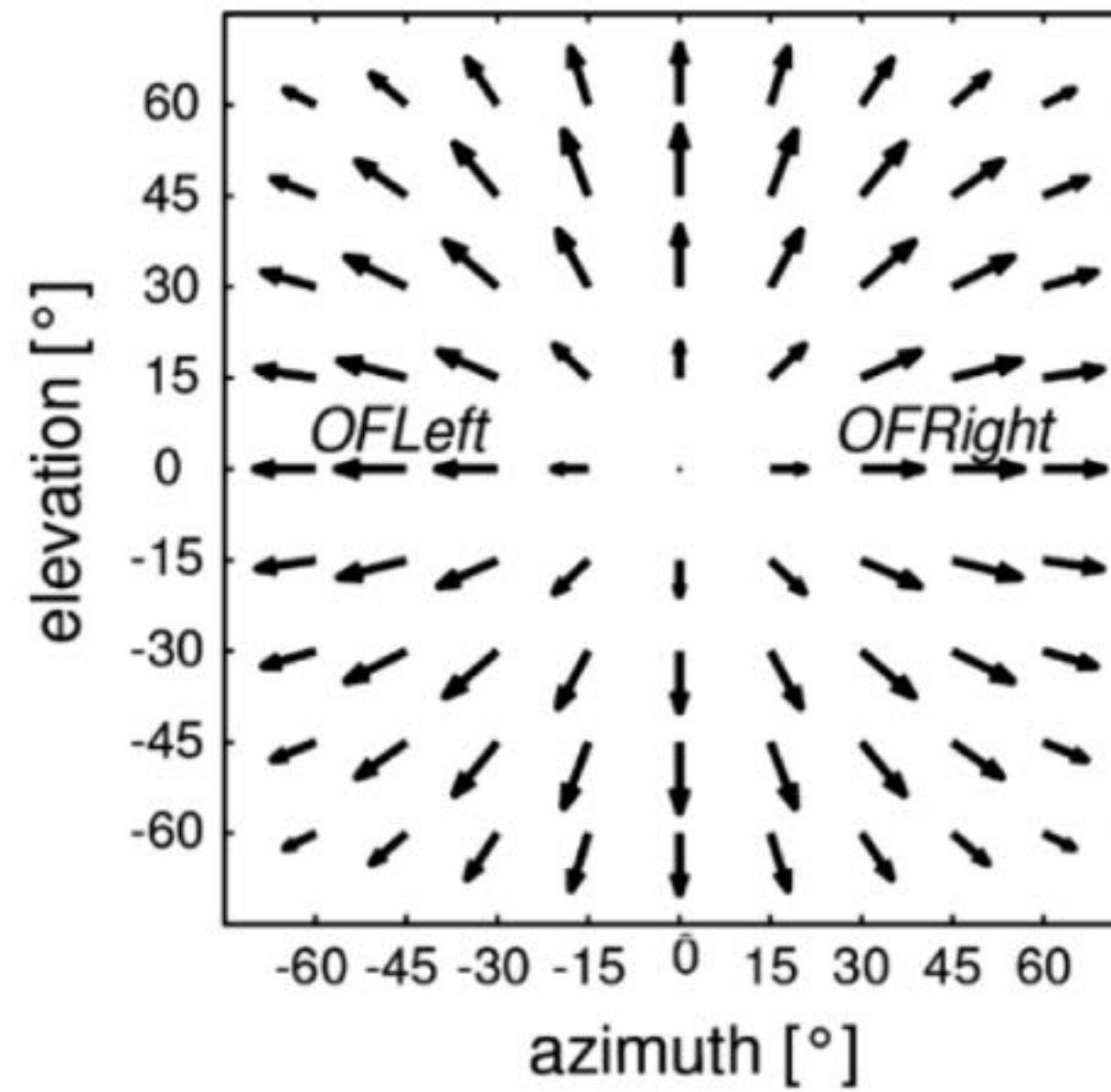


Bo, H., Kocer, B.B. and Kovac, M., 2022. Vision based crown loss estimation for individual trees with remote aerial robots. *ISPRS Journal of Photogrammetry and Remote Sensing*

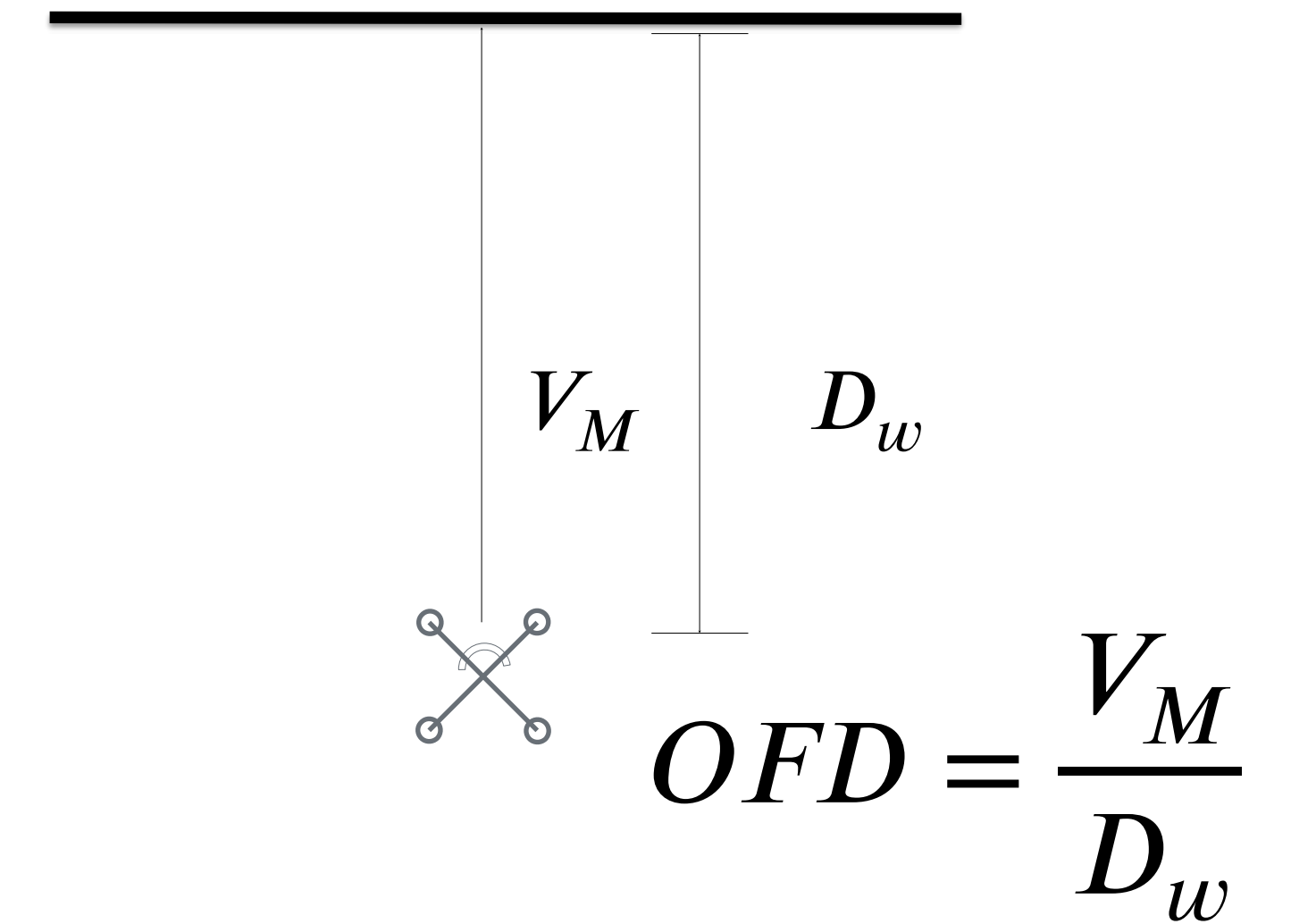
Bio-inspired forrest flight autonomy



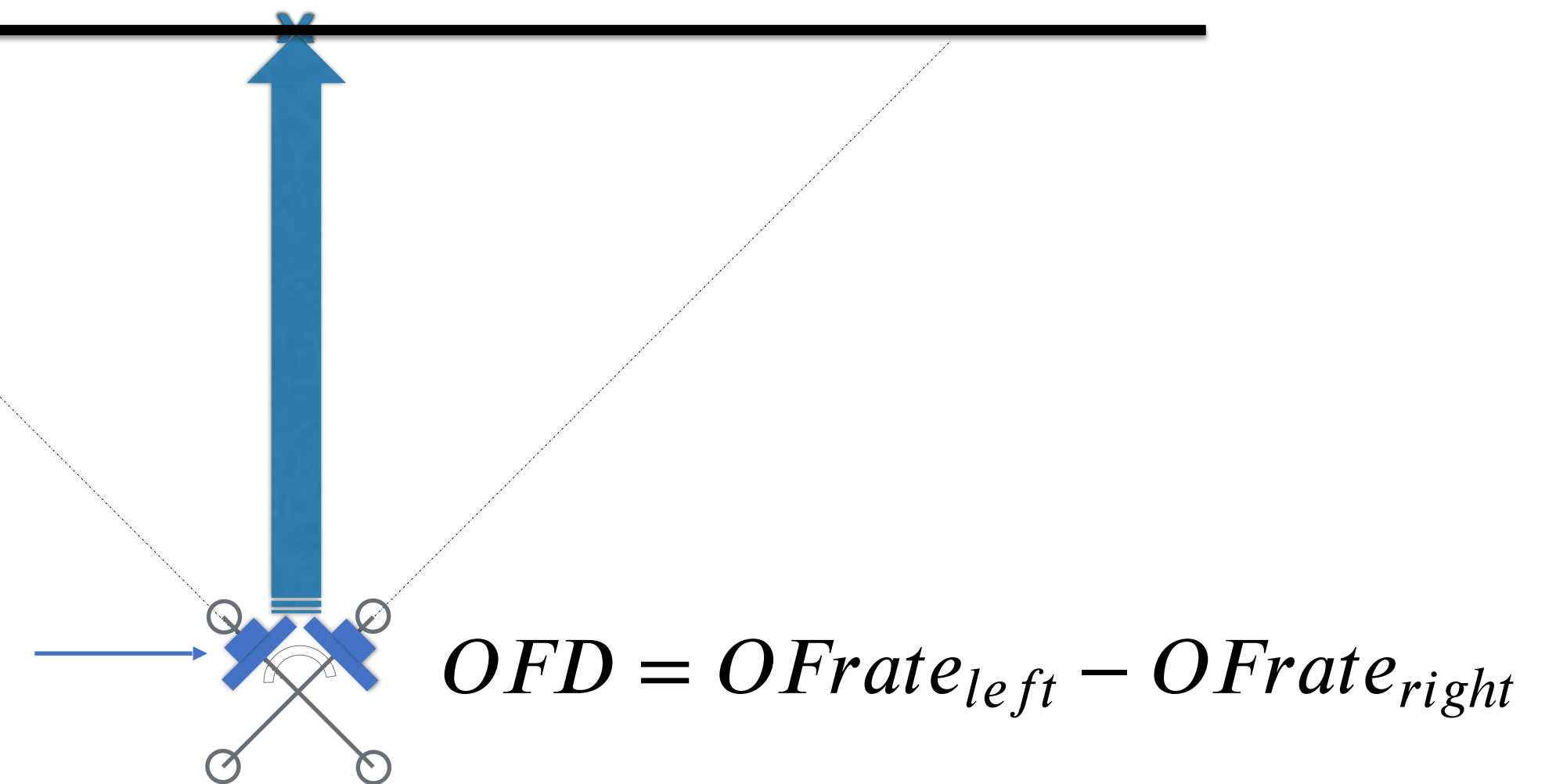
[1]



[2]



Divergent Optical Flow Pair
(DOFP)

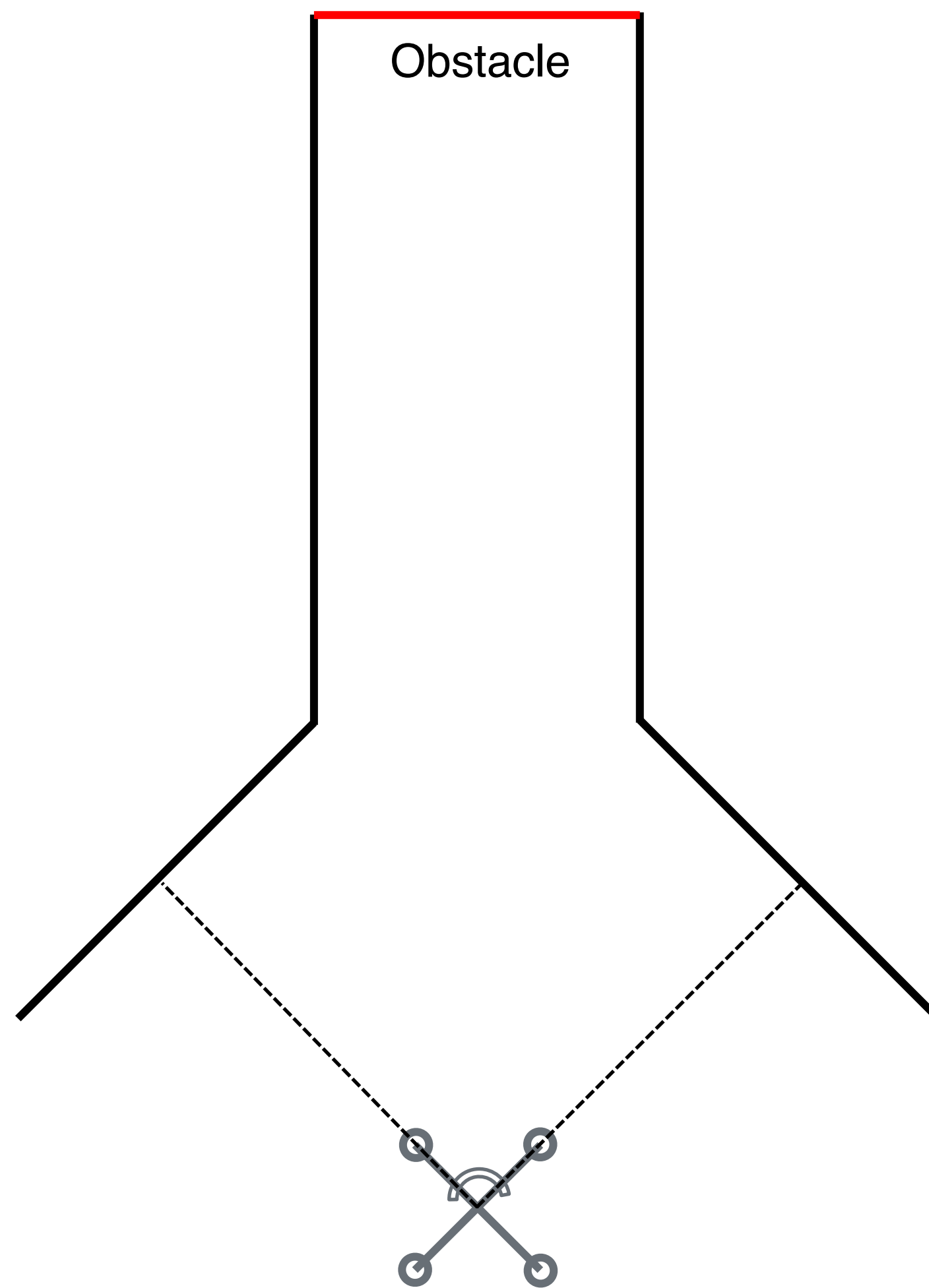


[1] Evangelista C, Kraft P, Dacke M, Reinhard J, Srinivasan MV (2010) The moment before touchdown: Landing manoeuvres of the honeybee *Apis mellifera*. *J Exp Biol* 213(2): 262–270

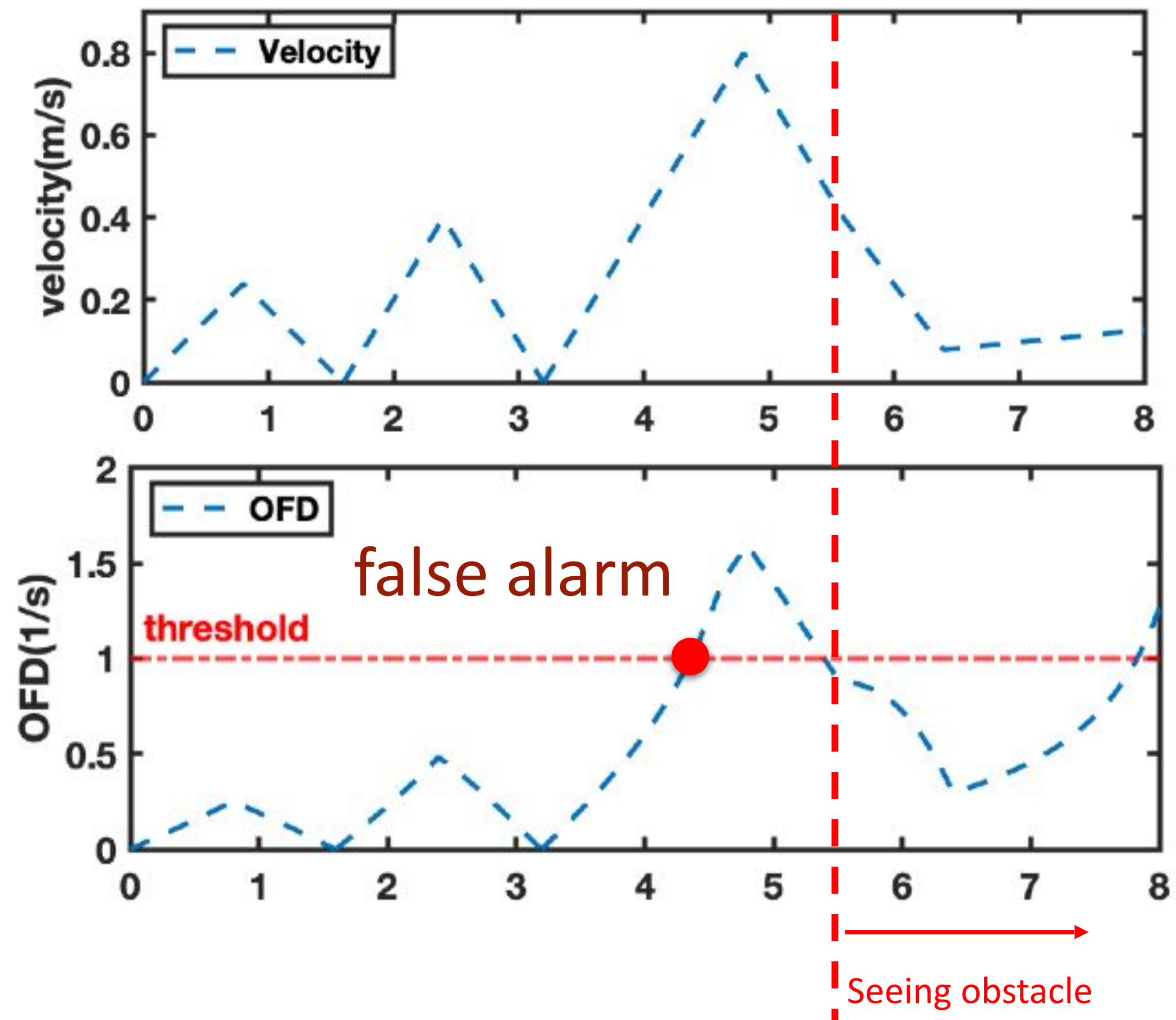
[2] J. C. Zufferey and D. Floreano, "Fly-Inspired Visual Steering of an Ultralight Indoor Aircraft," *IEEE Transactions on Robotics*, vol. 22, no. 1, pp. 137–146, 2006.

Constant OFD threshold could give false alarm

29

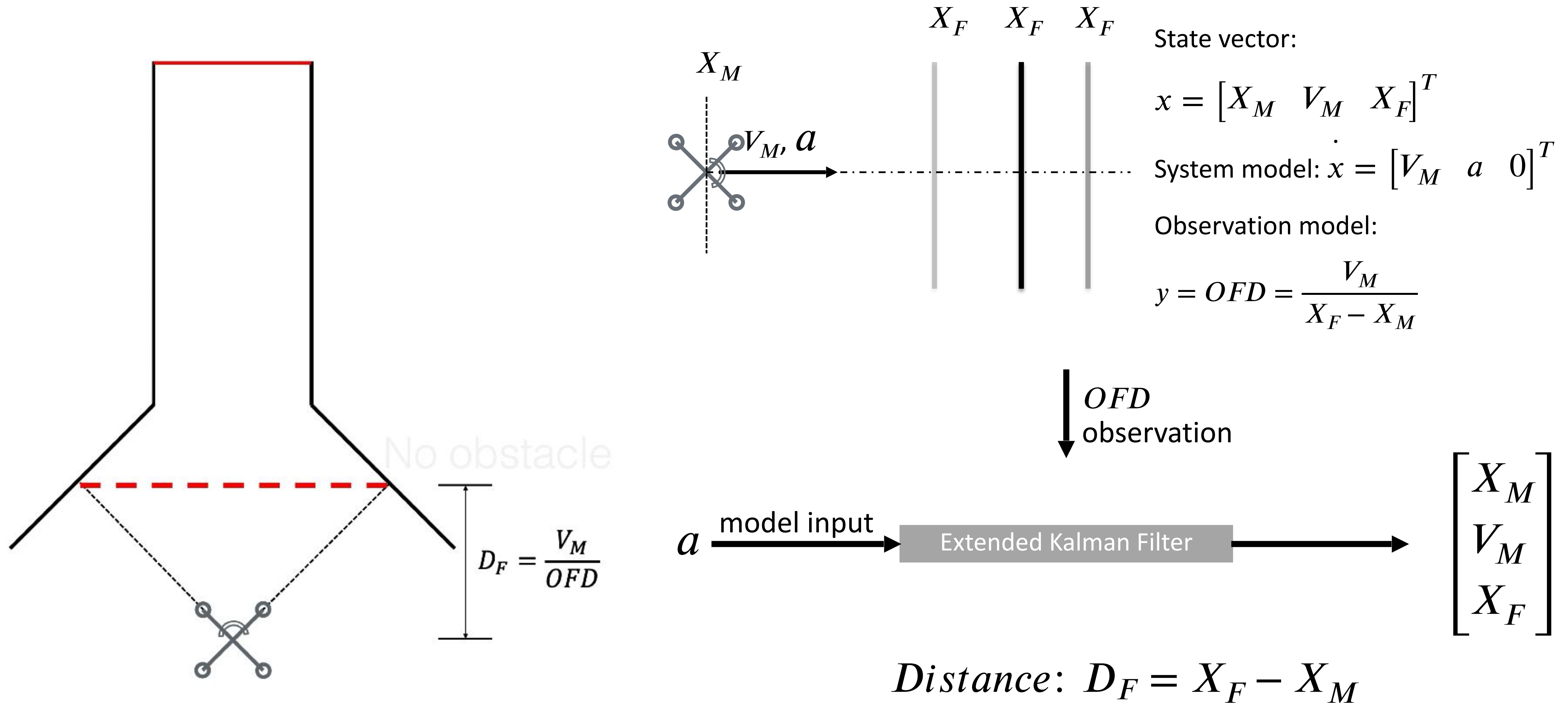


$$OFD = OFrate_{left} - OFrate_{right}$$



Fictitious wall hypothesis

30

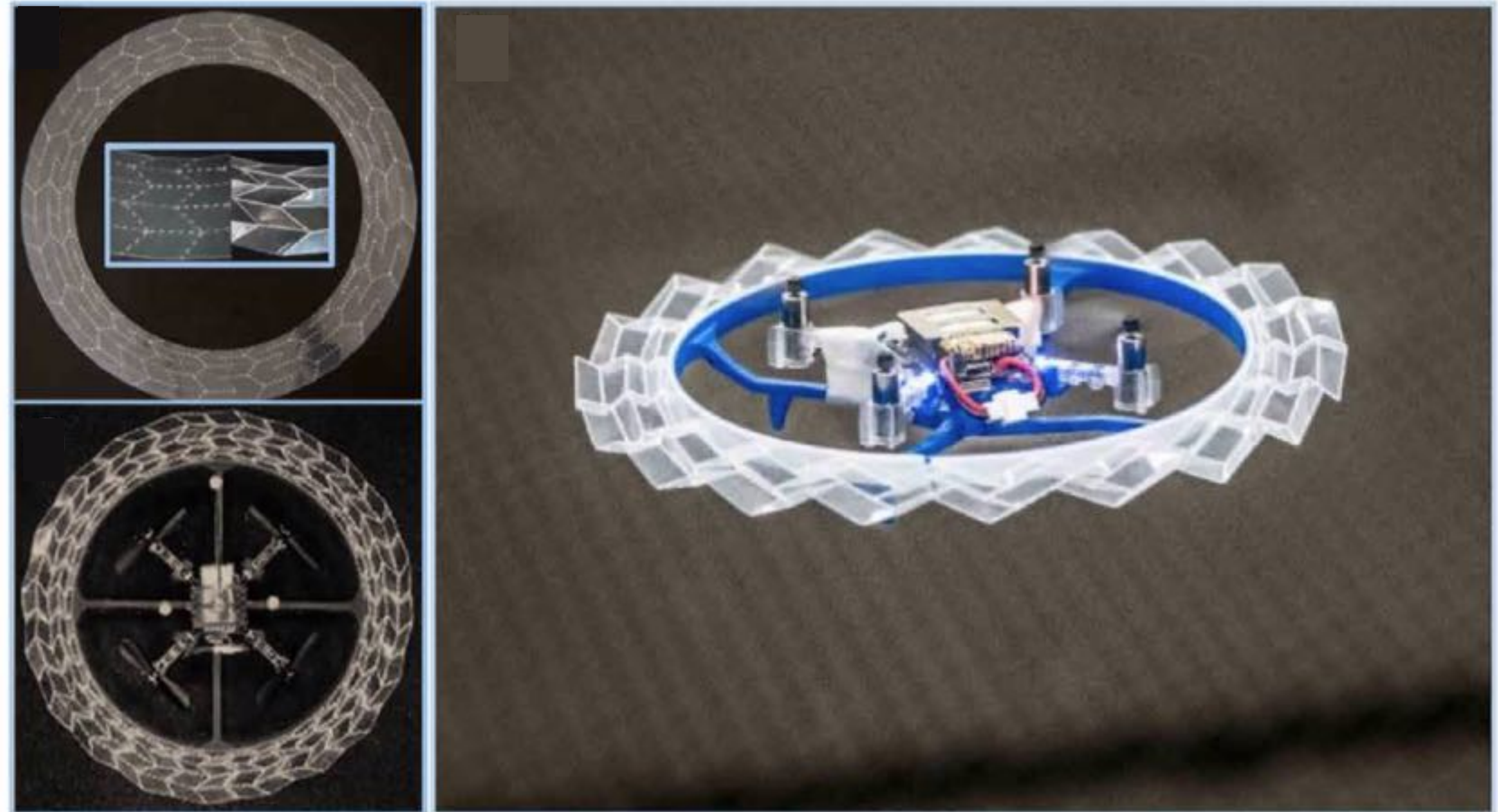
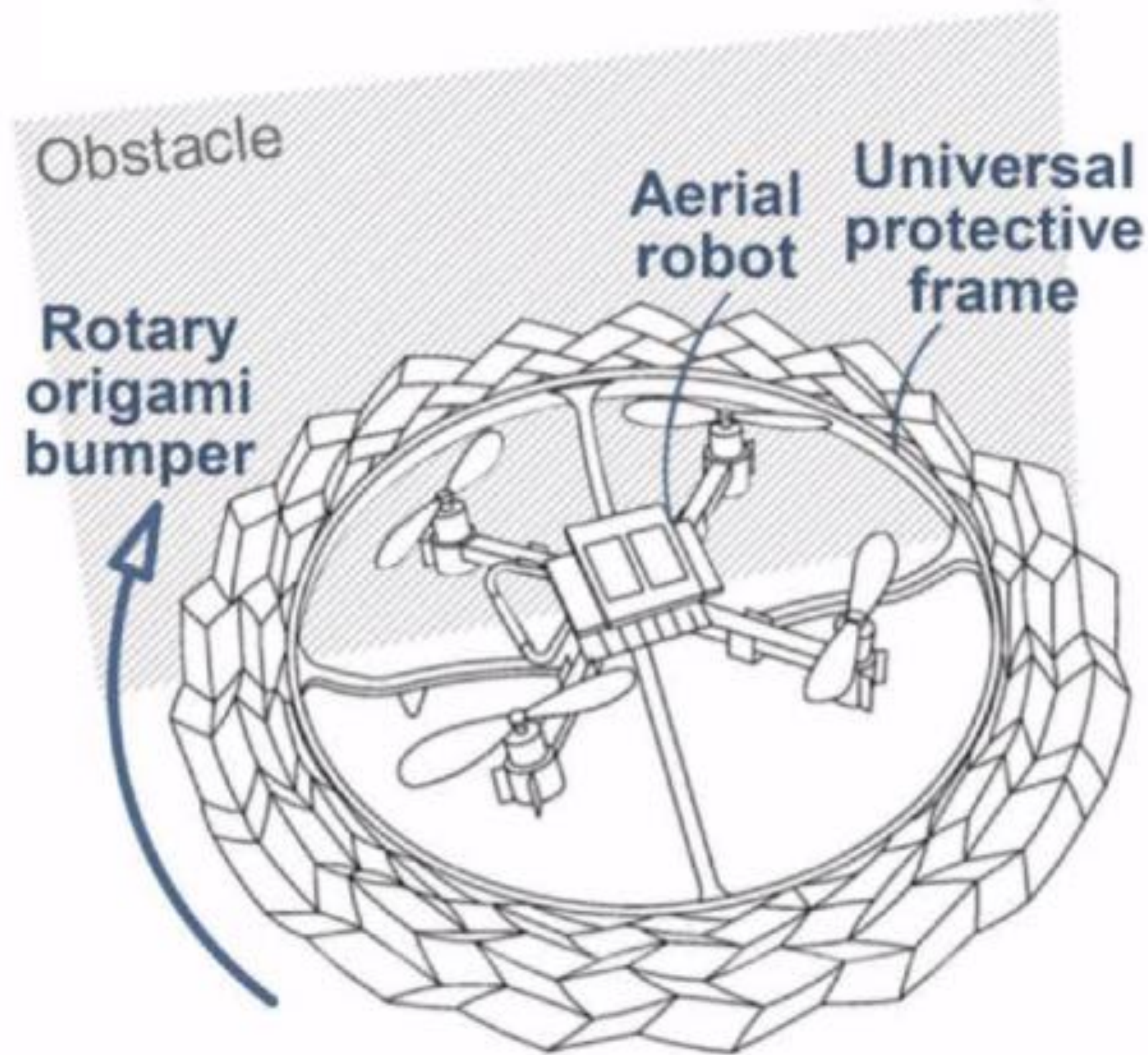






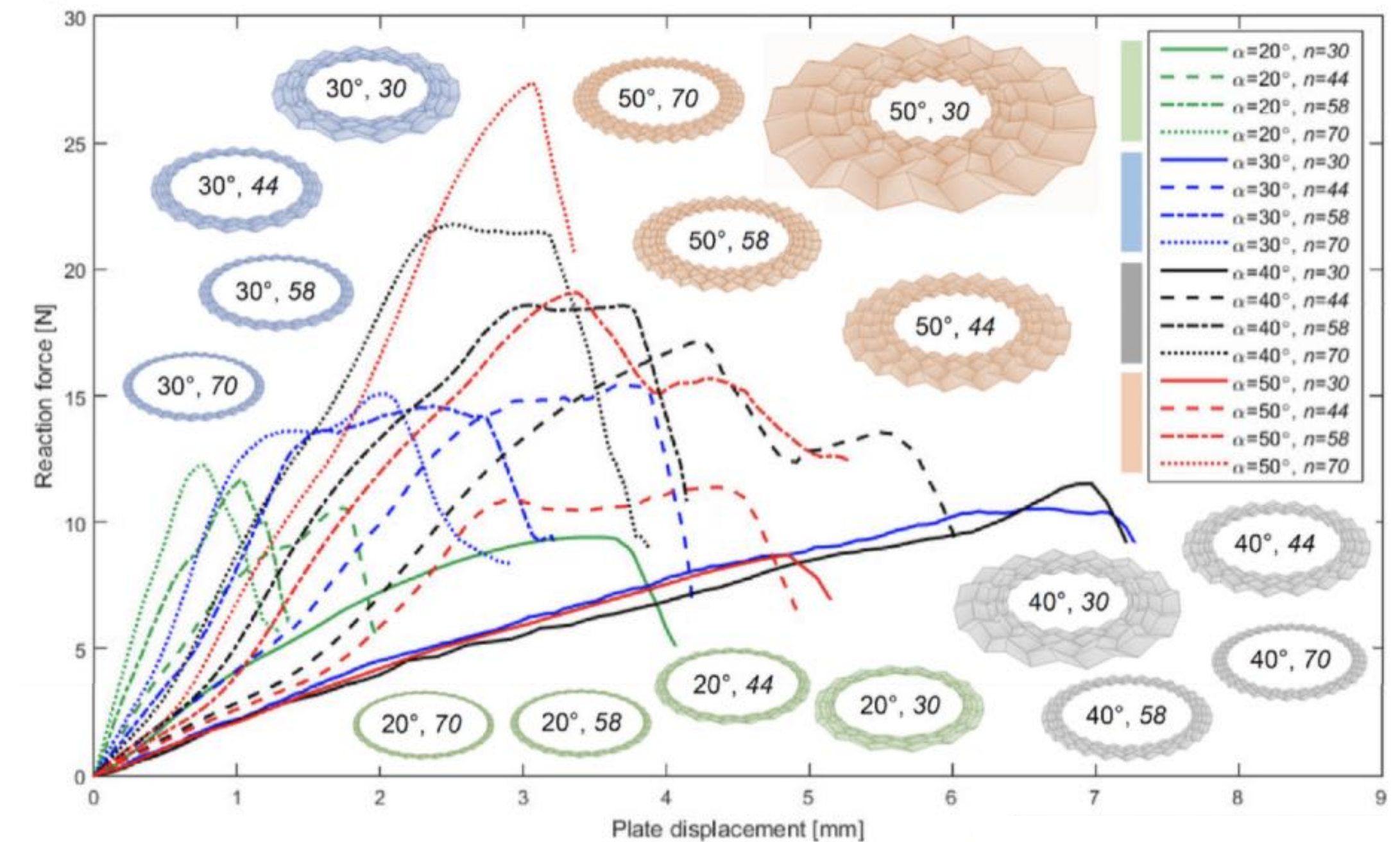
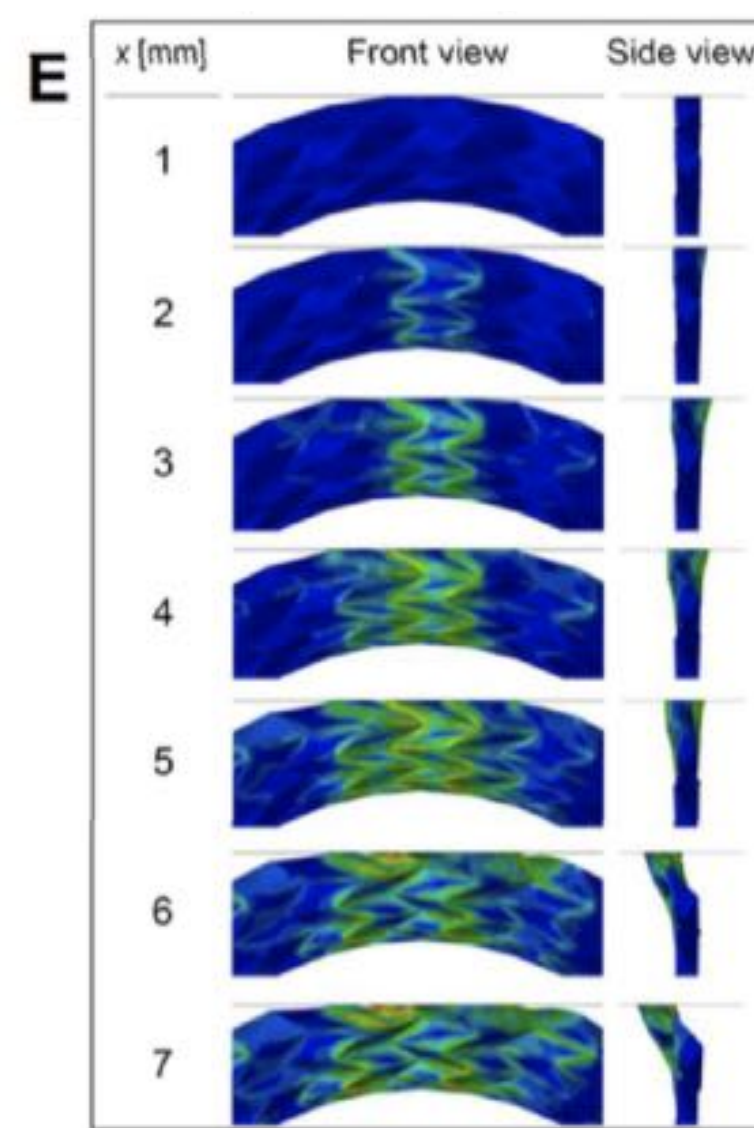
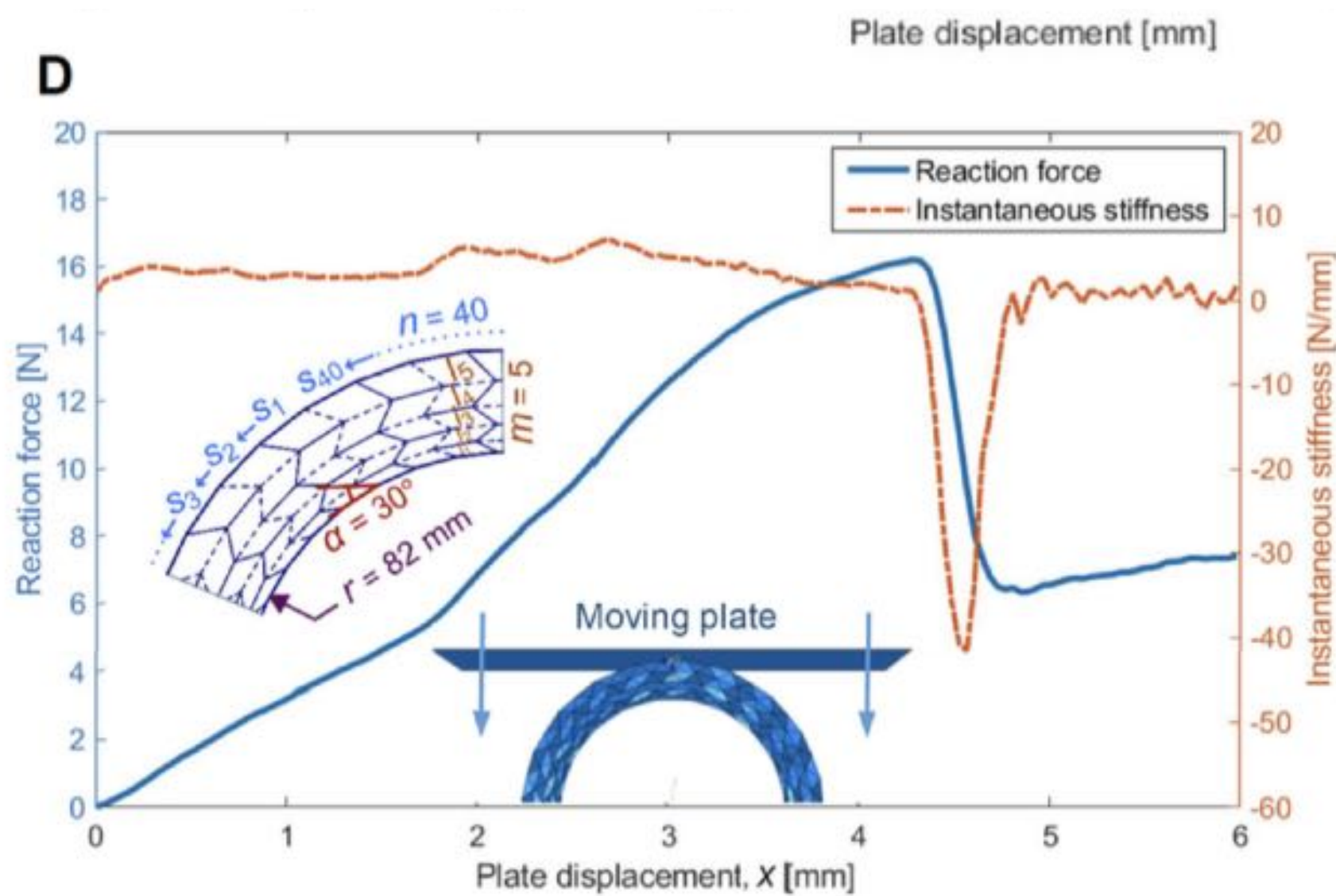
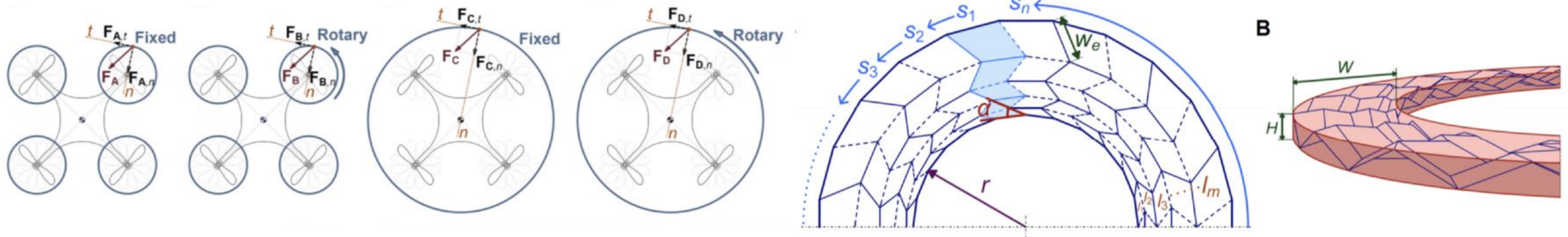
Rorigami for impact protection

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Rotorigami for impact protection

34



Rorigami for impact protection

35

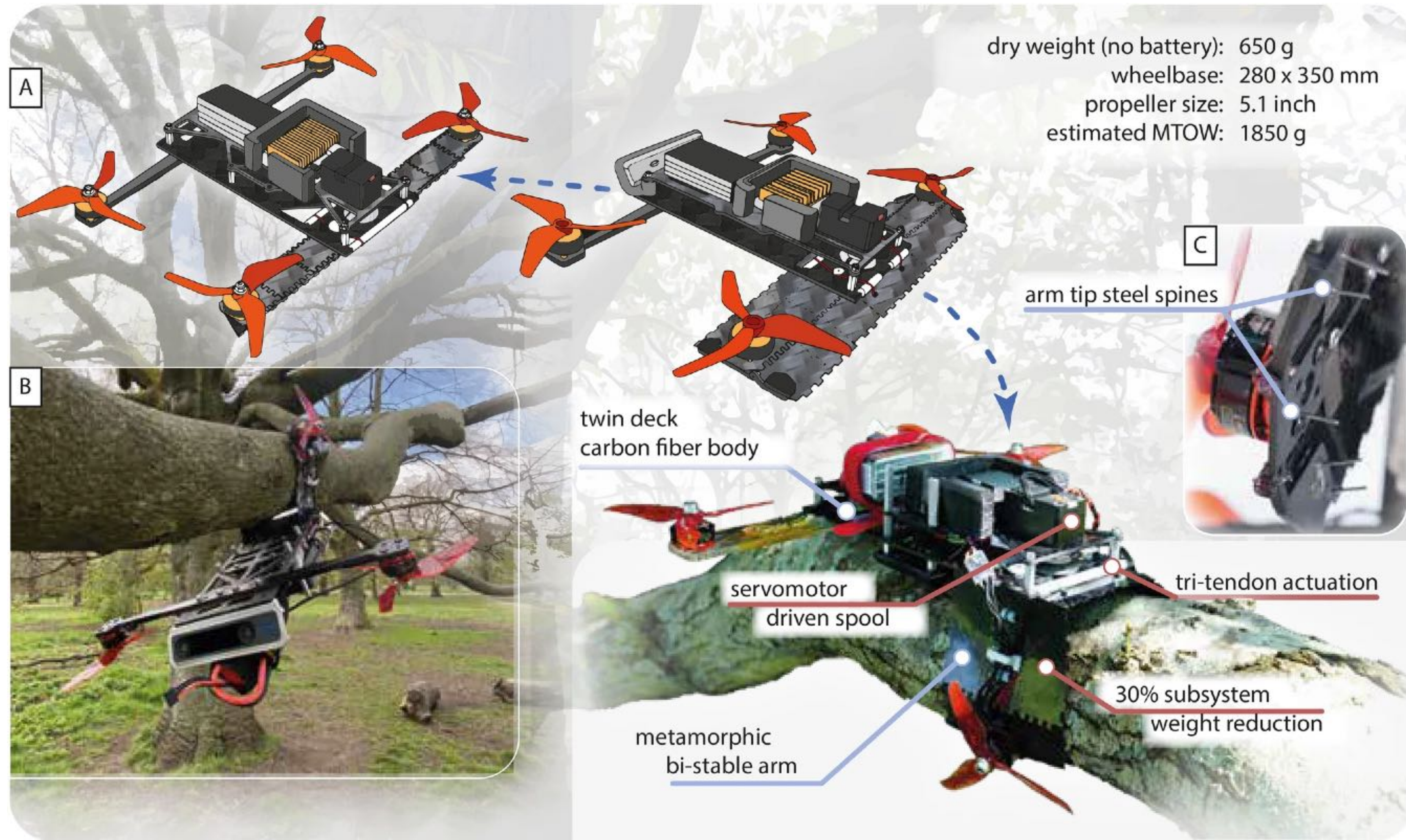


Fixed-Naked

Rotary-Origami

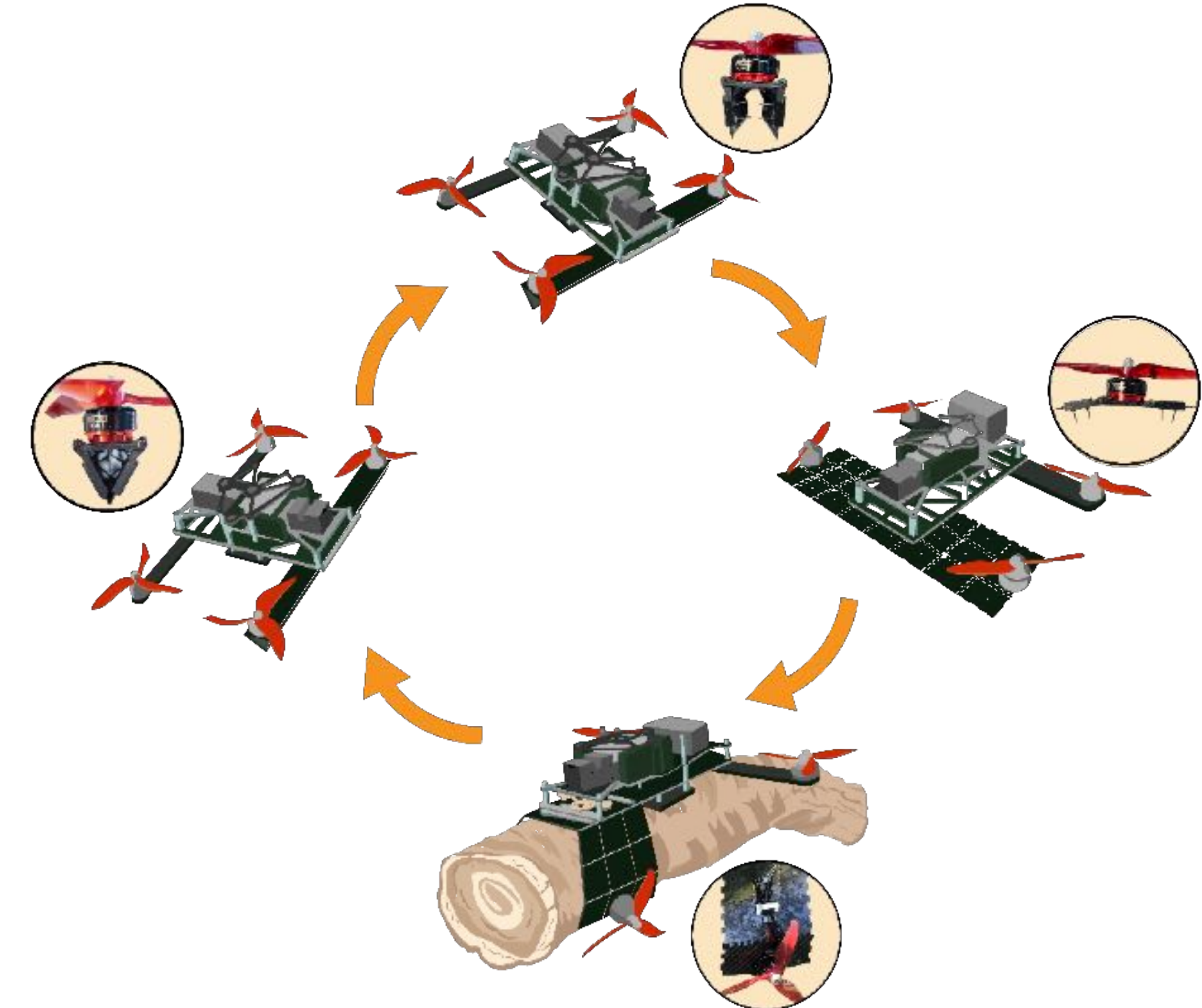
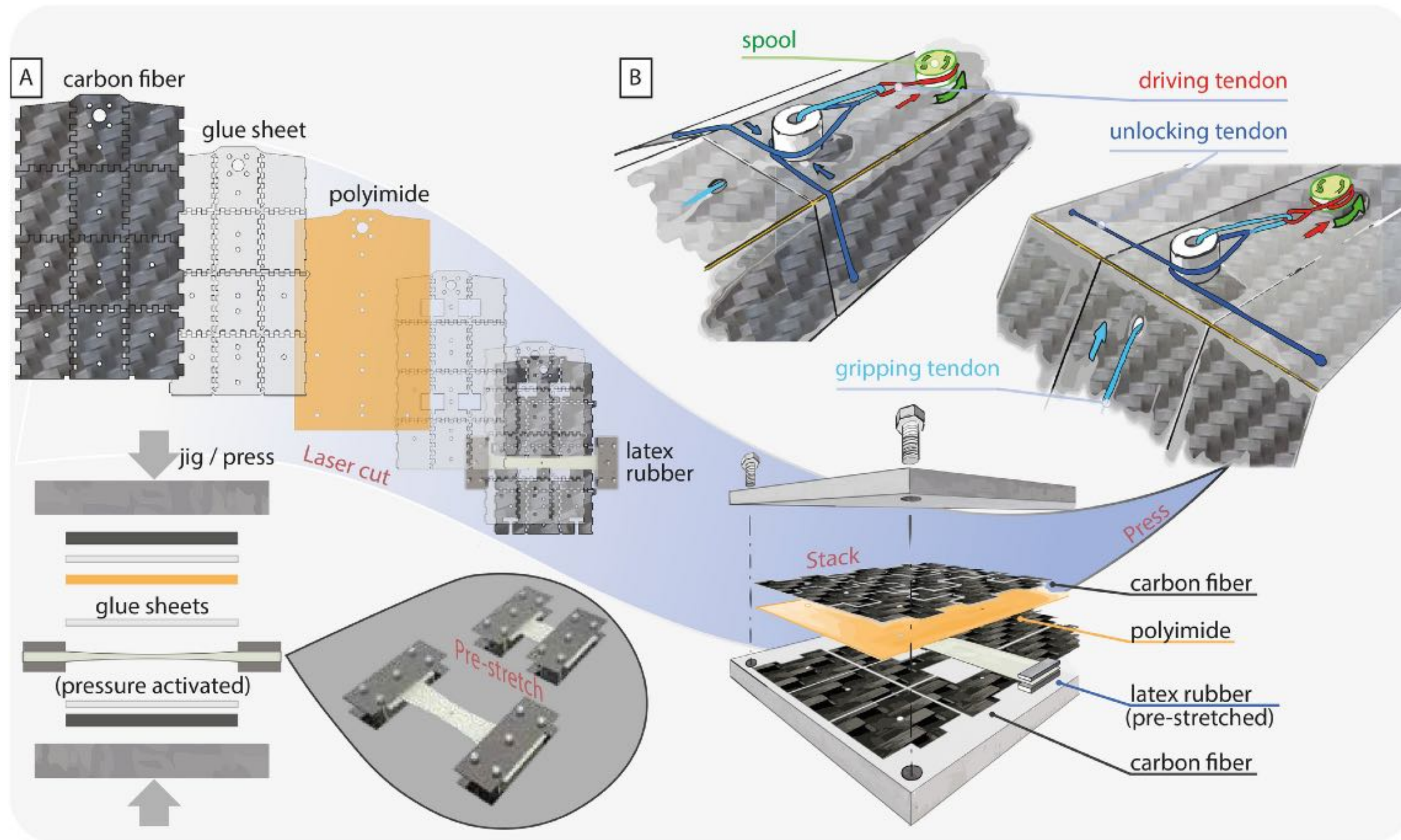
P. Sareh, P. Chermprayong, M. Emmanuelli, H. Nadeem, M. Kovac
Science Robotics (2018)

Meta-morphic full body perching



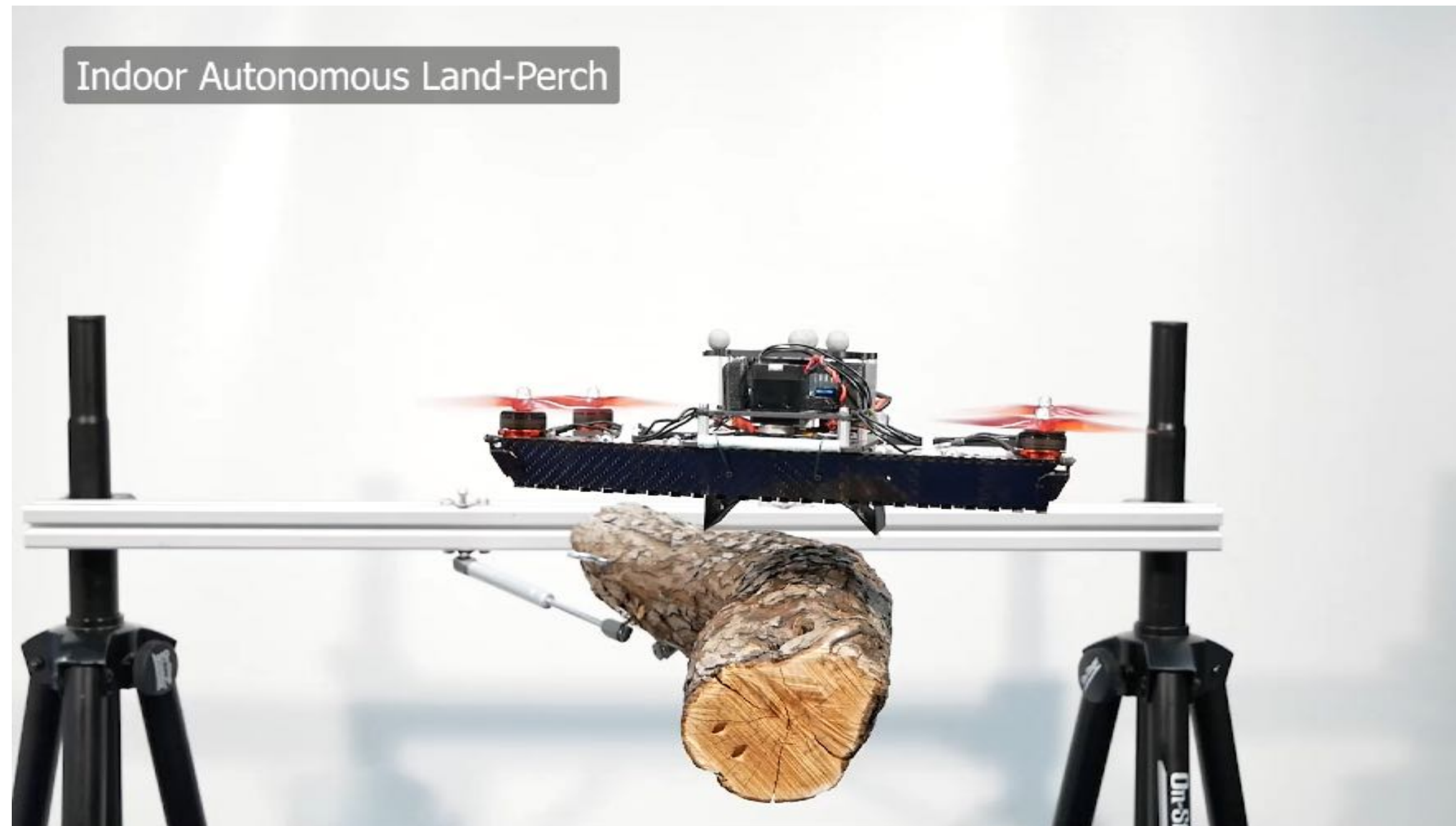
Zheng, P., Xiao, F., Nguyen, P. H., Farinha, A. and Kovac, M., (2023) Metamorphic Aerial Robot capable of mid-air shape morphing for rapid perching, *Nature Scientific Reports*

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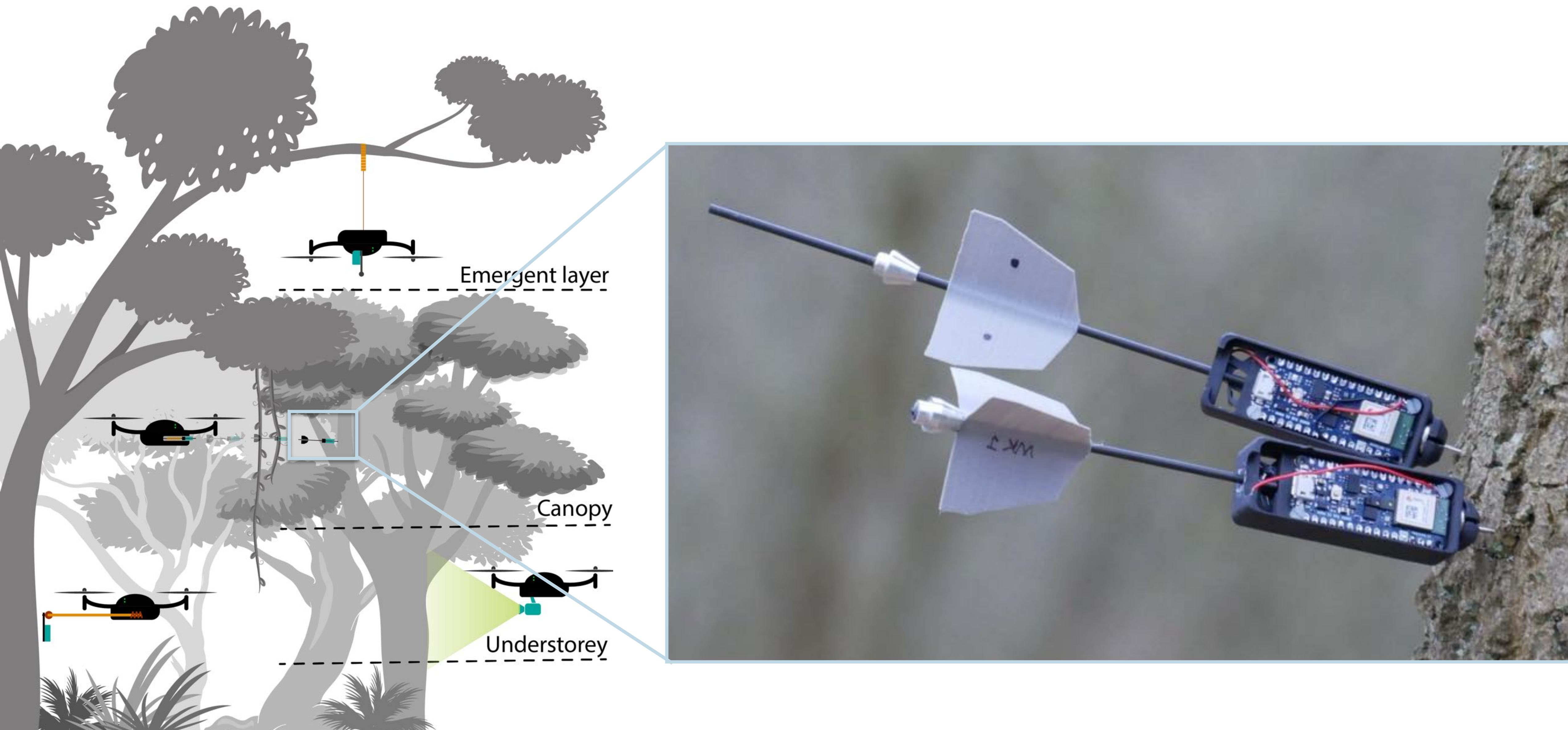


Zheng, P., Xiao, F., Nguyen, P. H., Farinha, A. and Kovac, M., (2023) Metamorphic Aerial Robot capable of mid-air shape morphing for rapid perching, *Nature Scientific Reports*

Meta-morphic full body perching



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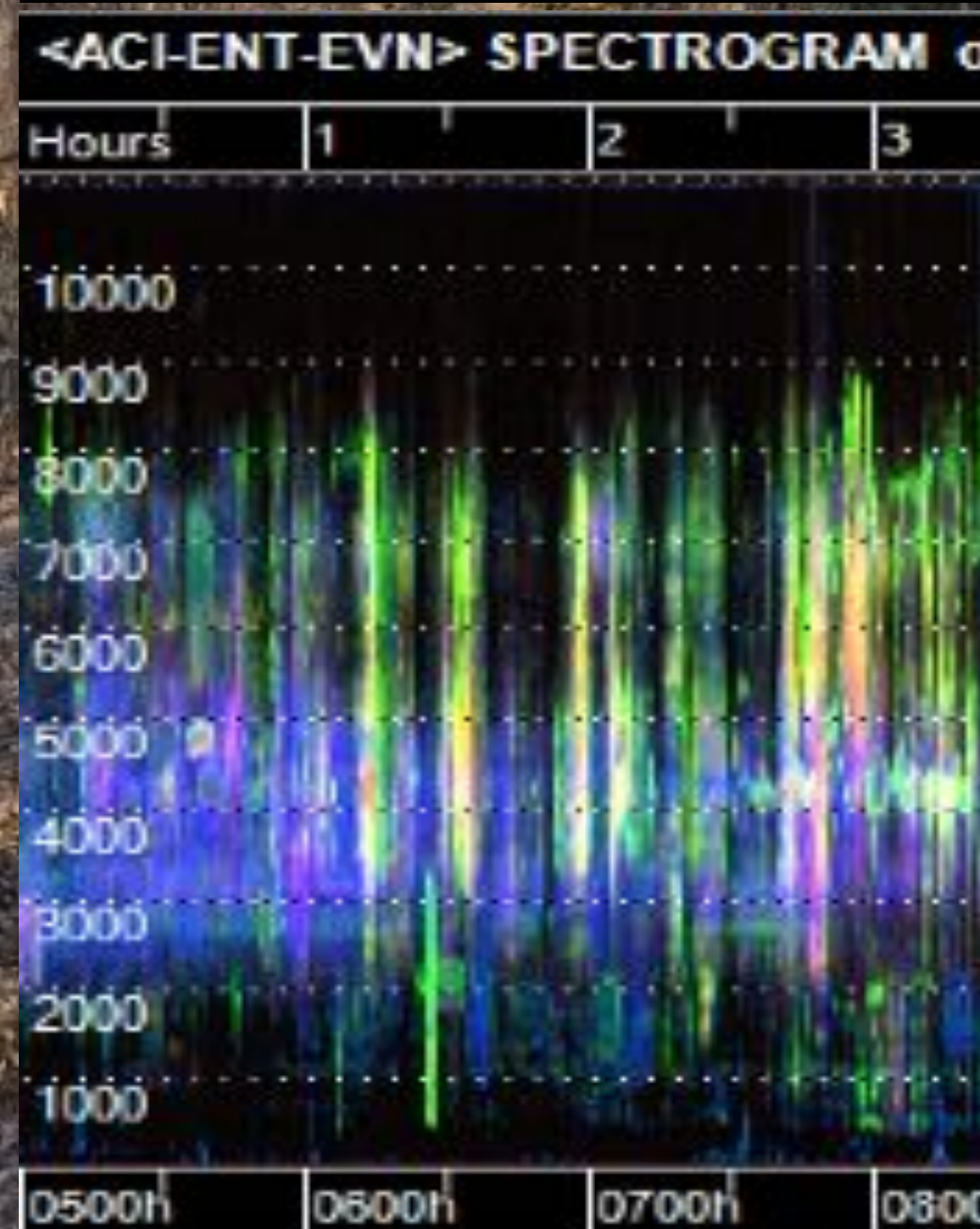


A. Farinha, R. Zufferey, P. Zheng, S. F. Armanini and M. Kovac,
IEEE Robotics and Automation Letters (2020)





Acoustic signature



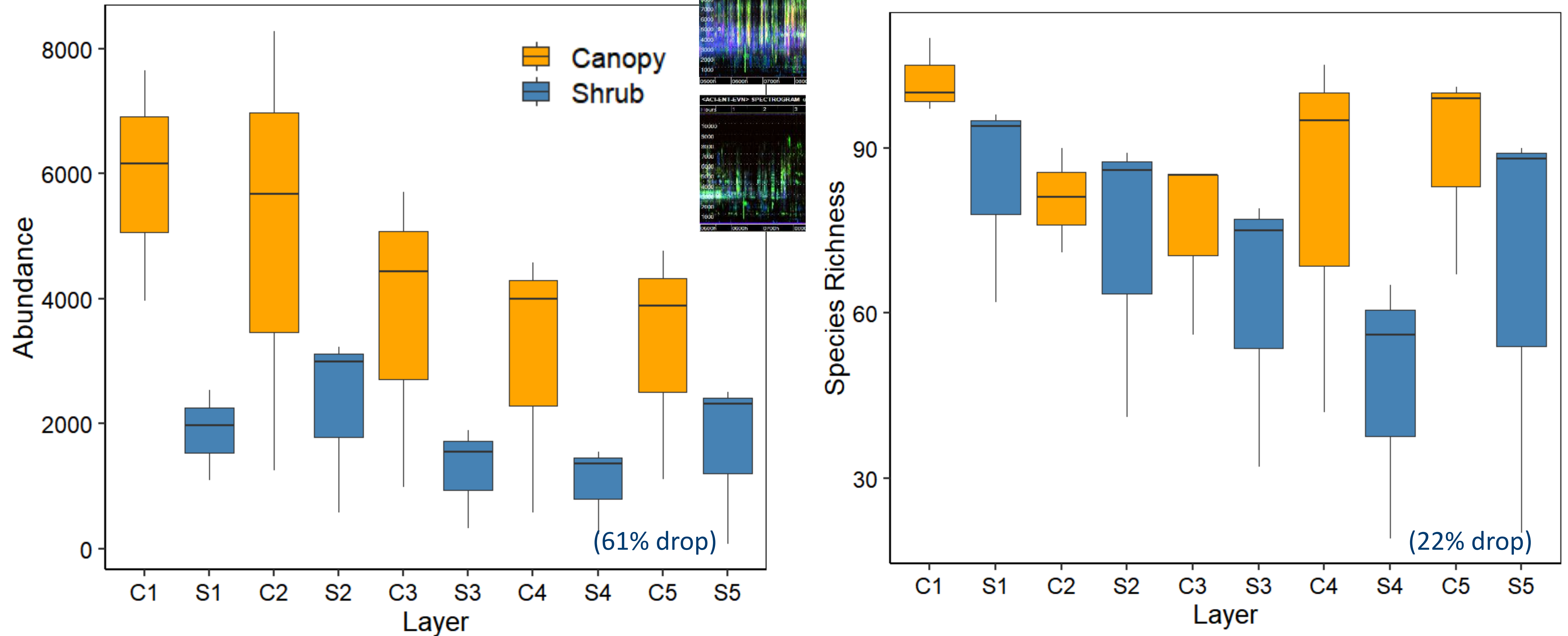
Hamaza, S., Farinha, A., Nguyen, H. N., & Kovac, M. *IEEE IROS*, 2020

A. Farina, M. Kovac et. al *IEEE Robotics and Automation Letters*, 2022 and in preparation

Bird abundance and richness differs across layers

42

135 species recorded



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

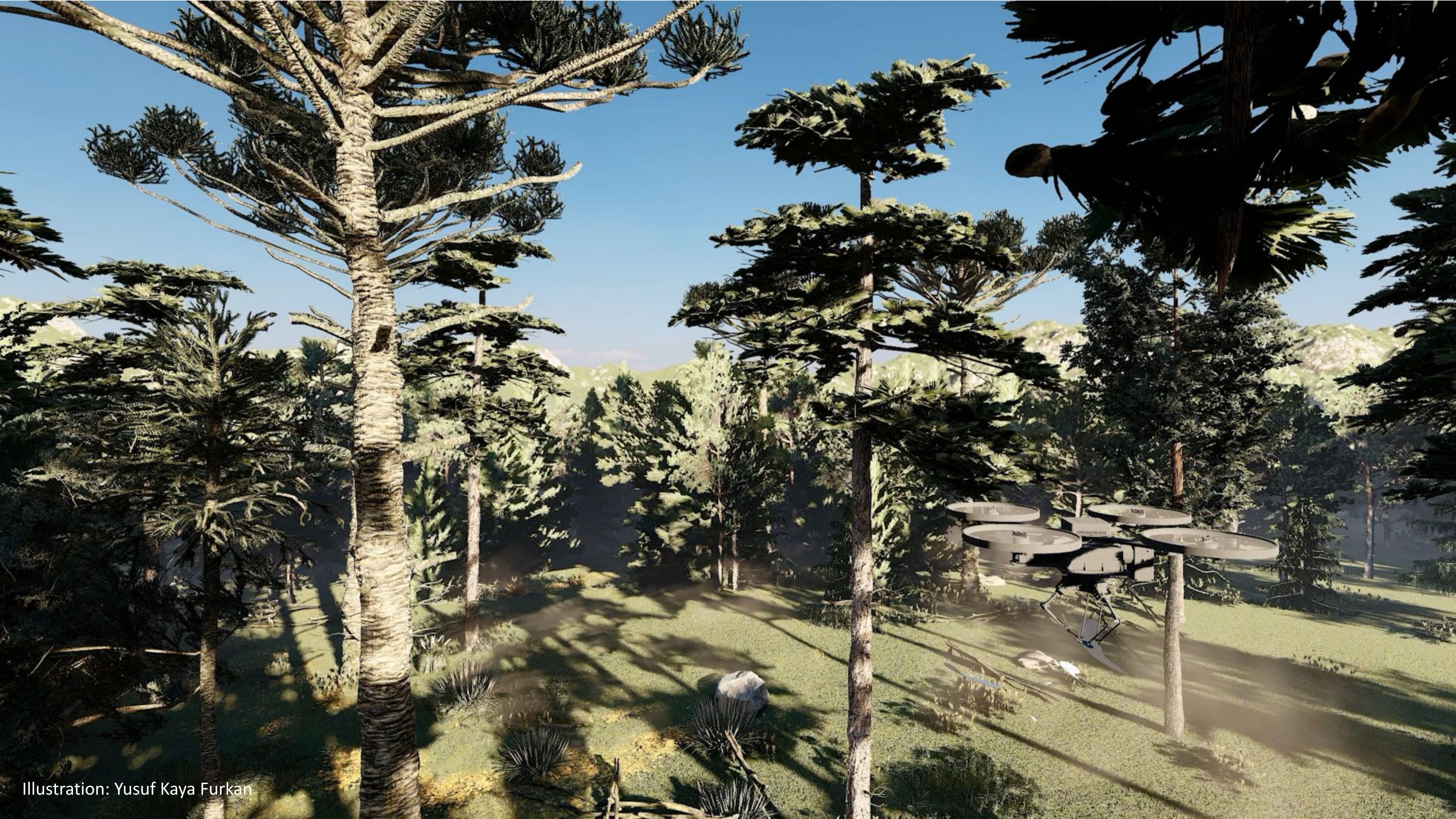
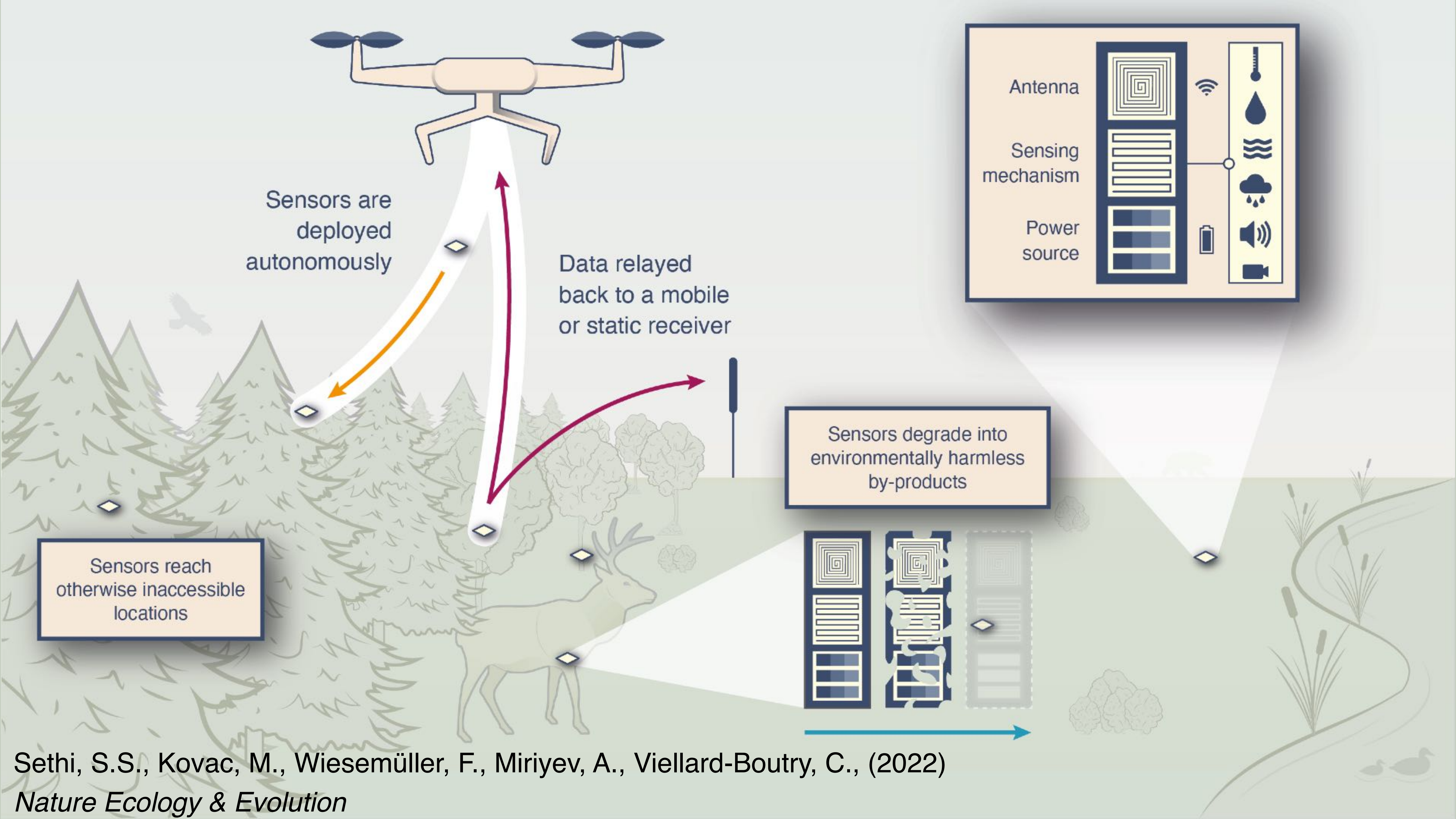
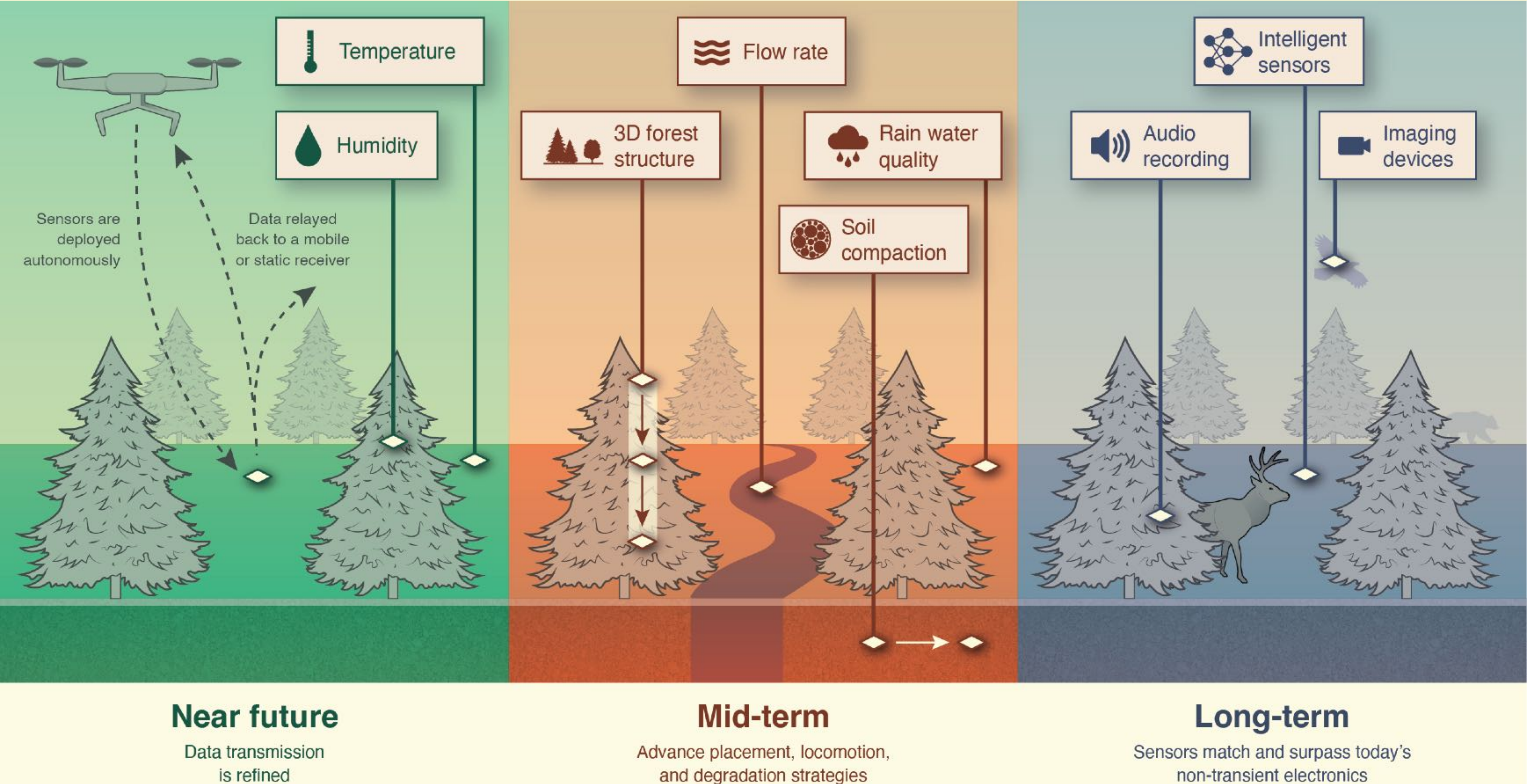


Illustration: Yusuf Kaya Furkan



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

Nature Ecology & Evolution



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

Nature Ecology & Evolution

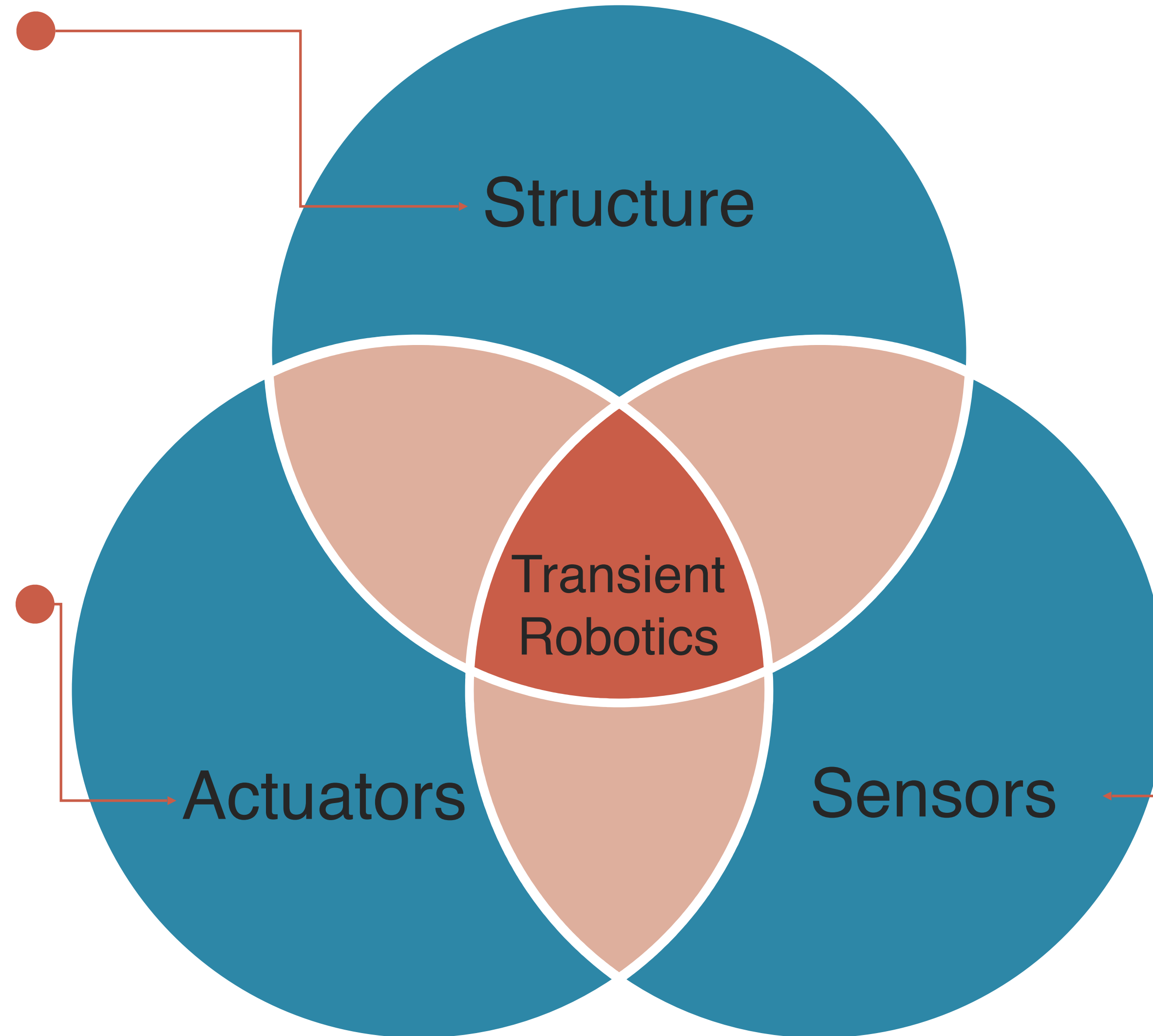
Transient Robotics

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)

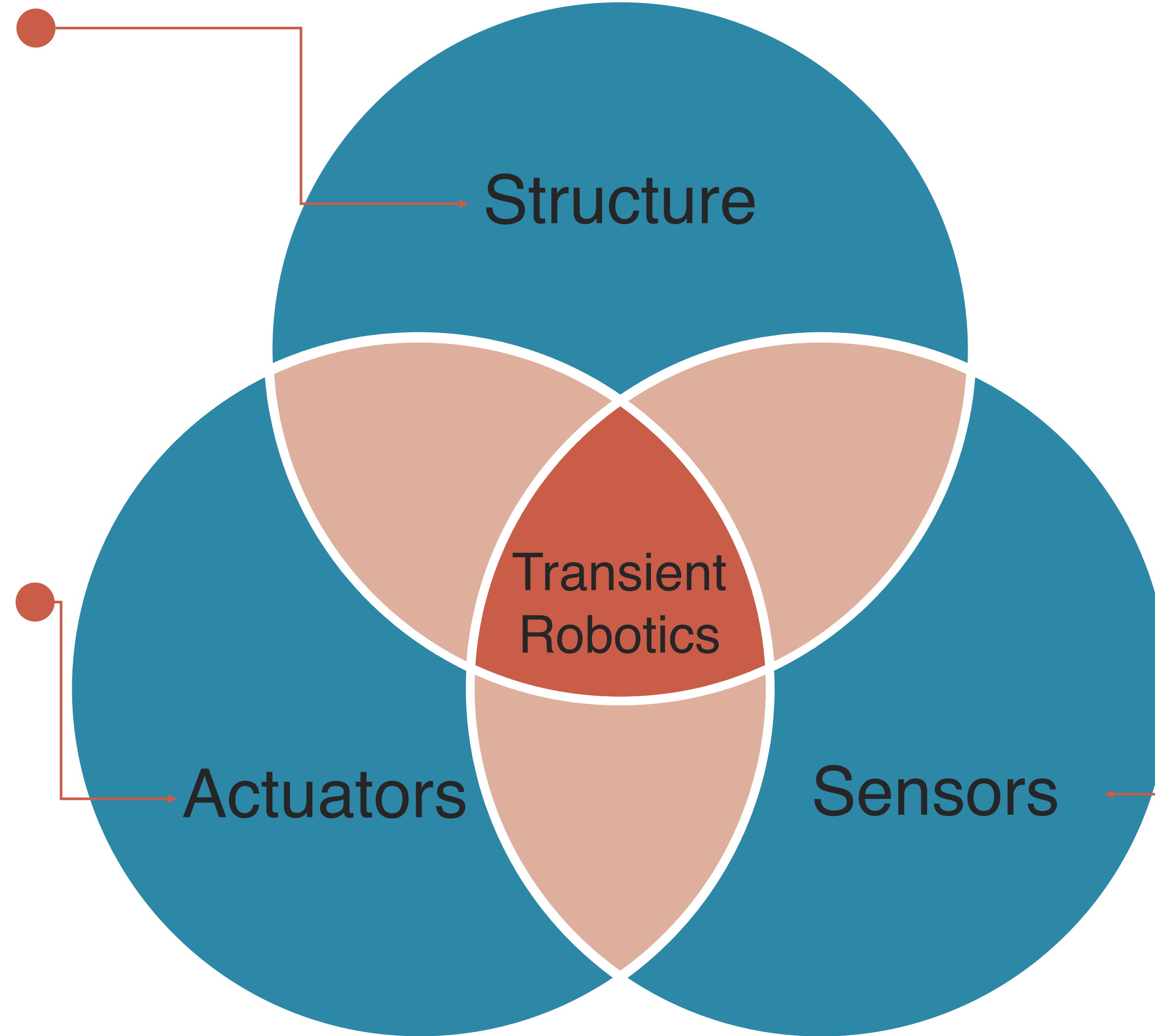
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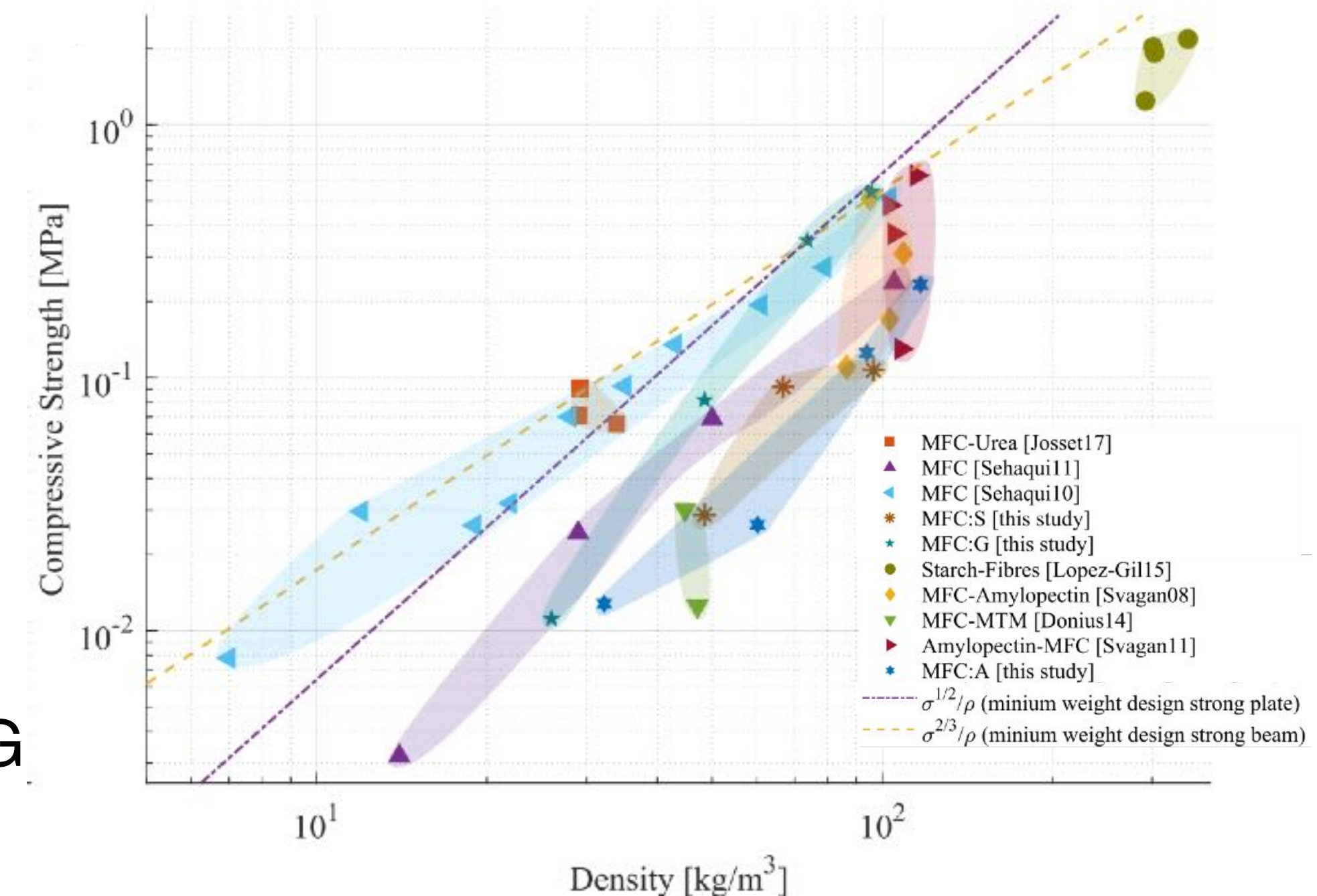
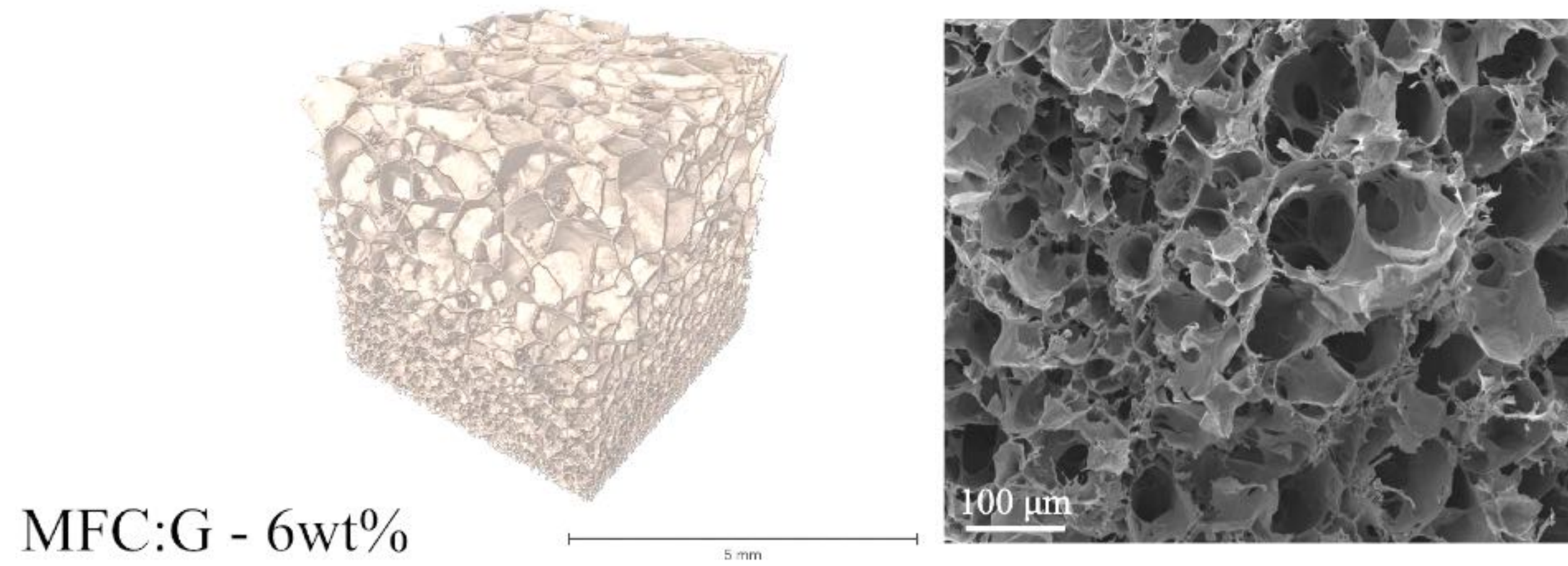
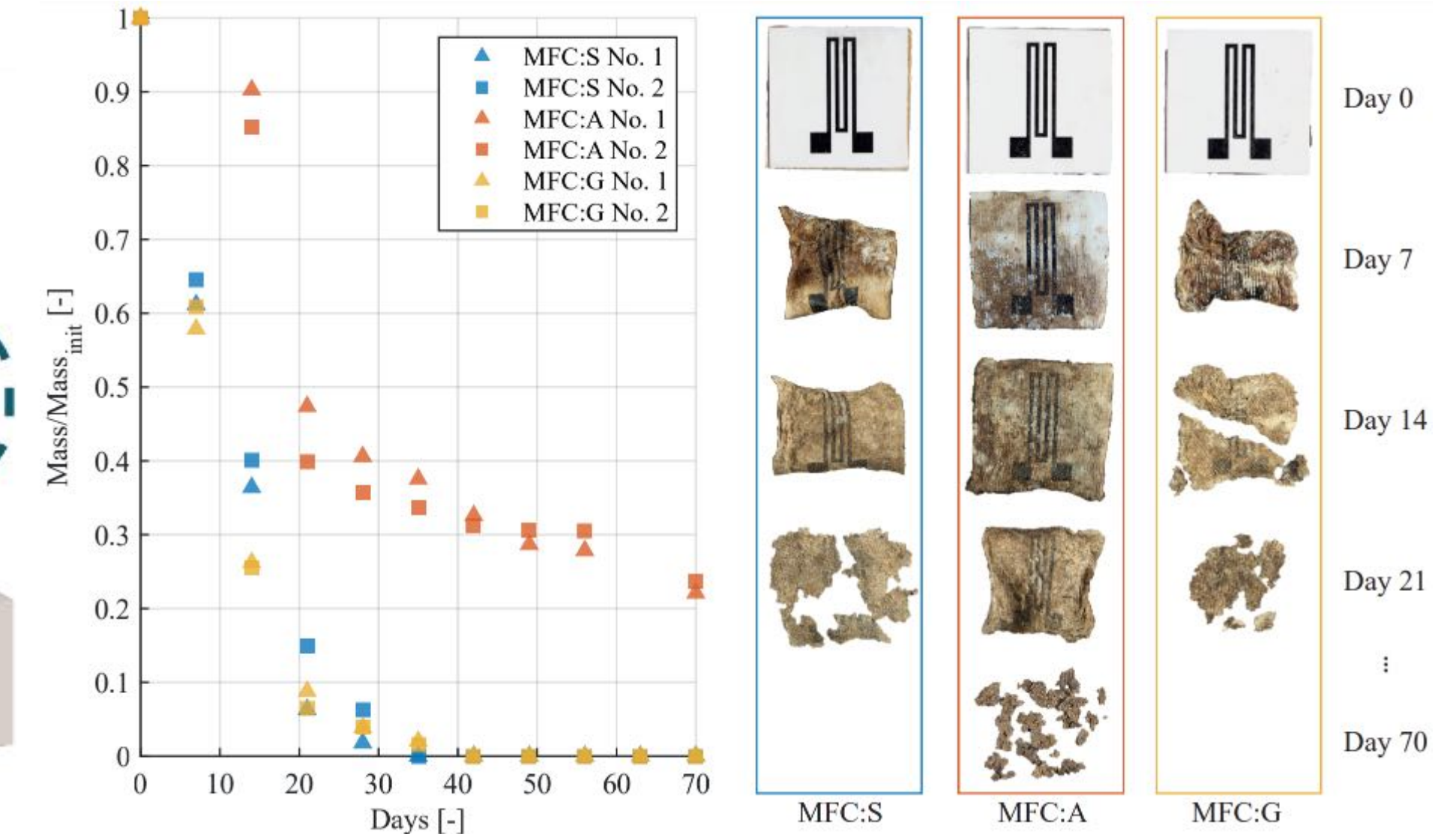
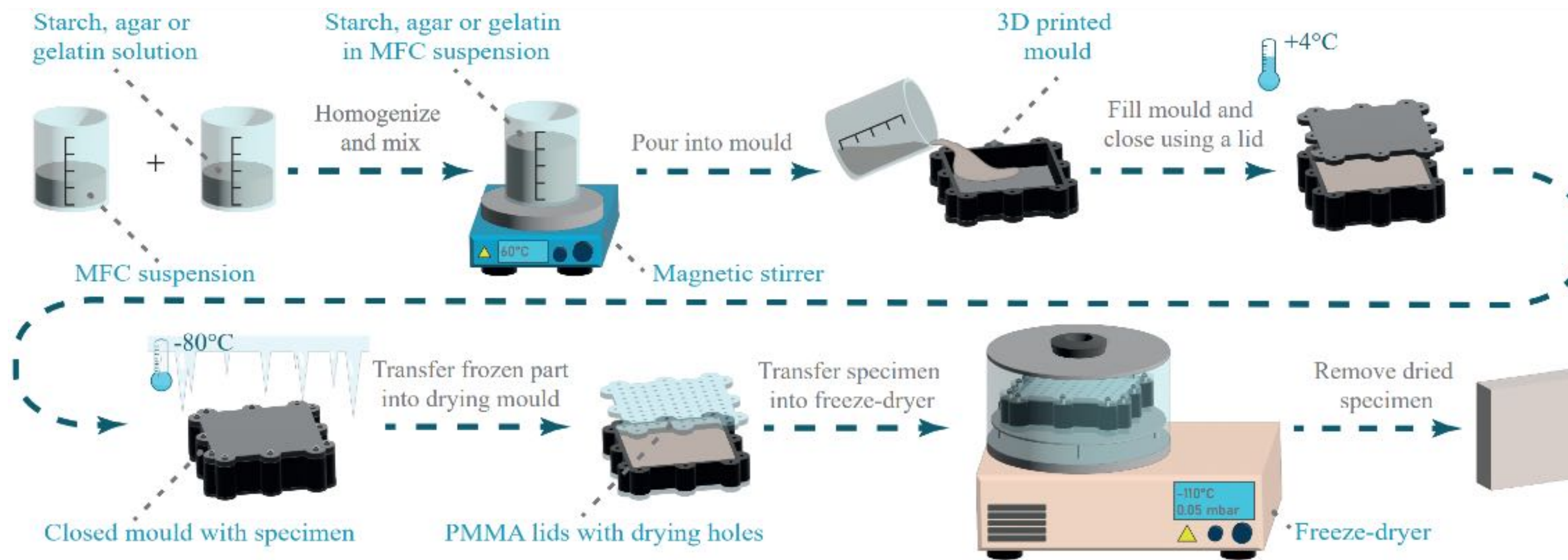
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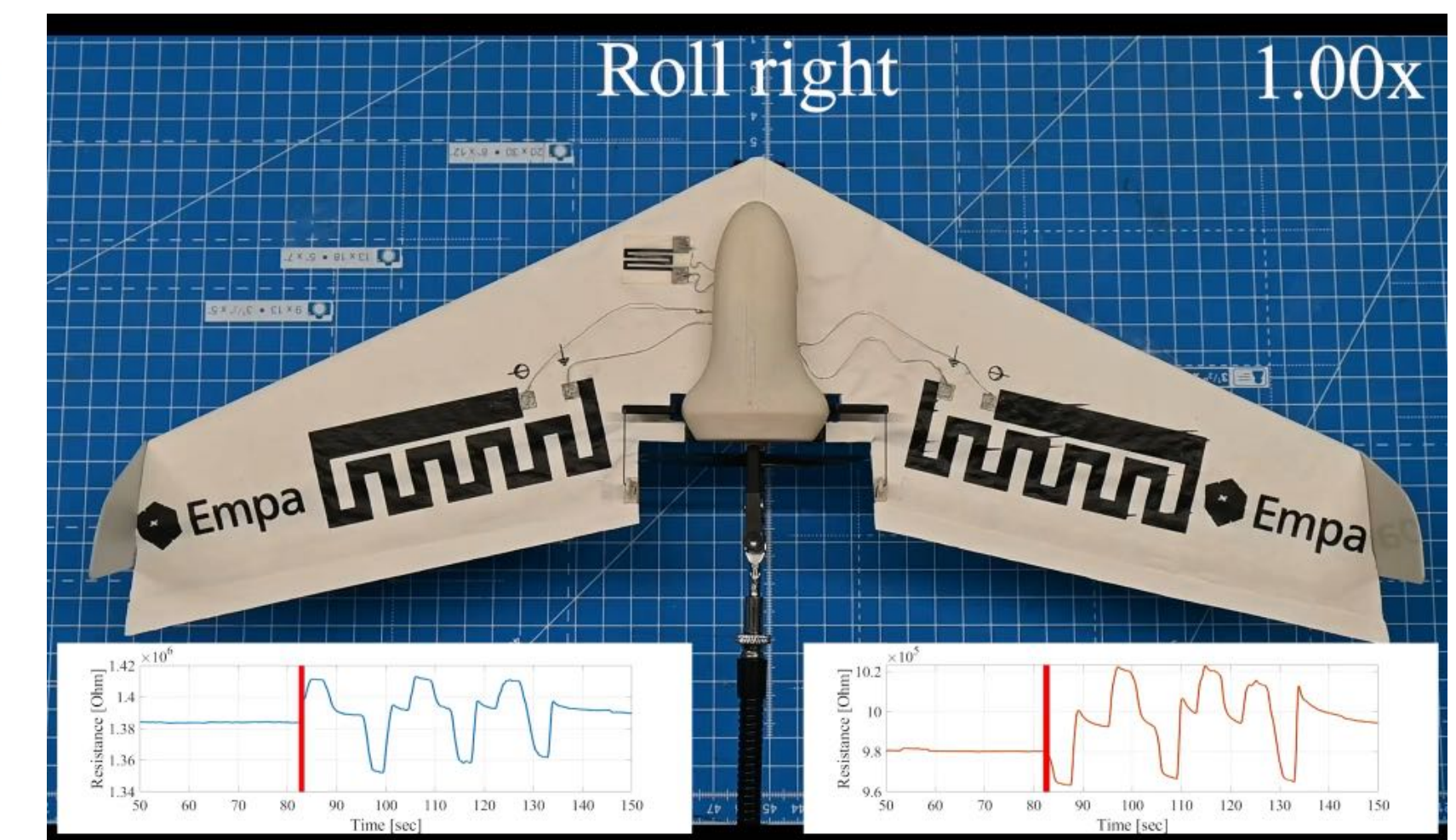
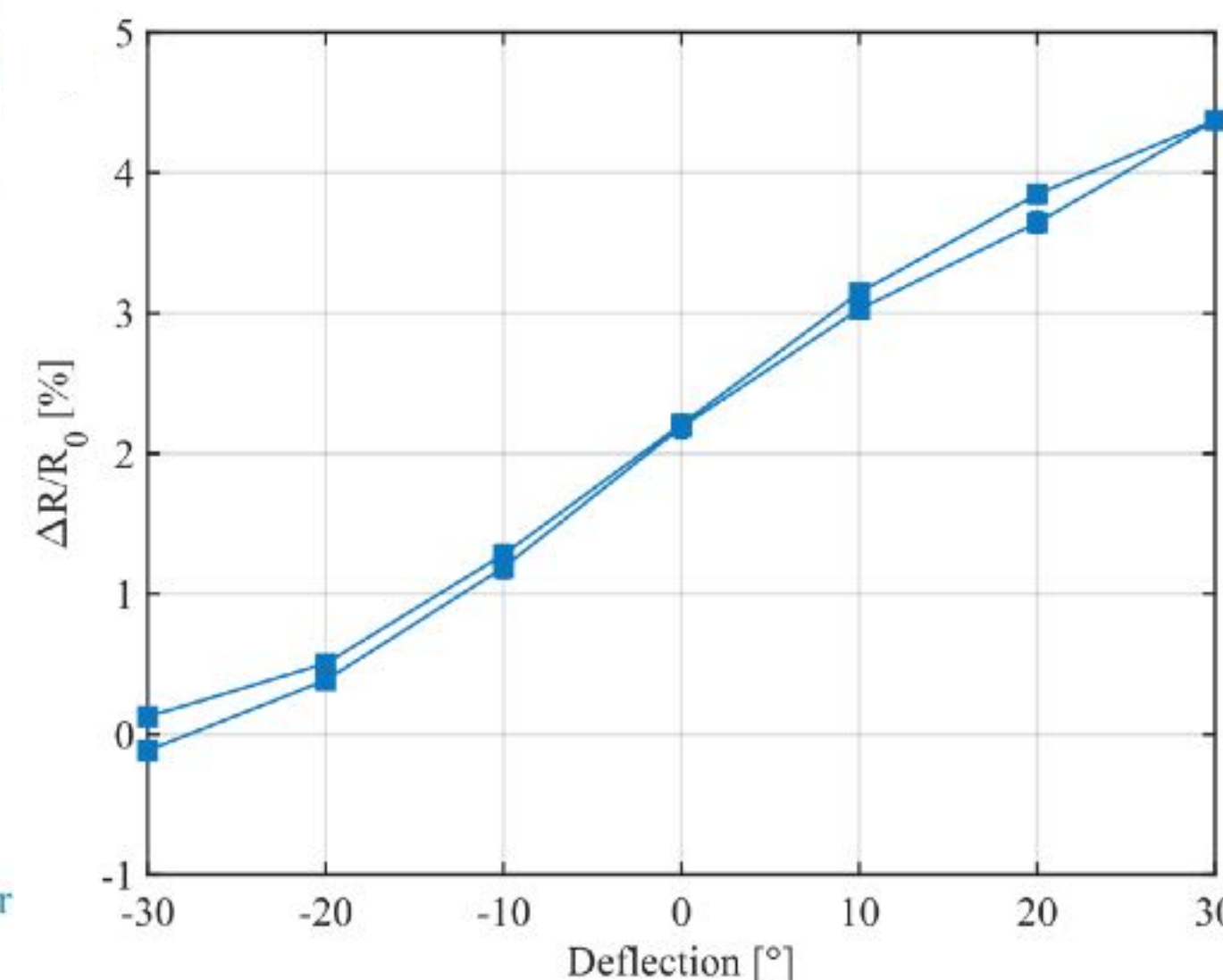
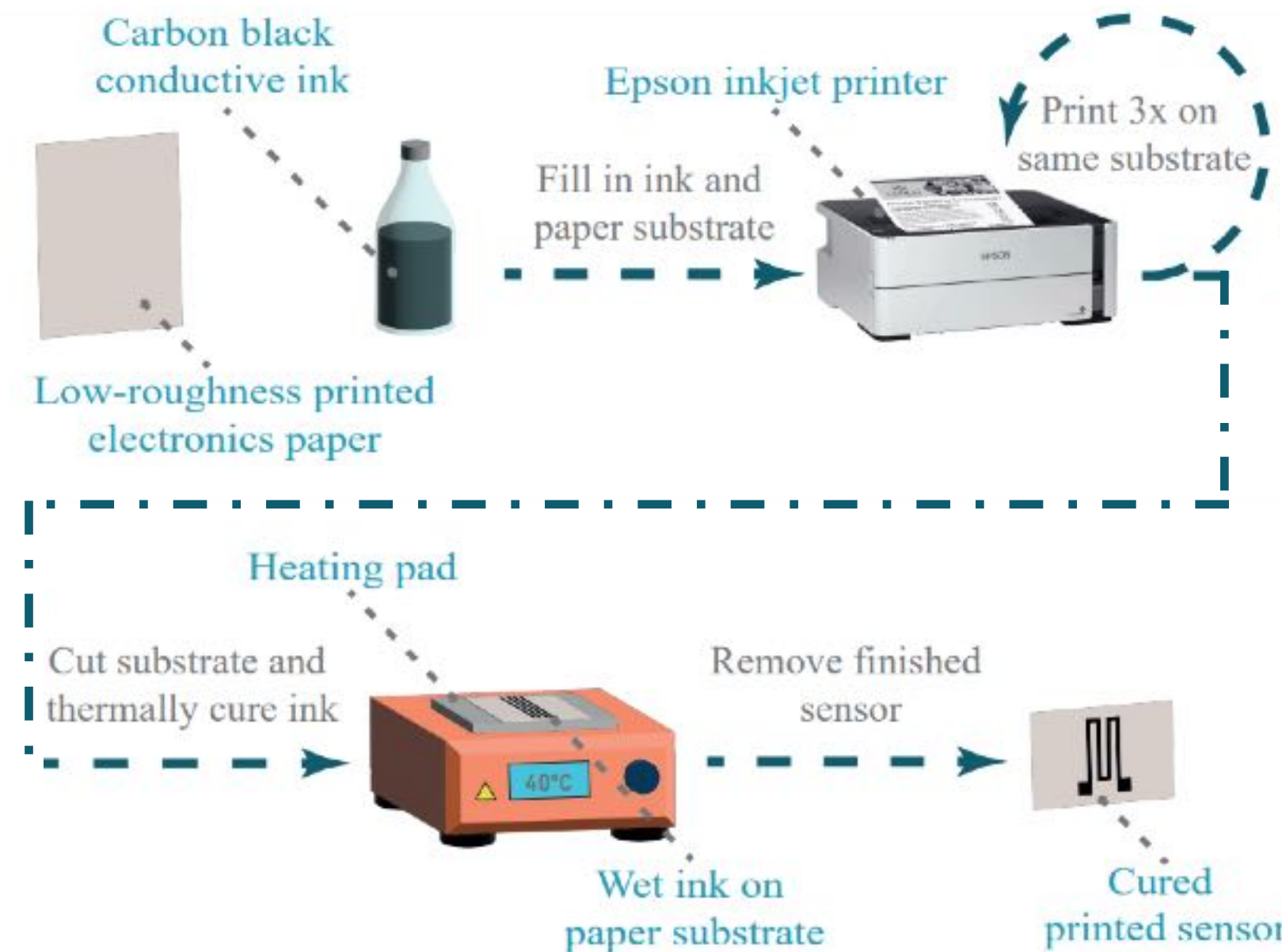
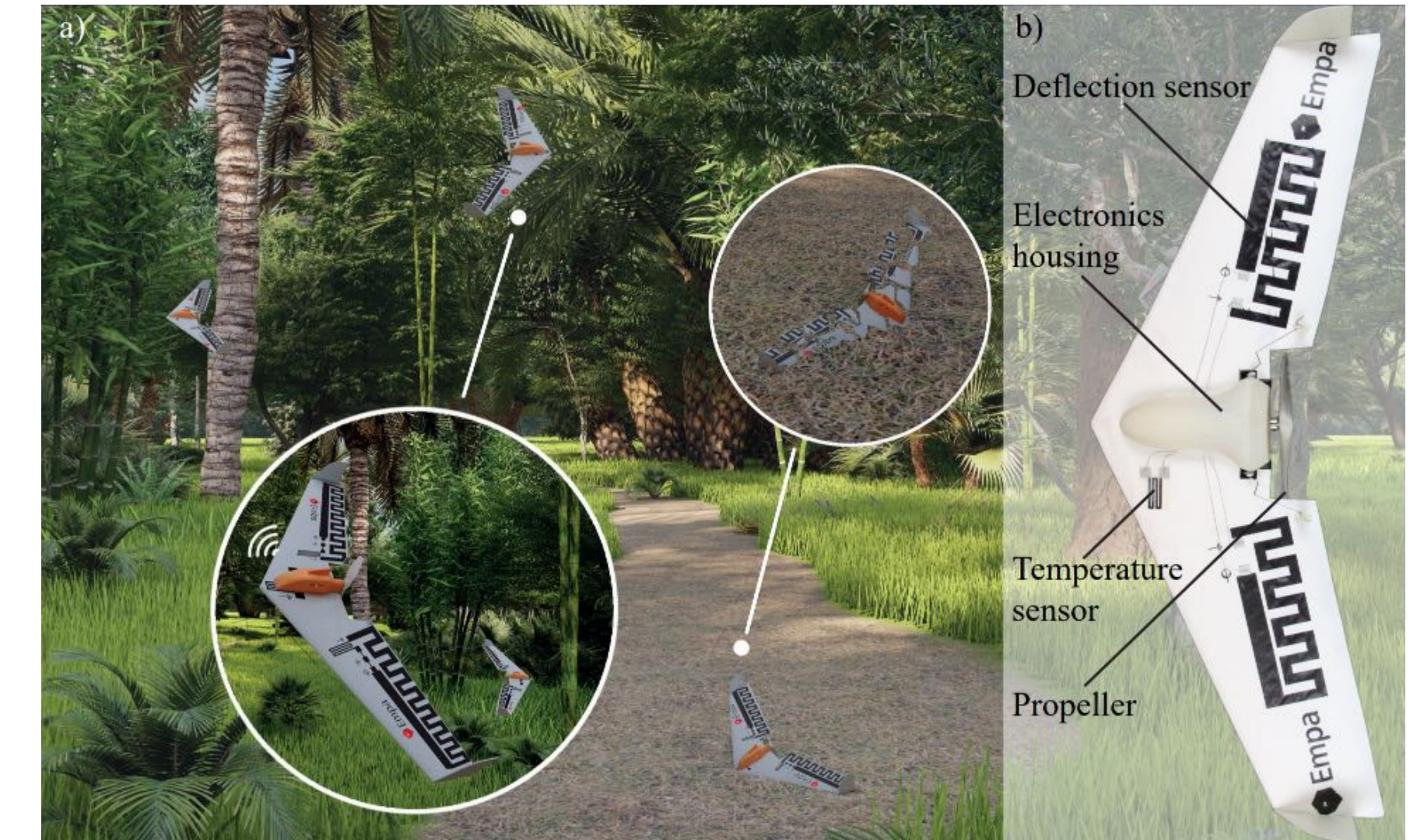
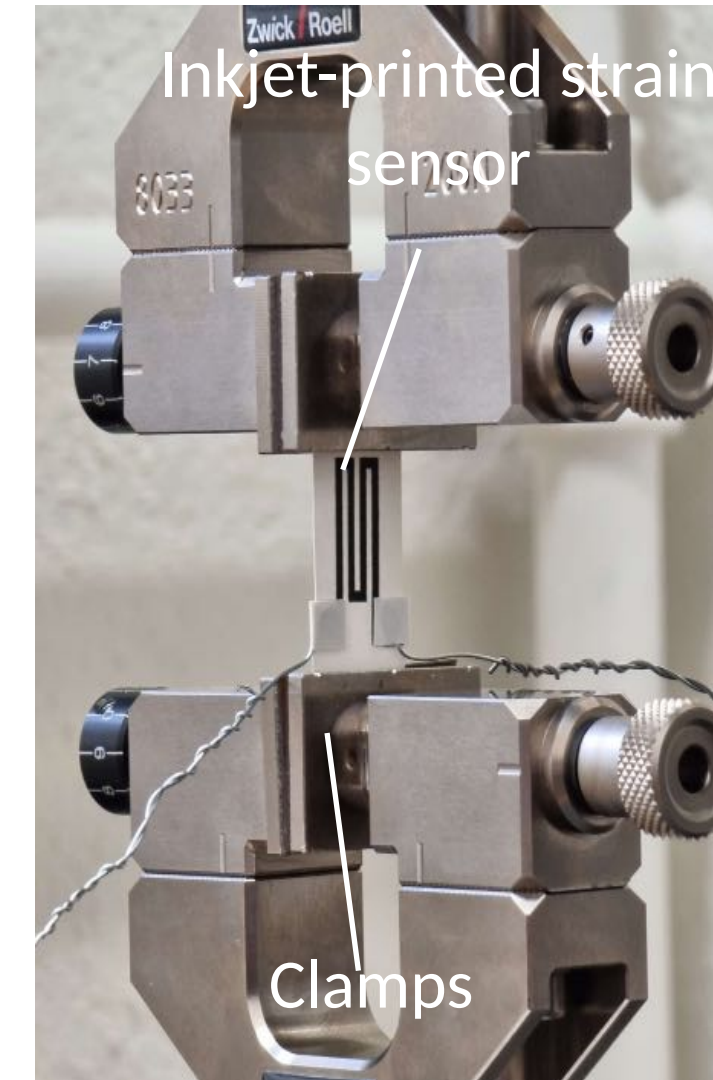
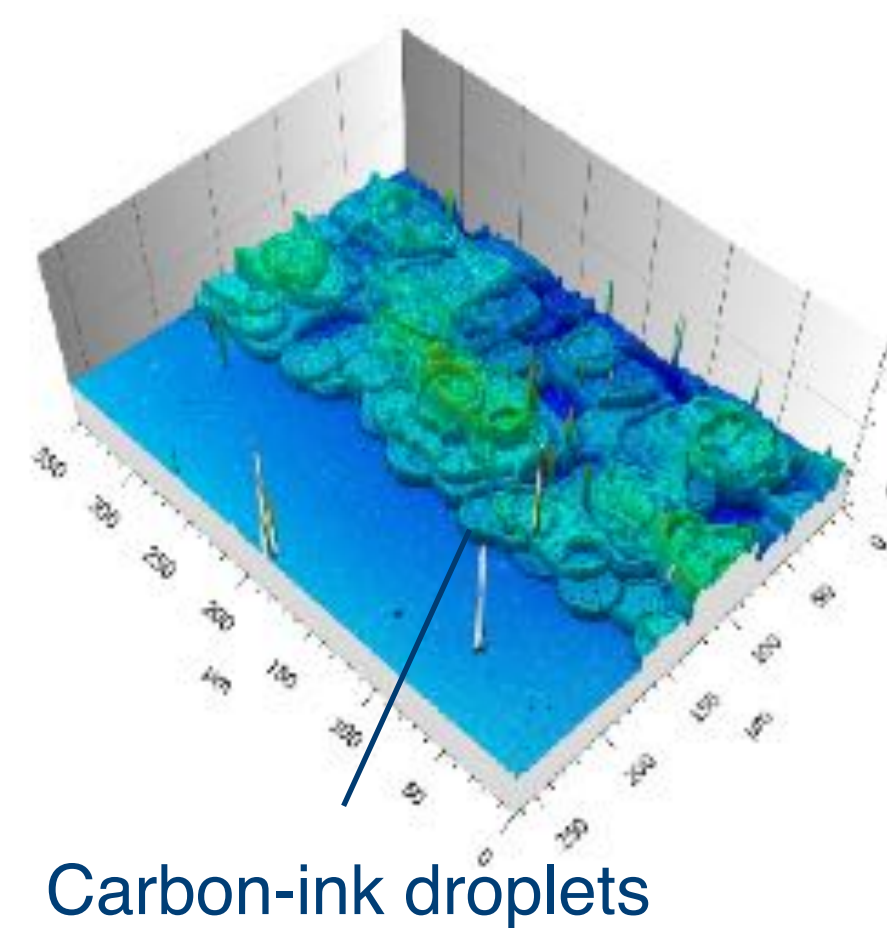
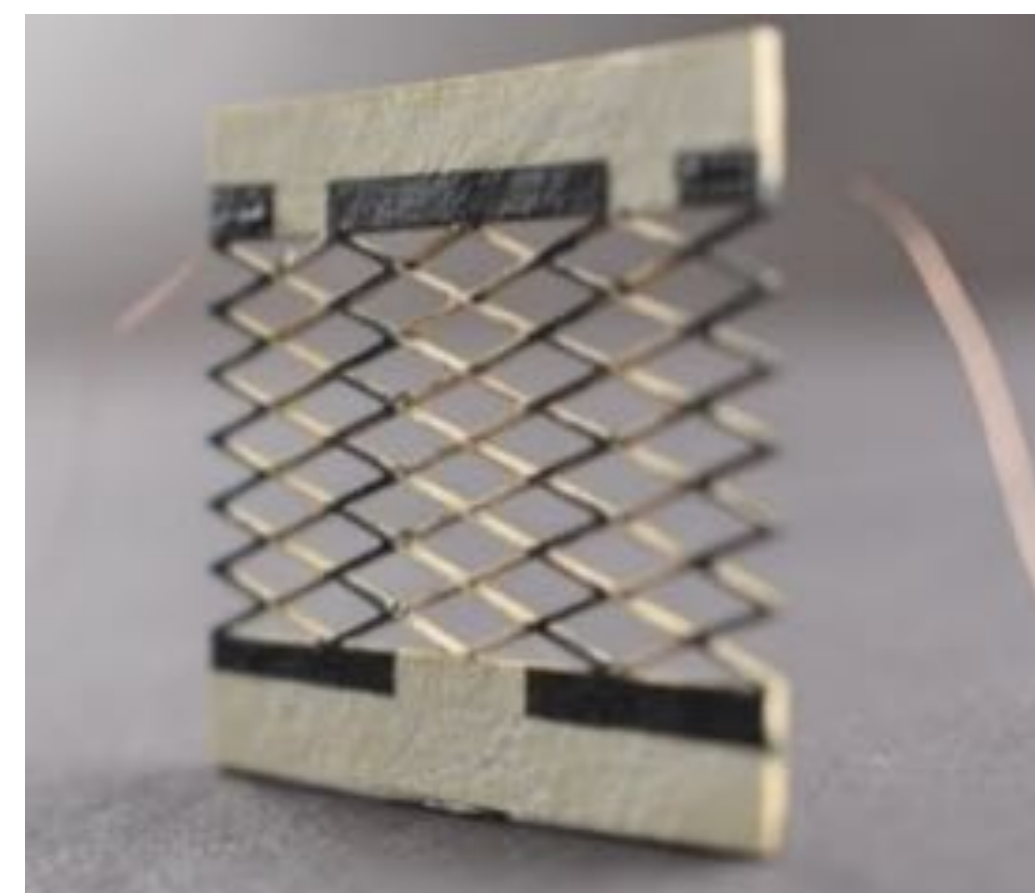
Structure: Cellulose composite cryogels



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

Sensing: Functionalised cellulose substrates

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

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

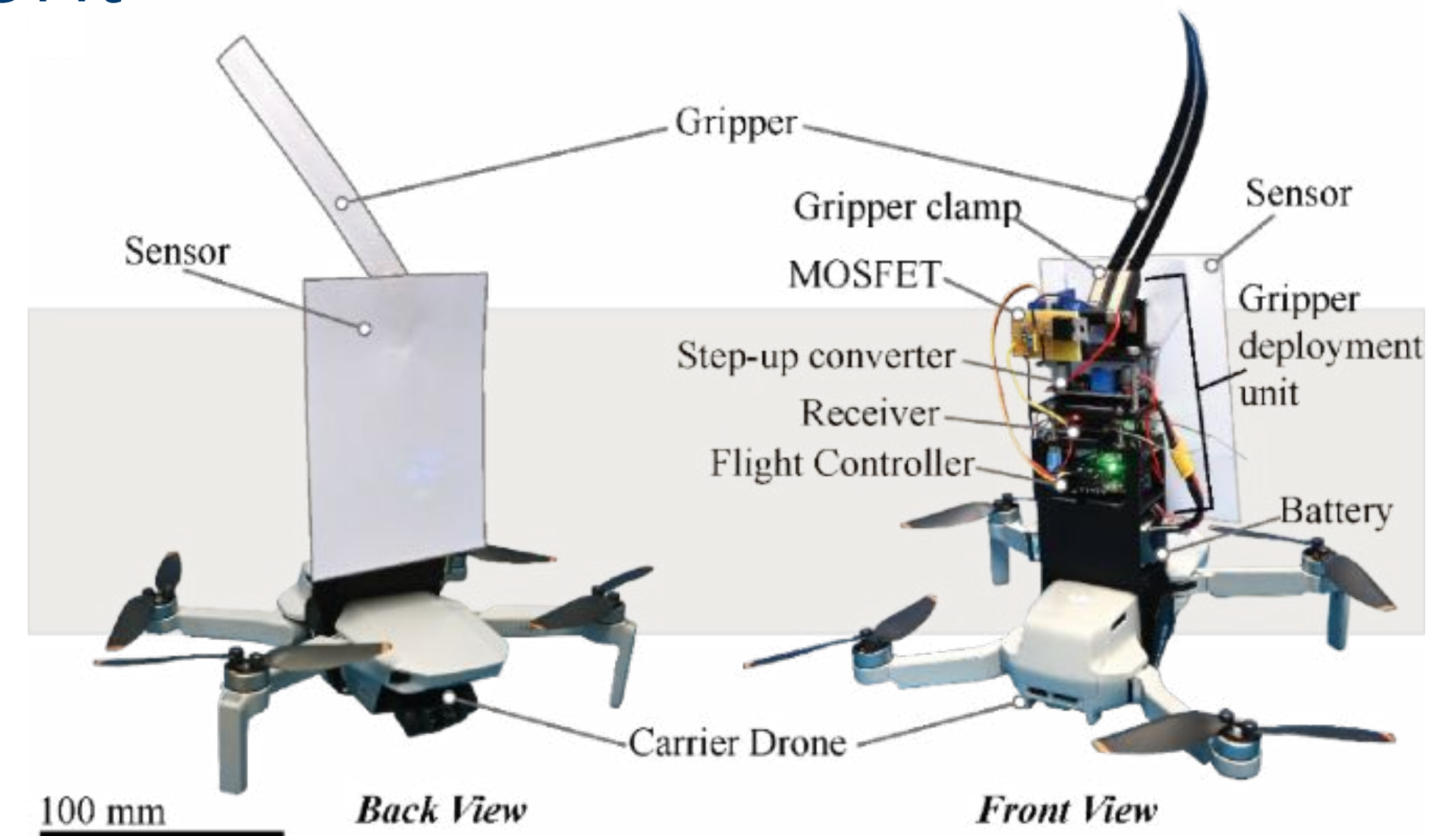
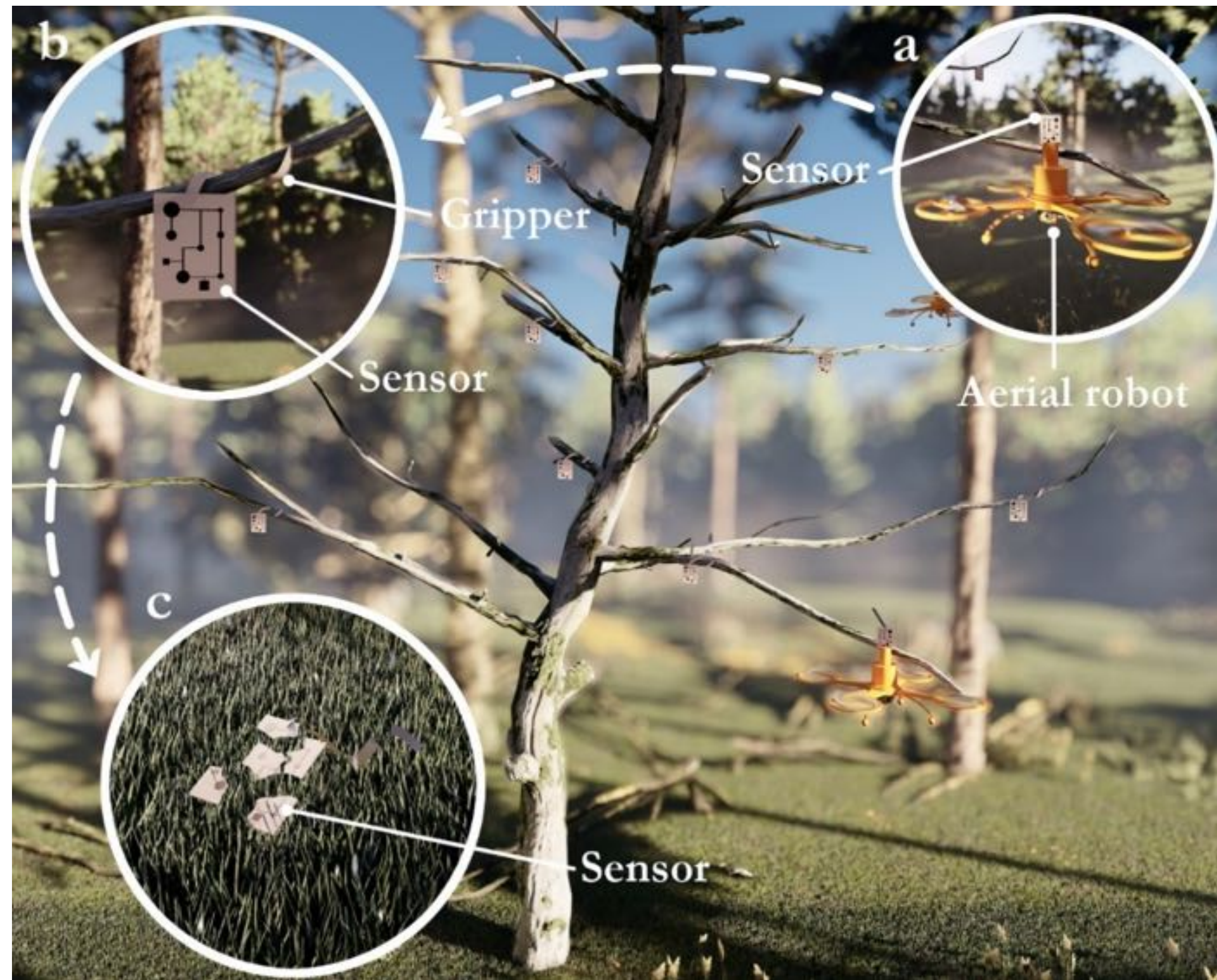
Actuation: Humidity responsive composites

50



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

Hygroscopically-driven transient actuator for environmental sensor deployment



- Development, manufacturing and testing of a transient high-deformation gripper for sensor deployment tasks
- Characterization of time-dependent coiling & maximum payload
- Deployment unit design & gripper integration with quadrotor
- Successful indoor deployment tests of sensing unit

M. Heinrich, F. Wiesemüller, X. Aeby, Y. F. Kaya, D. Sivaraman, P. H. Nguyen, S. Song, G. Nyström, M. Kovac, *IEEE Robosoft* 2023

Transient Robotics

Vol. 5 • No. 2 • February 2023
www.advintellsyst.com

ADVANCED INTELLIGENT SYSTEMS

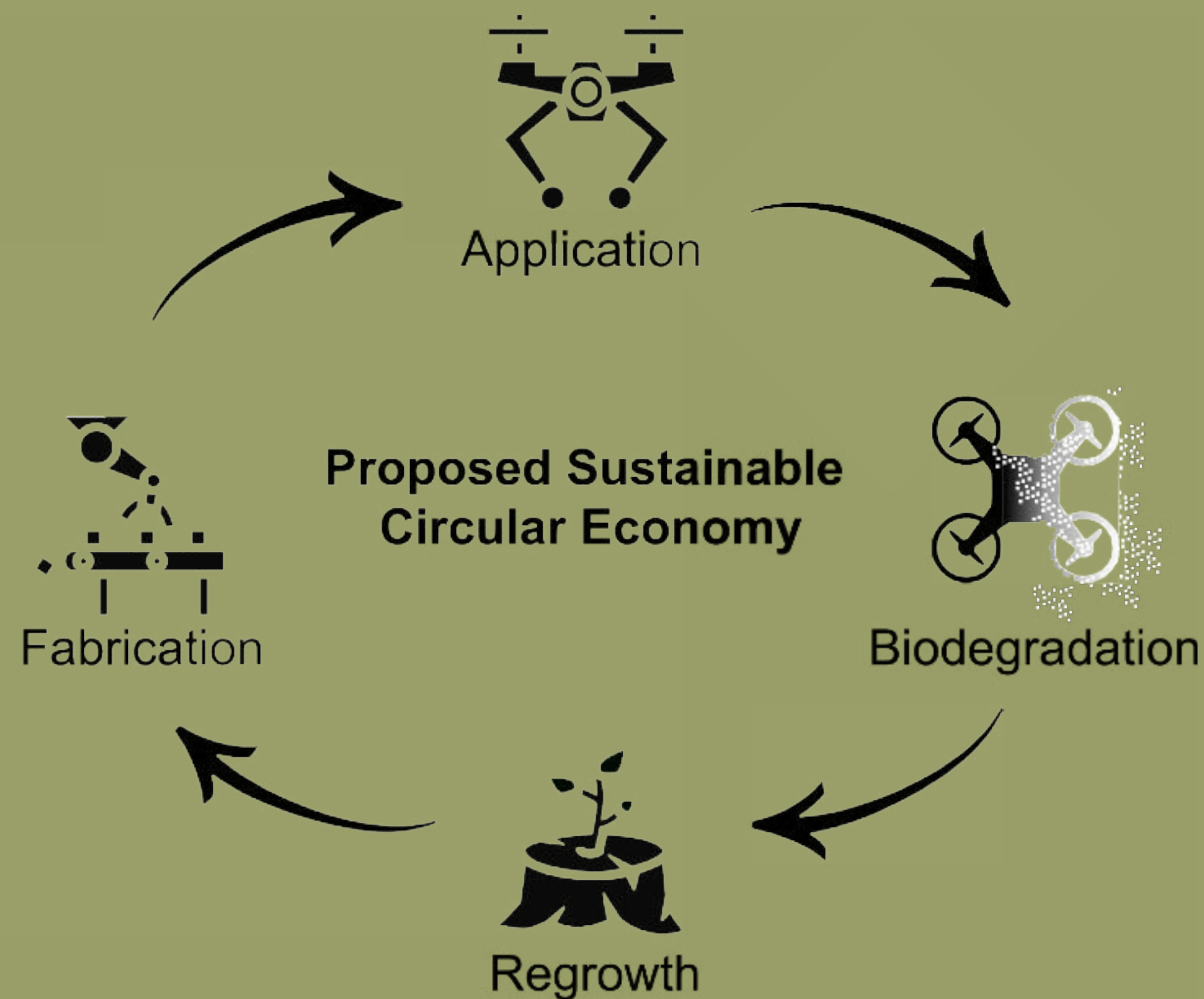
Open Access



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

WILEY-VCH

Transient Robotics



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

**ADVANCED
INTELLIGENT
SYSTEMS**

Open Access

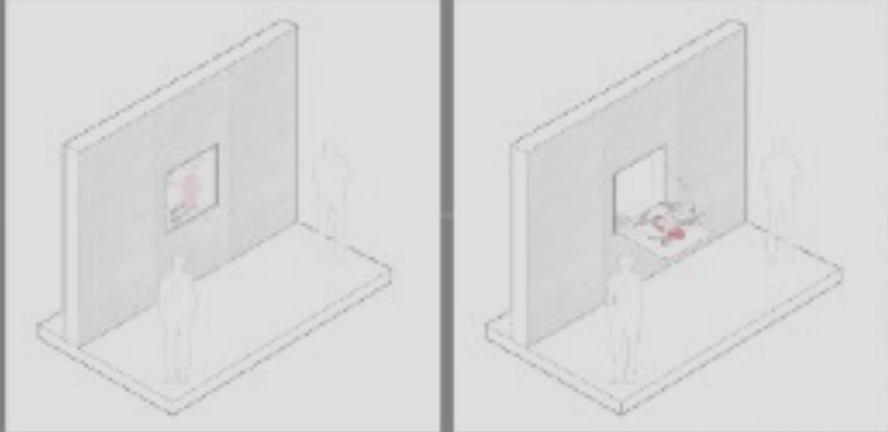
Vol. 5 • No. 2 • February 2023
www.advintellsyst.com

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Sustainability Robotics



Aerial Robots as first responders





Aerial Robotics for wind blade inspection





Eco-robotics to protect natural environments





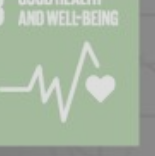
Aerial-aquatic robots to protect aquatic ecosystems





Aerial robotics for ageing infrastructure





Aerial Additive Manufacturing



Aerial Robotics for wind blade inspection

55



- Tensile perching to save energy
- String as sensing apparatus
- Tethered dynamic movement

Autonomous Tensile Perching

57

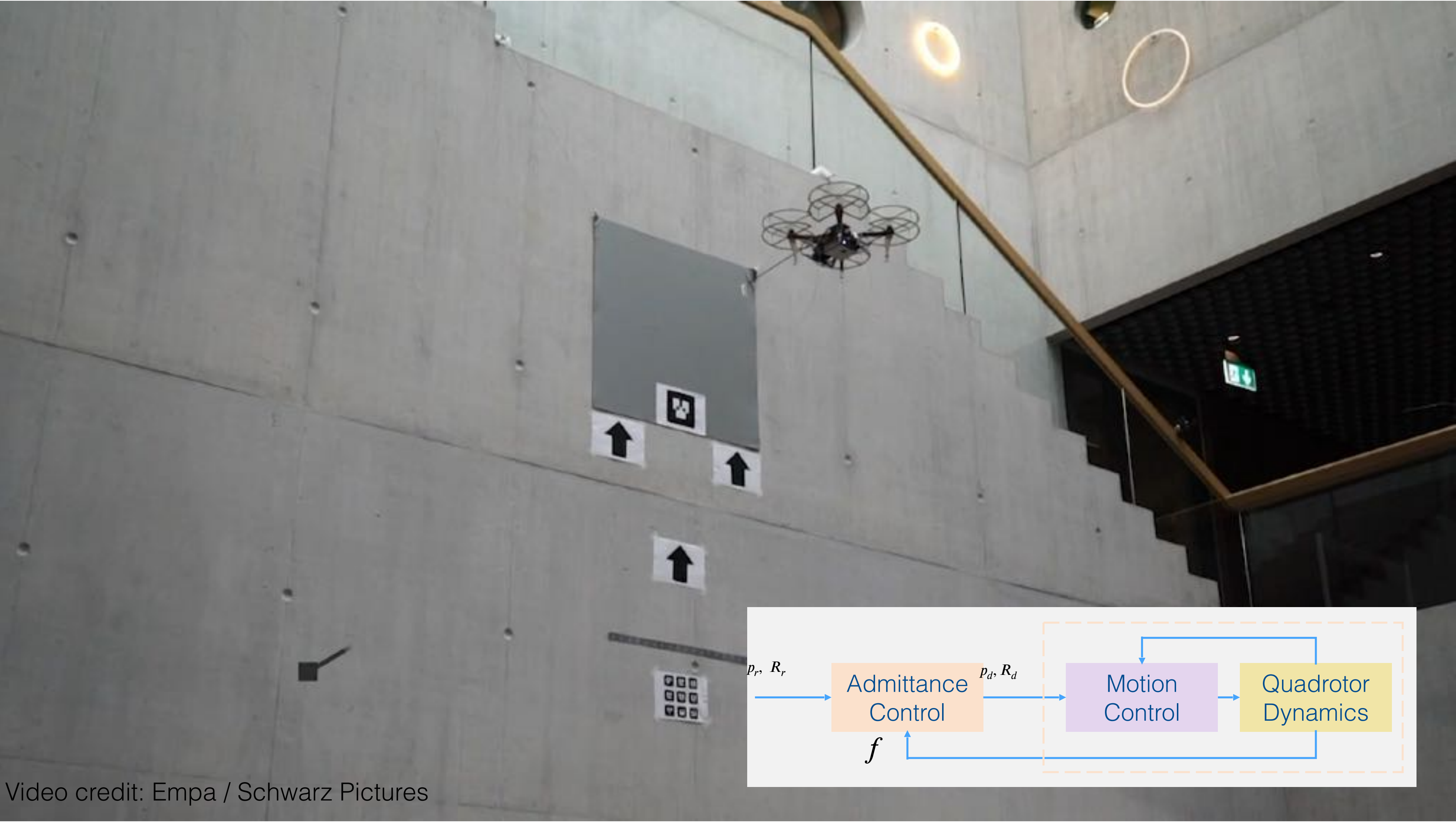
2x speed



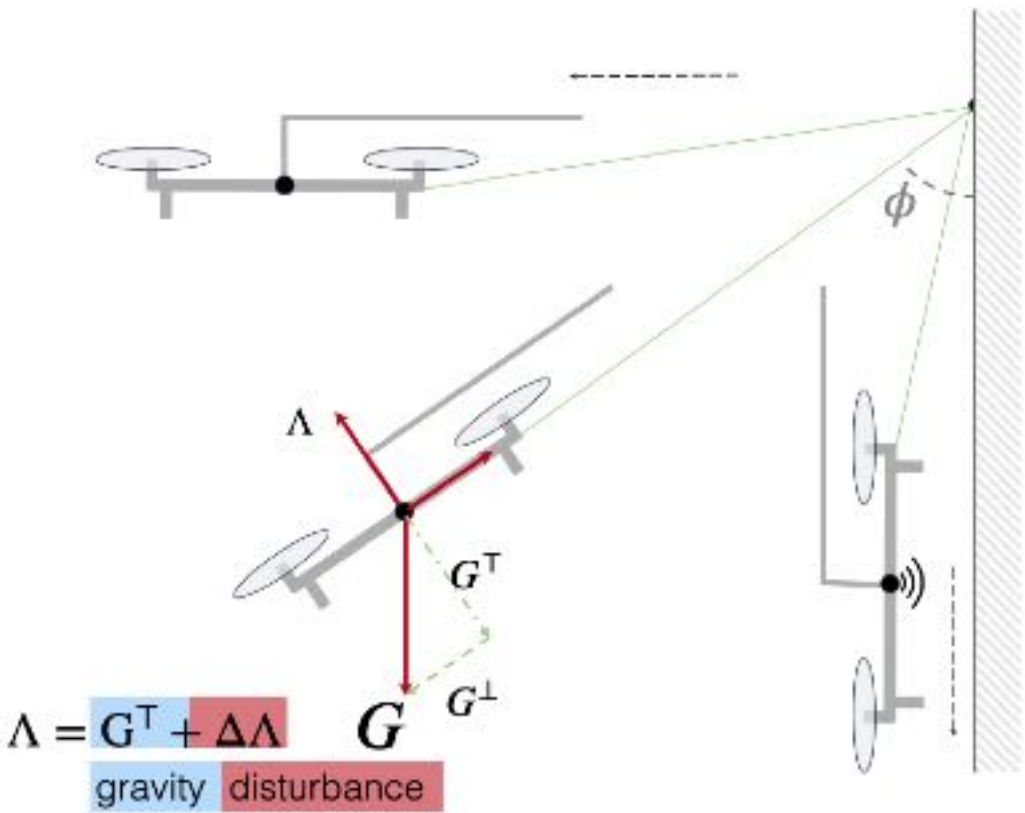
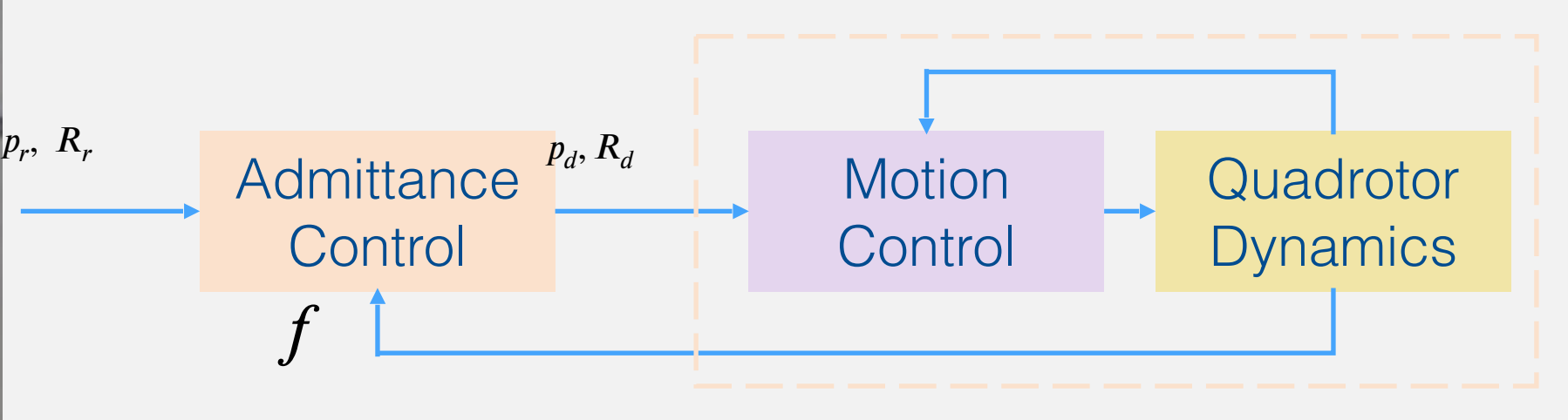
Braithwaite, A., Alhinai, T., Haas-Heger, M., McFarlane, E., Kovac, M., (2018)
Robotics Research: International Symposium ISRR, Springer International Publishing,



Autonomous Tensile Perching



Video credit: Empa / Schwarz Pictures



Tethered hovering thrust

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

BBC Sign in News Sport Reel Worklife Travel Future More

NEWS

Home Video World UK Business Tech Science Stories Entertainment & Arts Health

Scotland Scotland Politics Scotland Business Edinburgh, Fife & East Glasgow & West High

Robotic inspectors developed to fix wind farms

By Ken Macdonald
BBC Scotland Science Correspondent

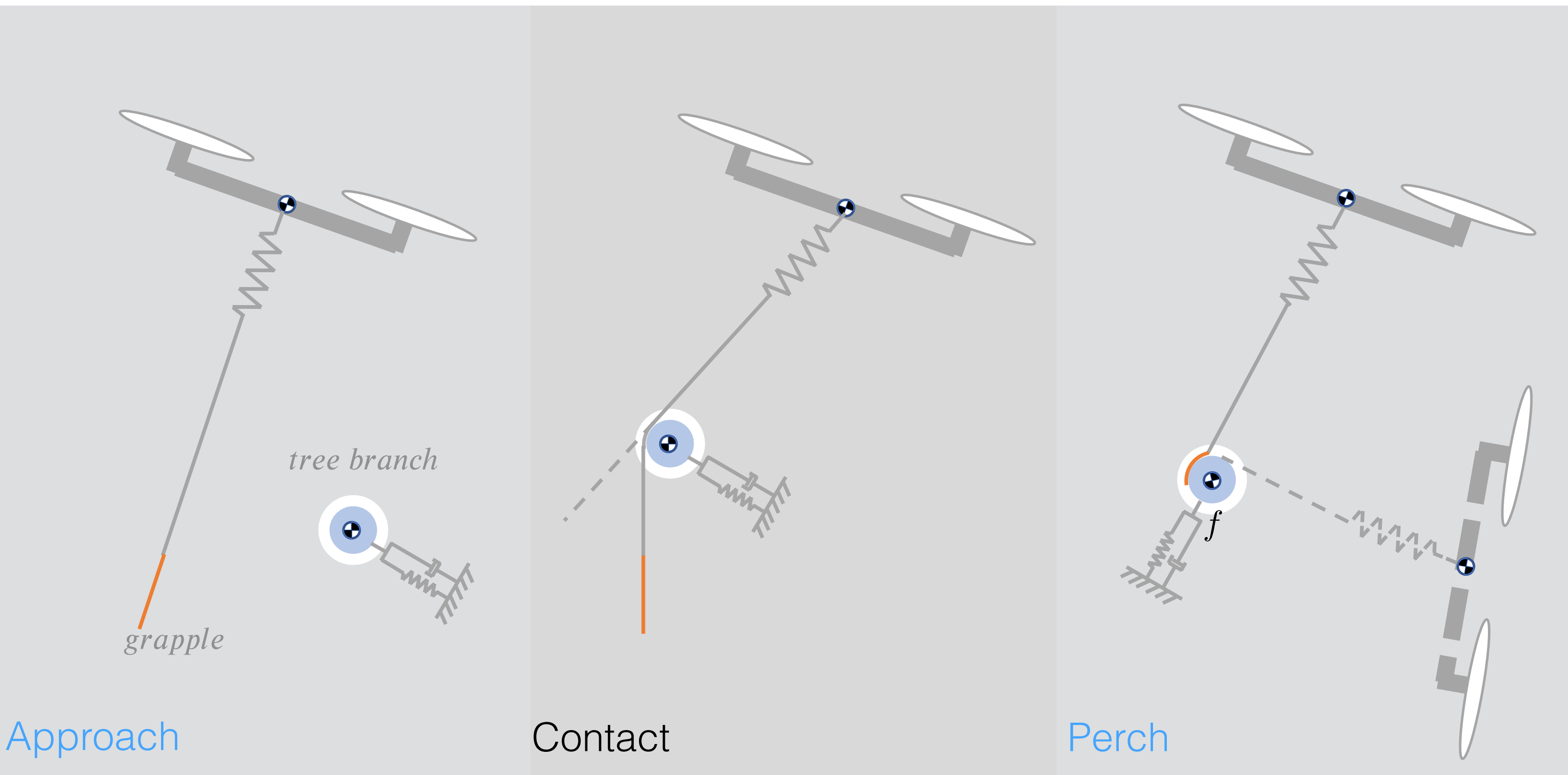
© 14 October 2019

f t Share



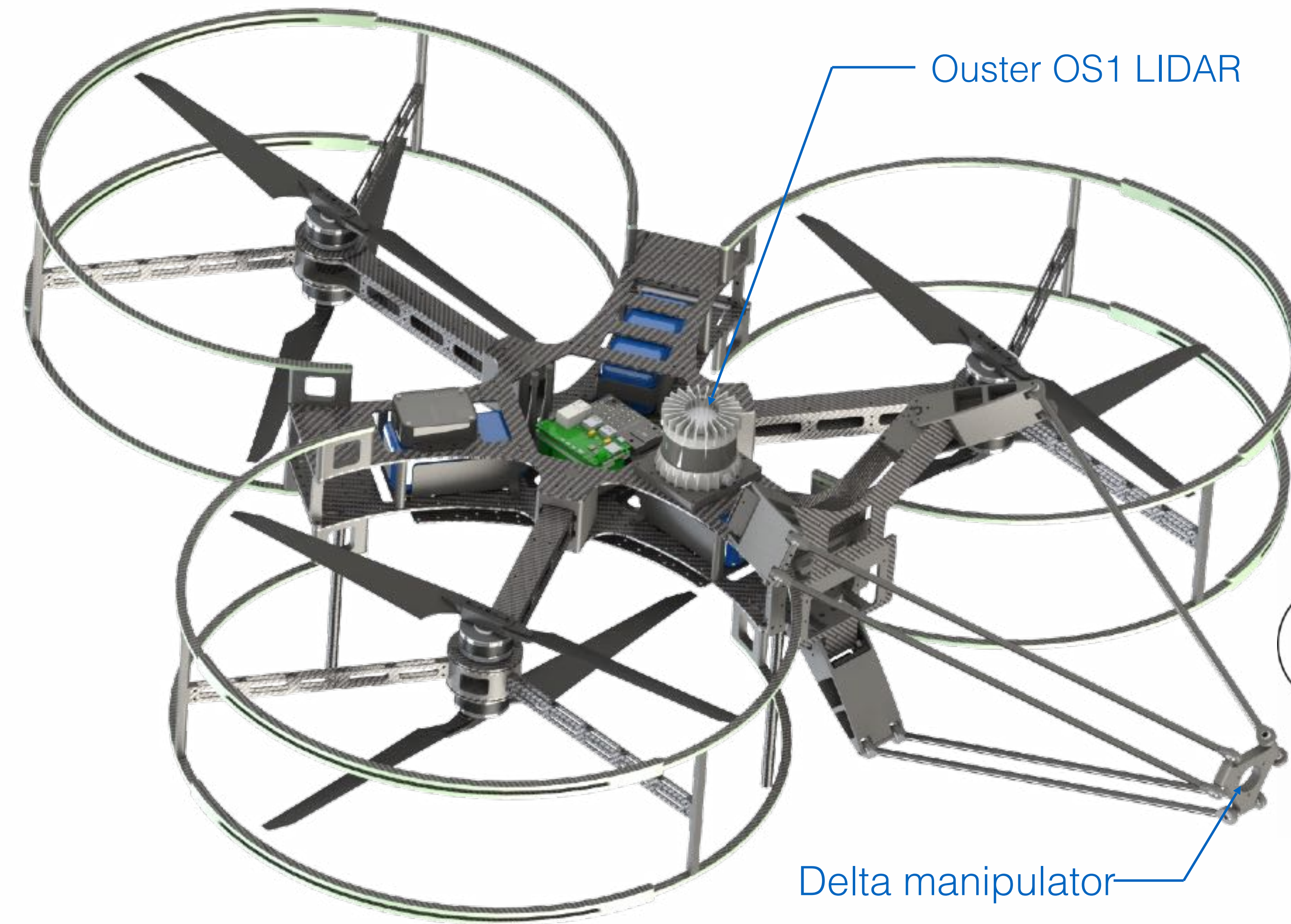
Autonomous Tensile Perching

60

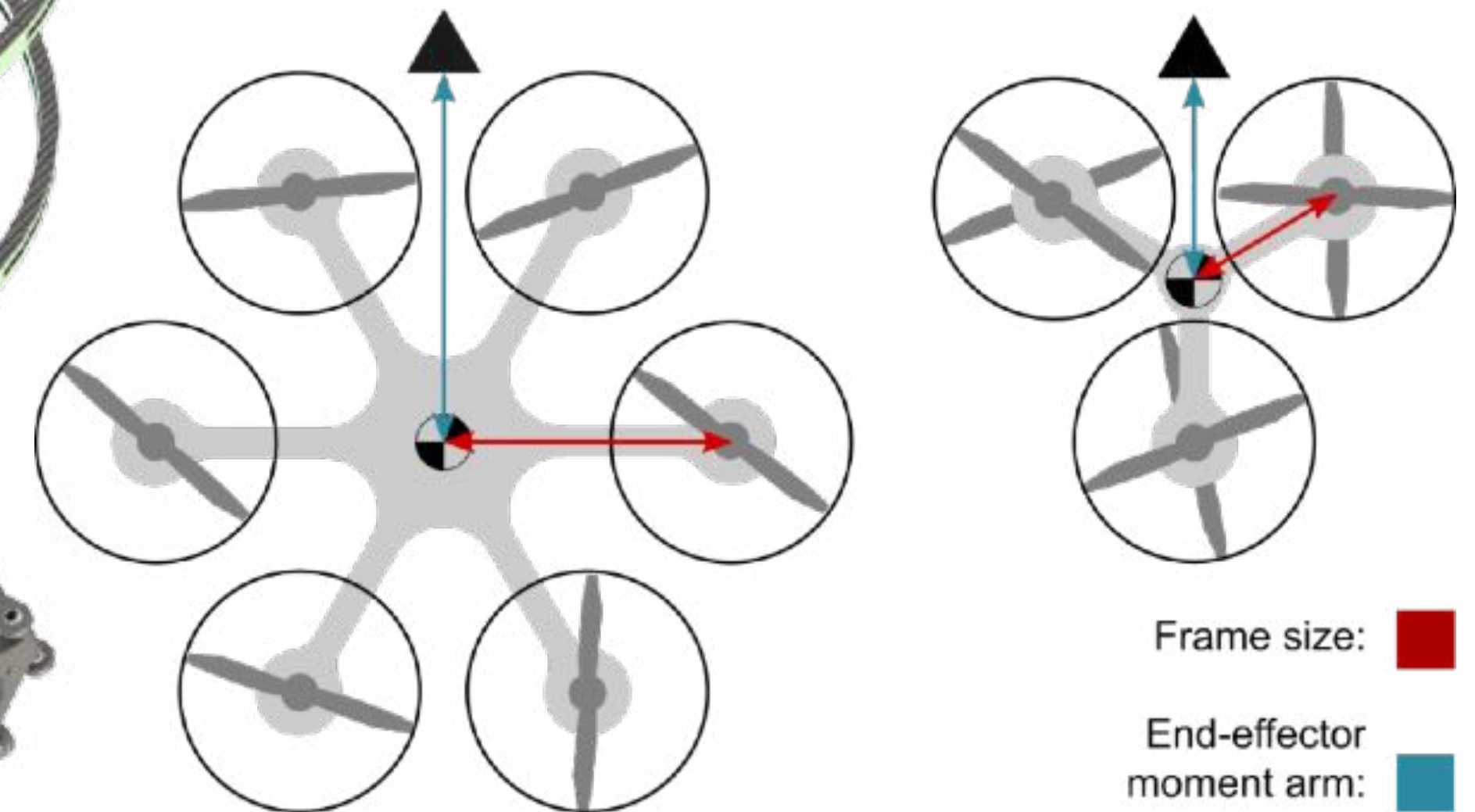


Nguyen, H-N, Siddall, R., Stephens, B., Navarro-Rubio A., Kovac, M., A Passively Adaptive Microspine Grapple for Robust, Controllable Perching *IEEE RoboSoft 2019*

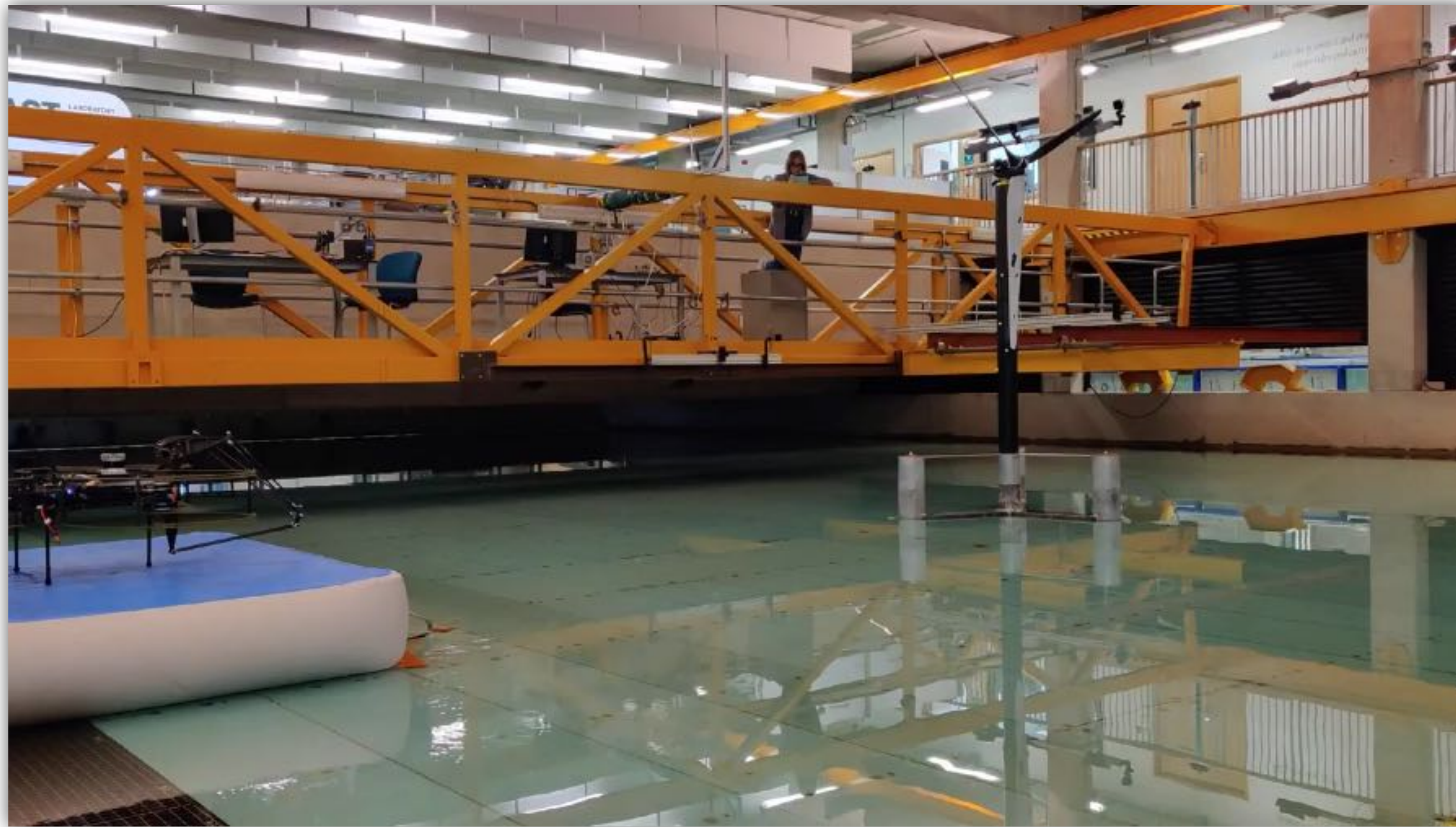
High payload coaxial tri-rotor



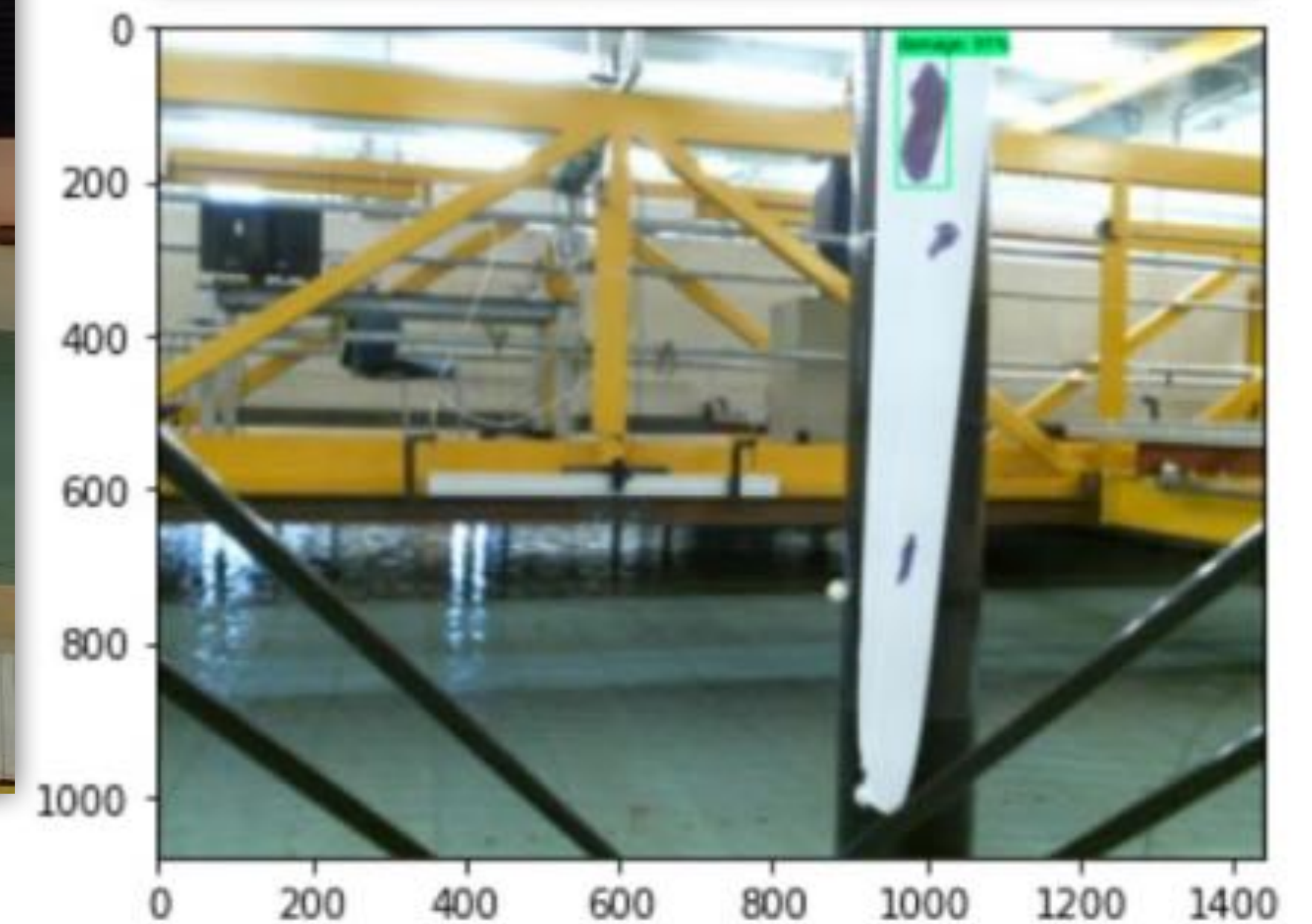
- Max. Take off Mass: 14kg (7kg payload) – 1.3m span
- Frame designed and manufactured in-house at ICL
- Compact coaxial frame layout



Autonomous turbine model inspection



x4 speed



B. Kocer, L. Orr, B. Stephens, Y. Kaya, T. Buzykina, A. Khan and M. Kovac,
UKACC 13th International Conference on Control (2022) (best abstract award)

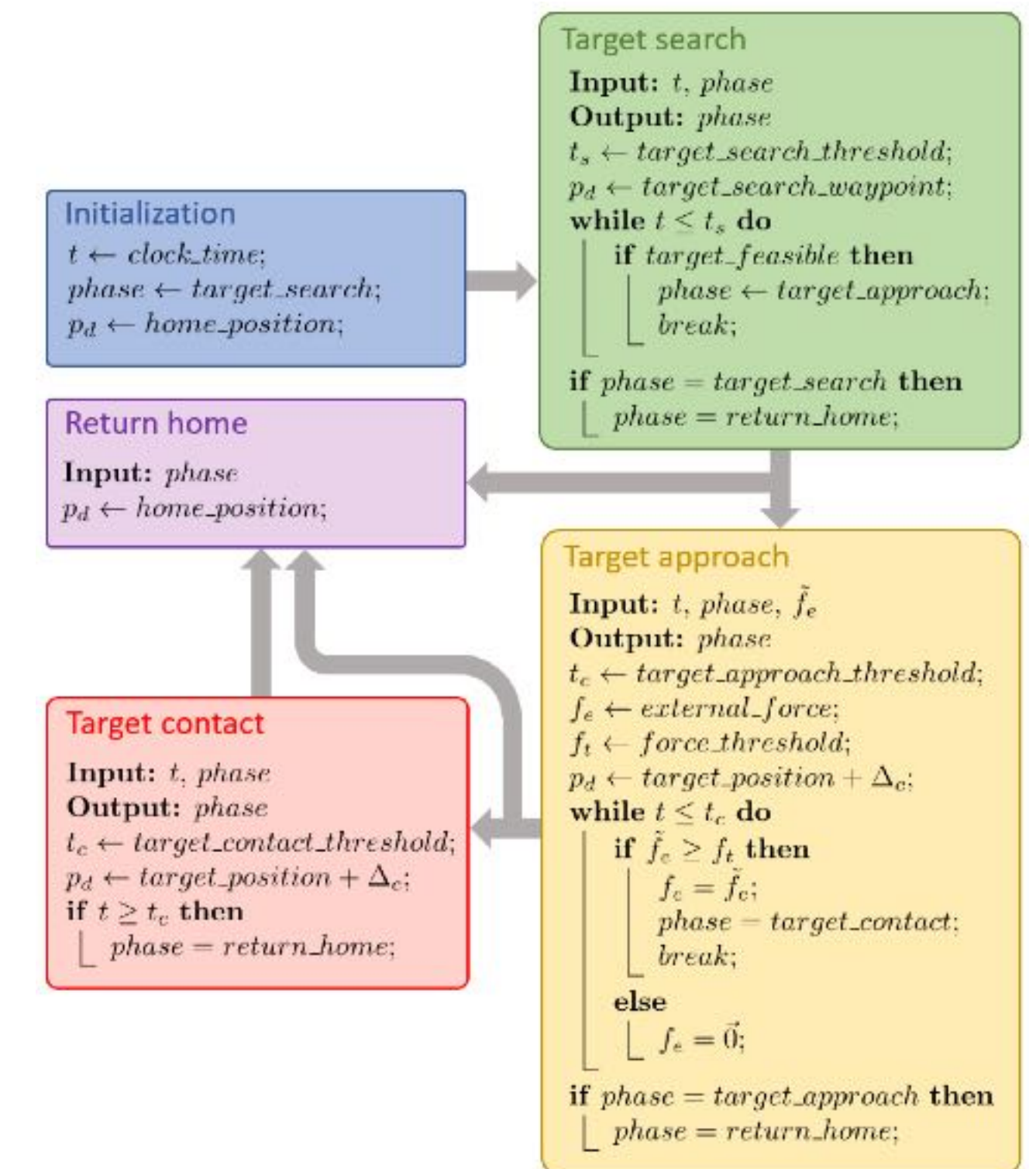
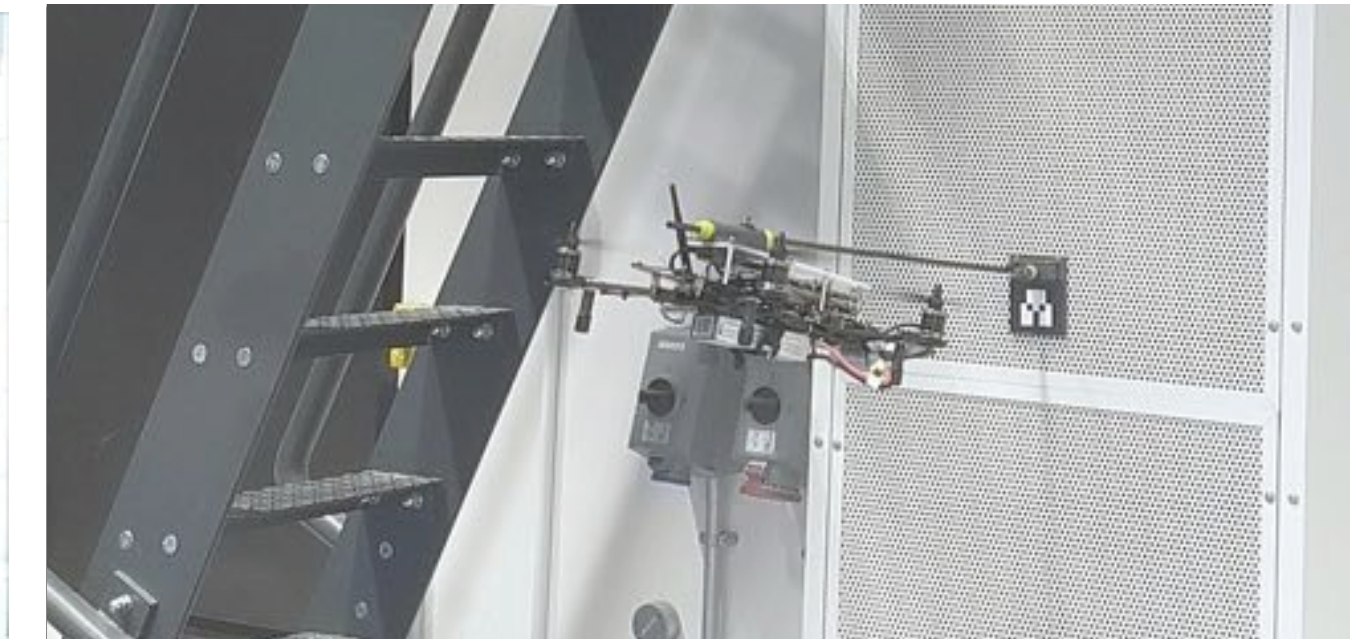


structure



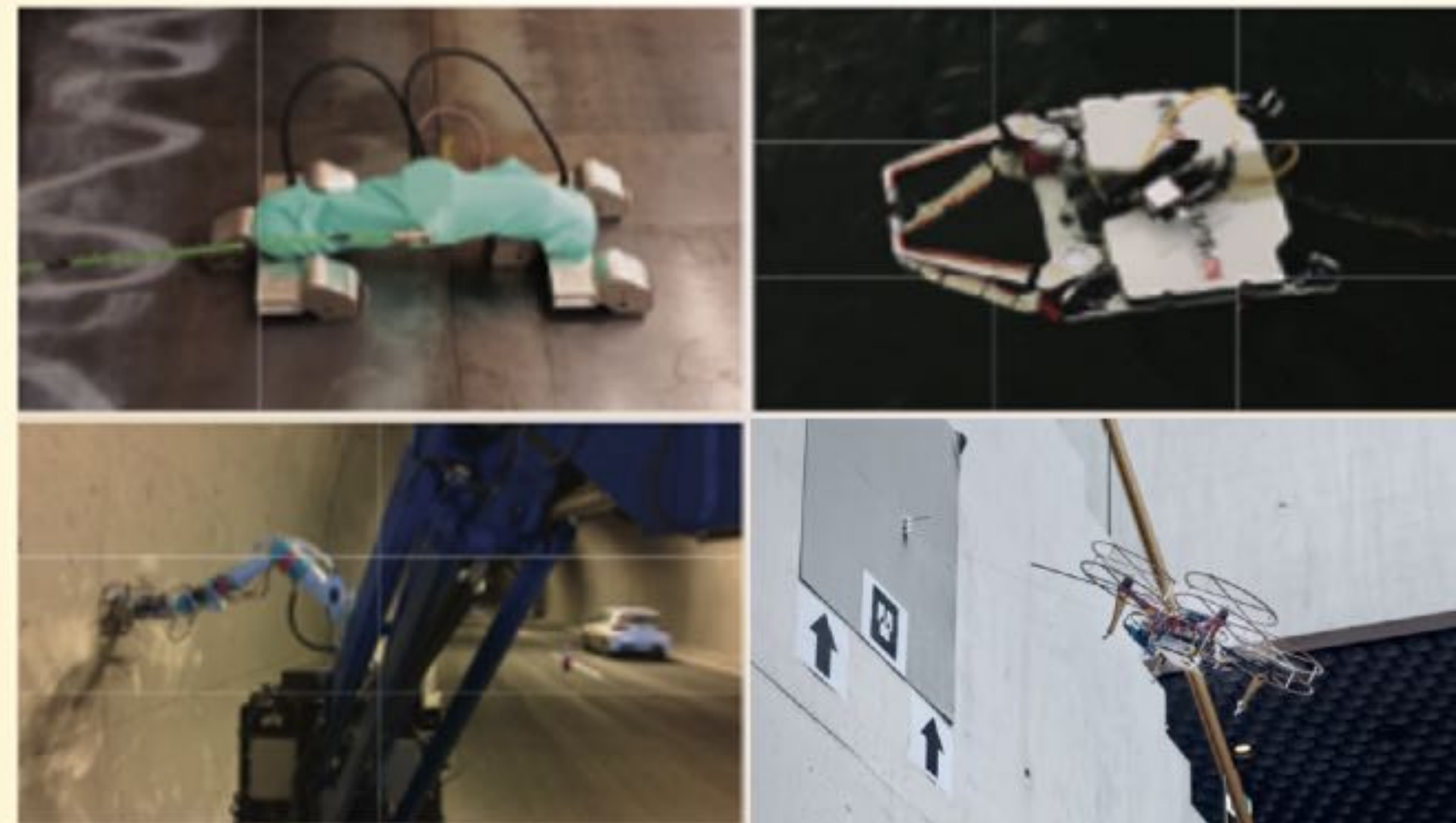
Autonomous sensor placement

64



Infrastructure Robotics

Methodologies, Robotic Systems and Applications



Edited by

Dikai Liu • Carlos Balaguer • Gamini Dissanayake
Mirko Kovac

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

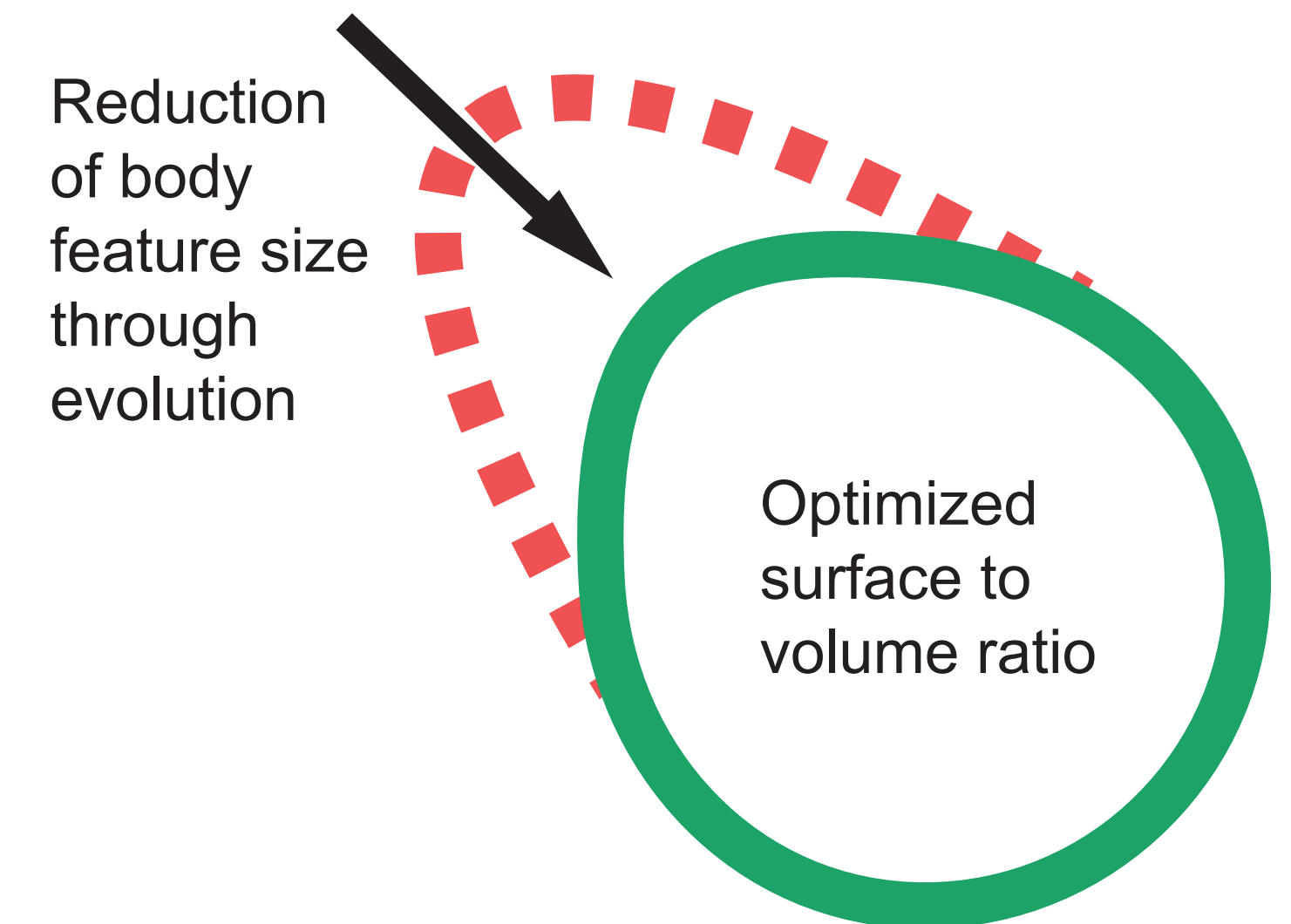
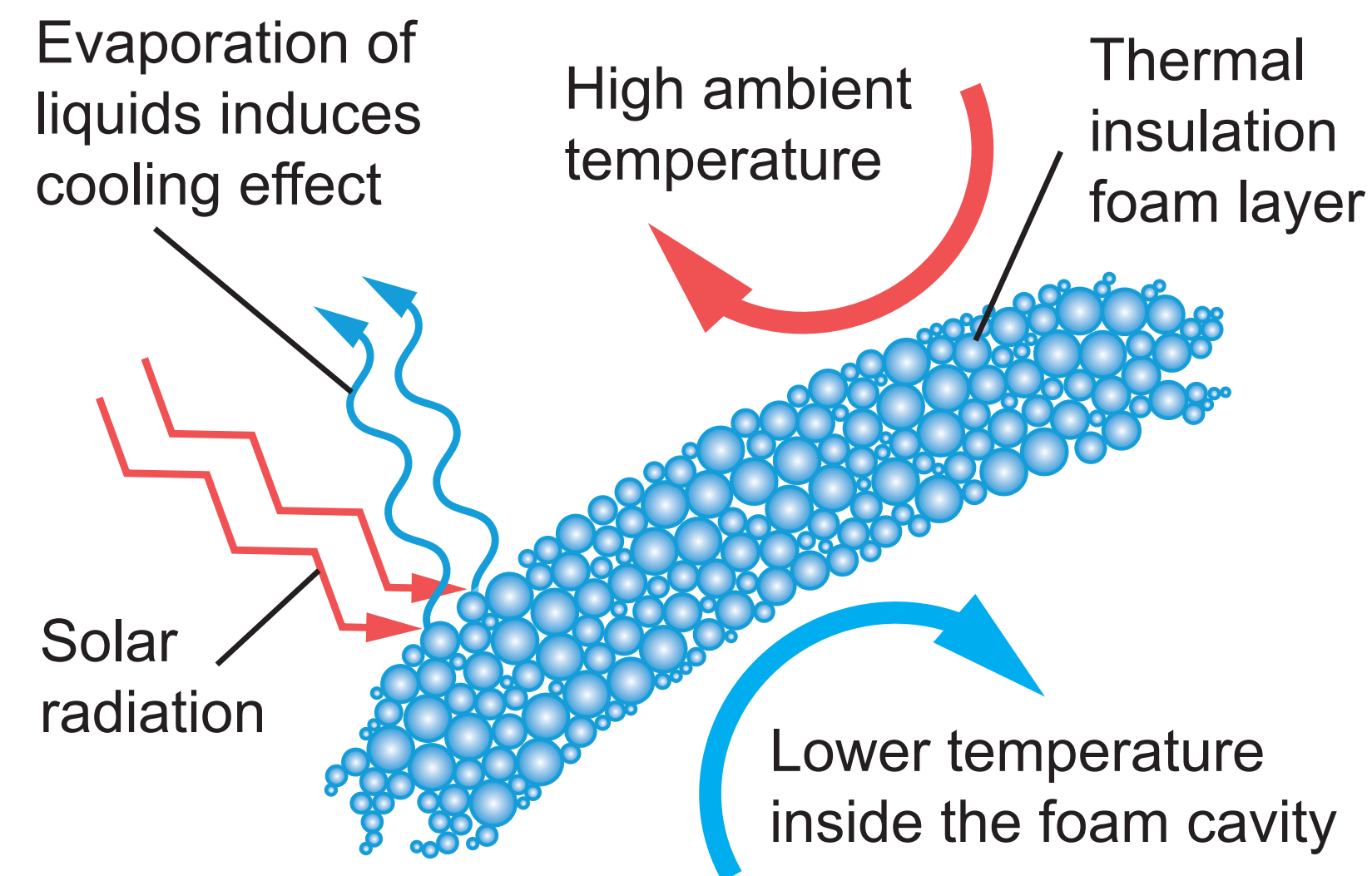
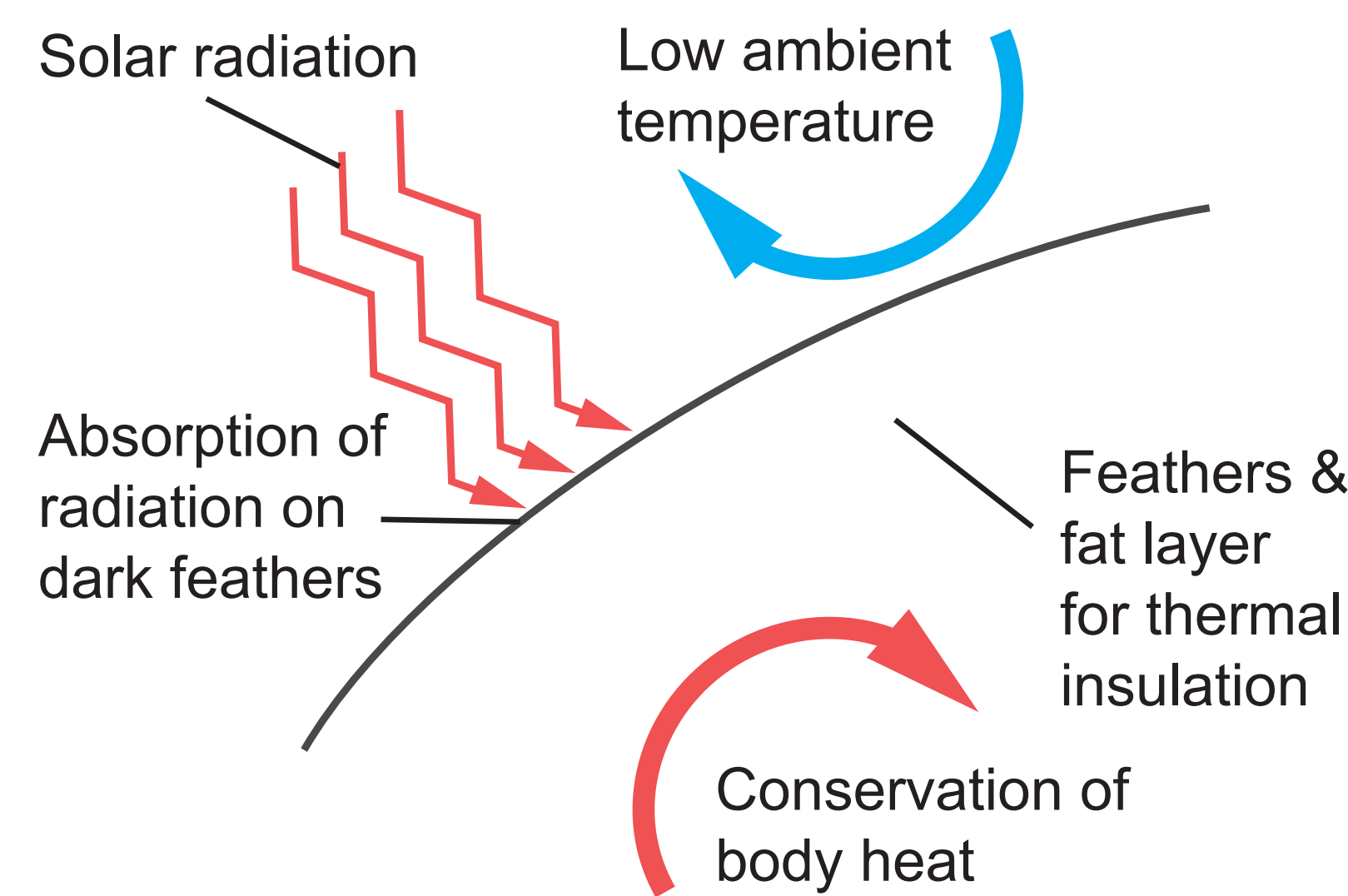


London Greenfell tower fire

67

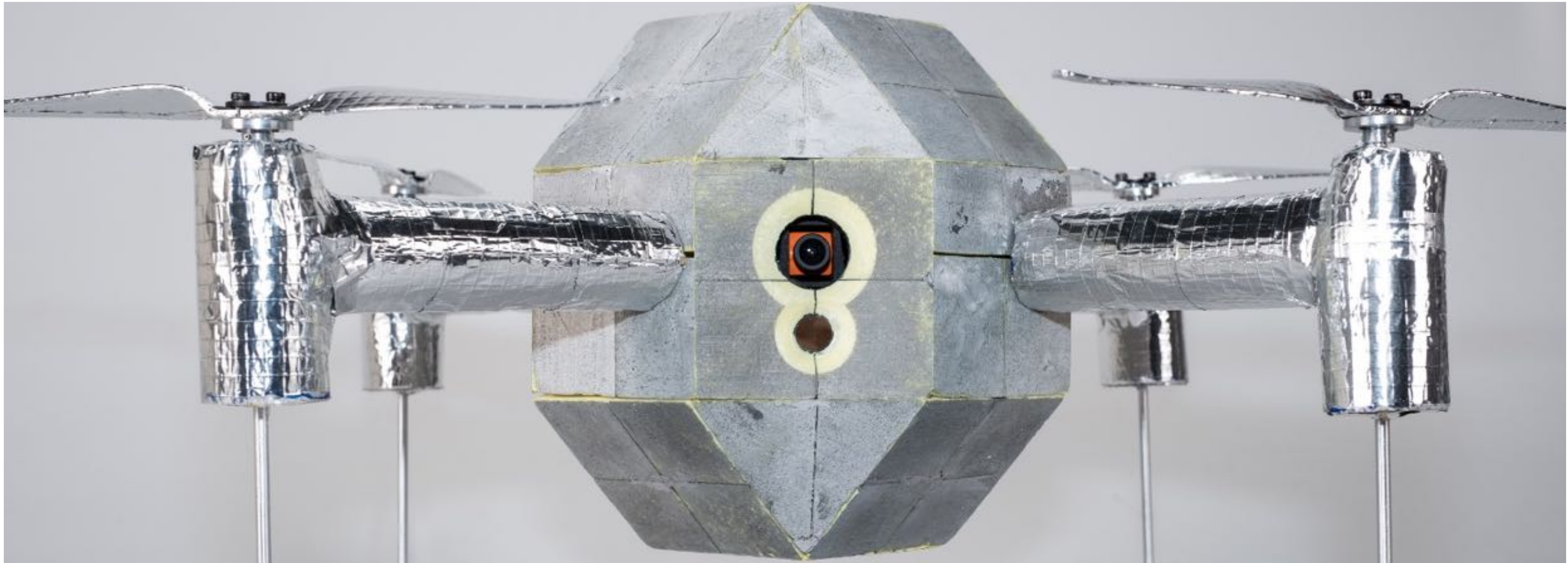


Image credit: Natalie Oxford (Wikipedia)



FireDrone - Temperature agnostic aerogel drone

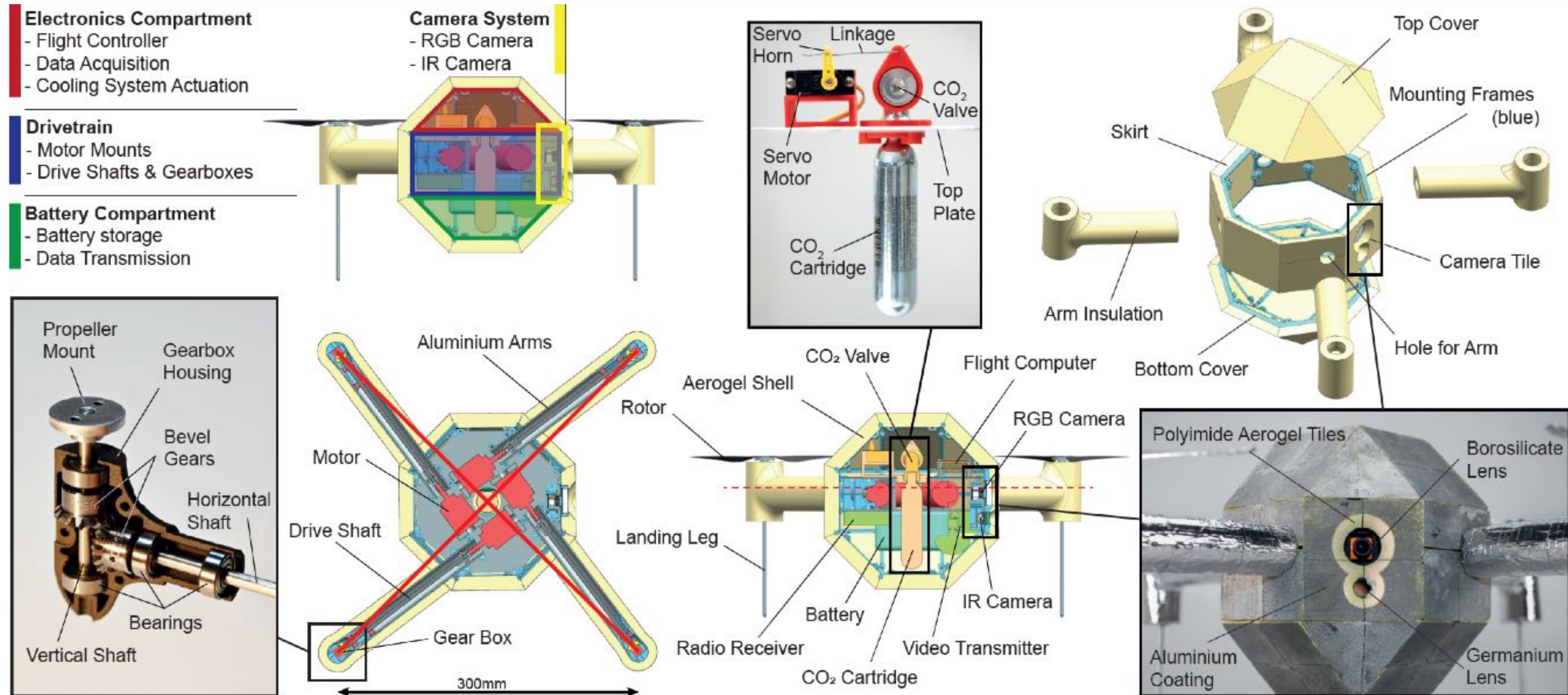
69



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*

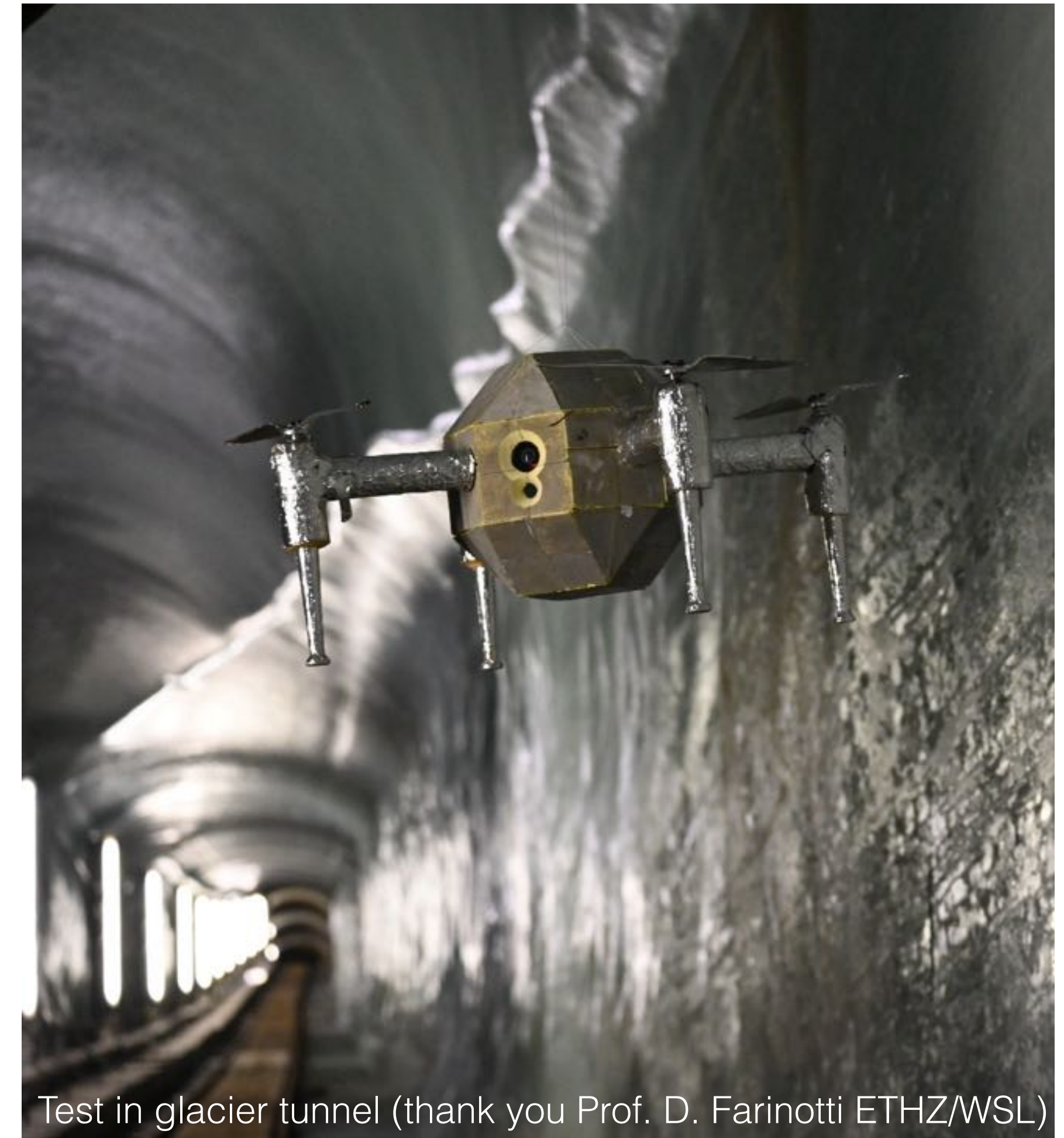
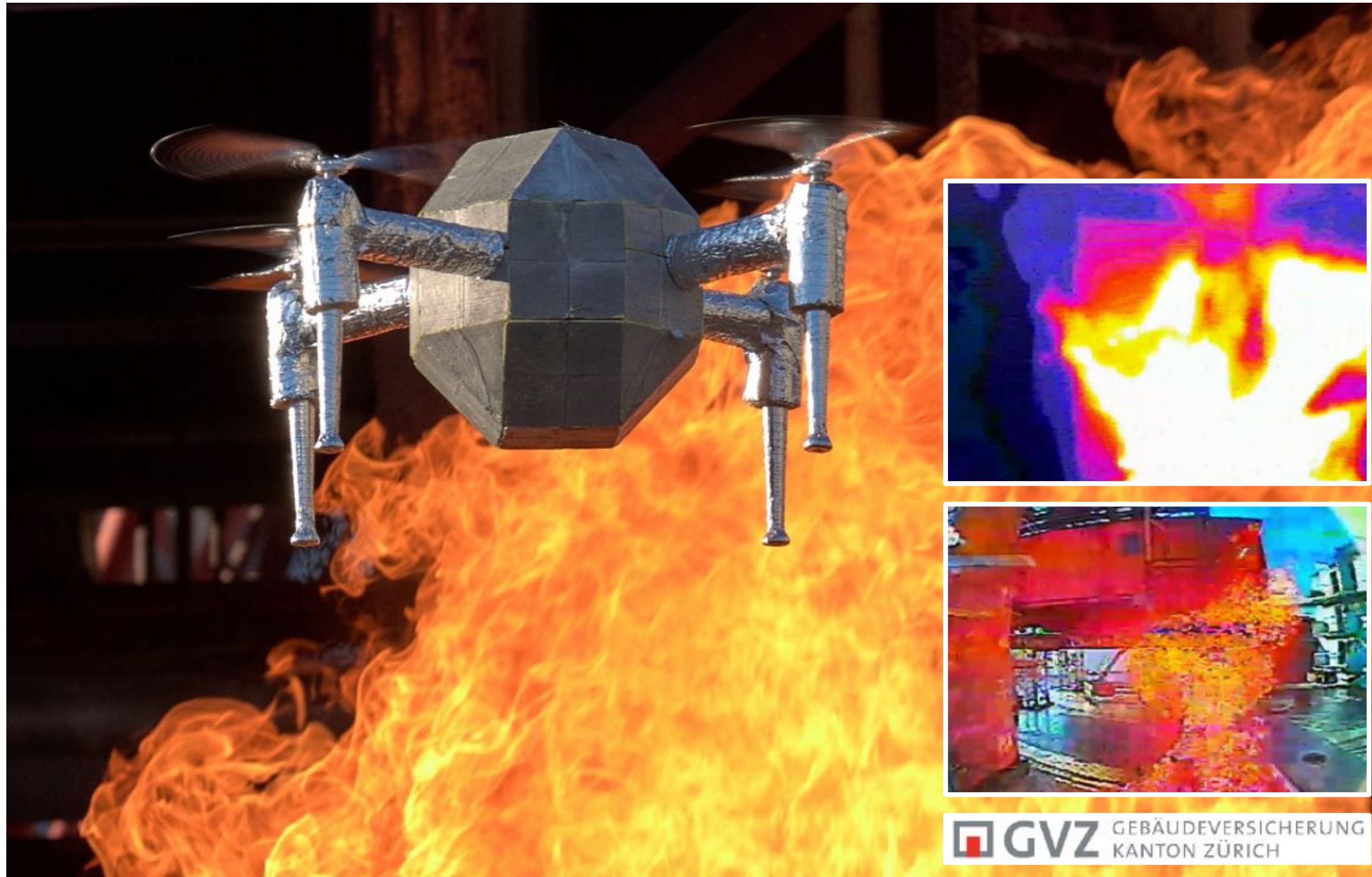
FireDrone - Temperature agnostic aerial robot

70



FireDrone - Temperature agnostic aerial robot

71



Test in glacier tunnel (thank you Prof. D. Farinotti ETHZ/WSL)

[FireDrone - Unmanned aerial vehicle for extreme temperature environments - YouTube](#)

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*

FireDrone

Temperature agnostic aerial robot

72
**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

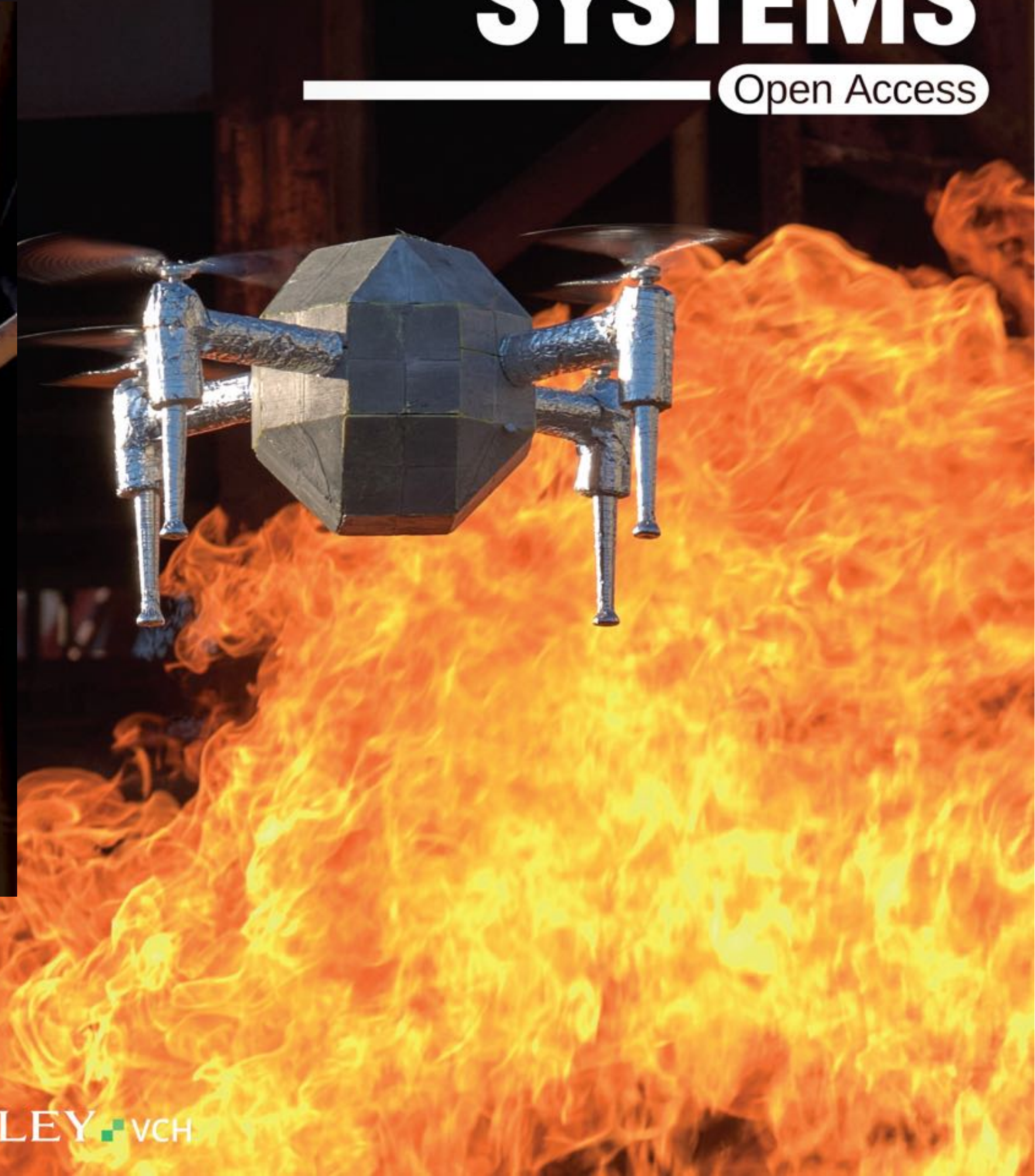


FireDrone

Temperature agnostic aerial robot

73
**ADVANCED
INTELLIGENT
SYSTEMS**

Open Access

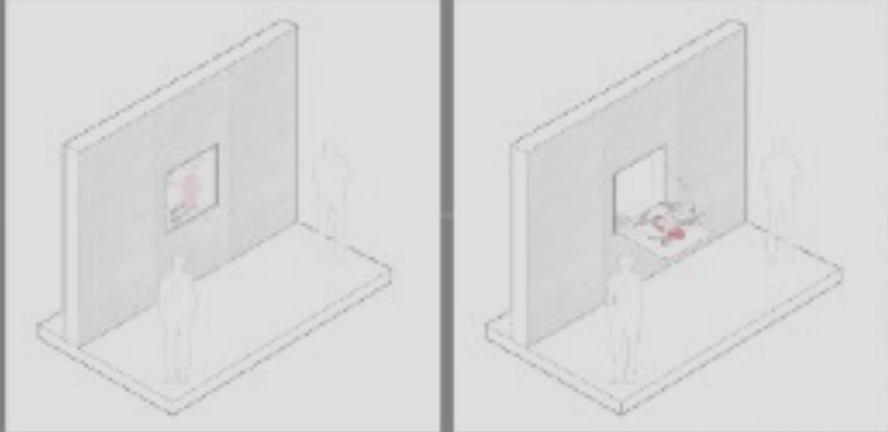


Häusermann, D., Bodry, S., Wiesemüller, F., Miriyev, A., Siegrist, S., Fu, F., Gaan, S., Koebel, M.M., Malfait, W.J., Zhao, S., Kovac, M., (2023) *Advanced Intelligent Systems* (cover)

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





Illustration: Yusuf Kaya Furkan

Aerial-AM

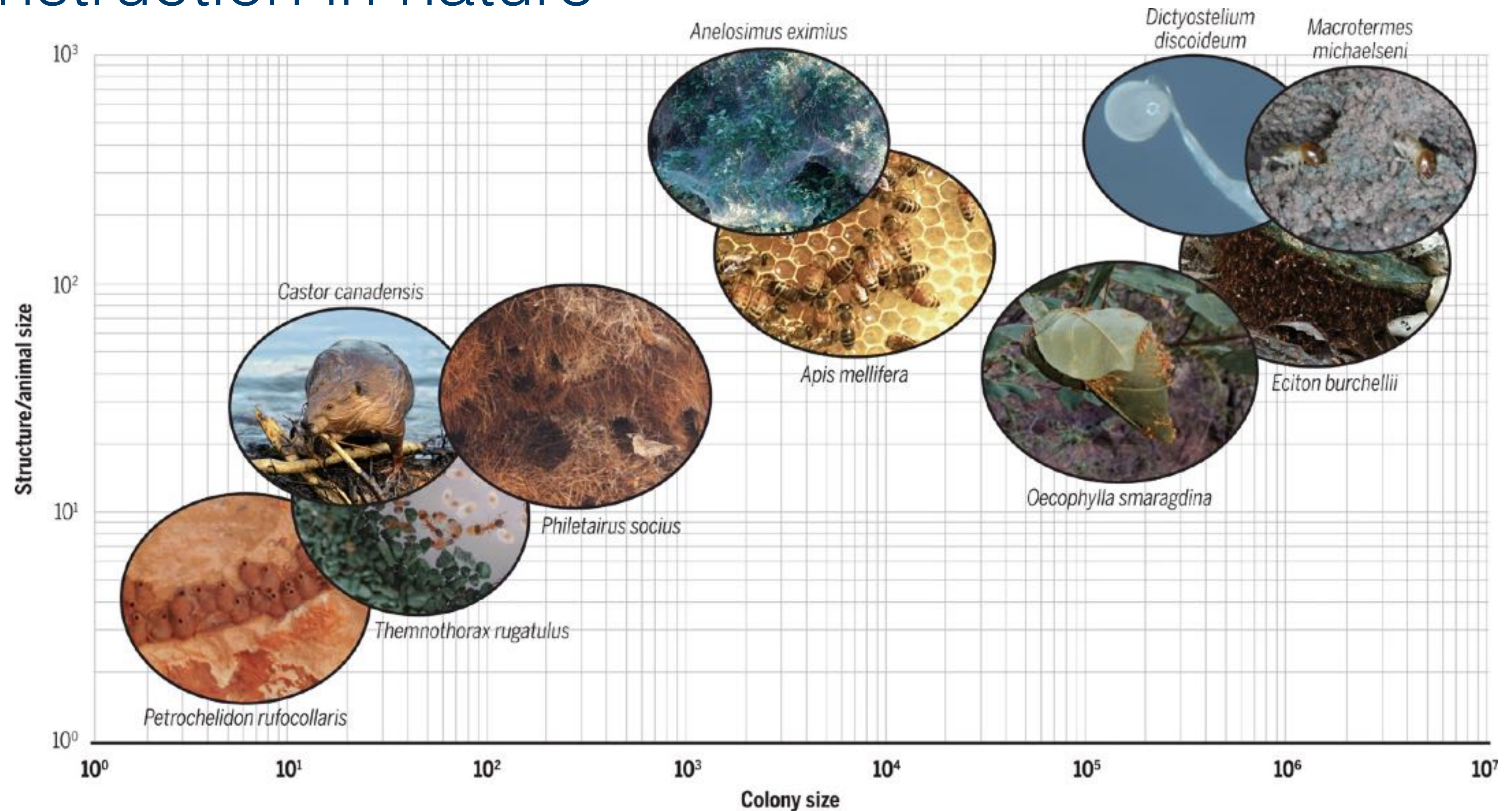
AERIAL ADDITIVE MANUFACTURING

3D Printing with Autonomous Aerial Robots

Imperial College London | University College London | University of Bath

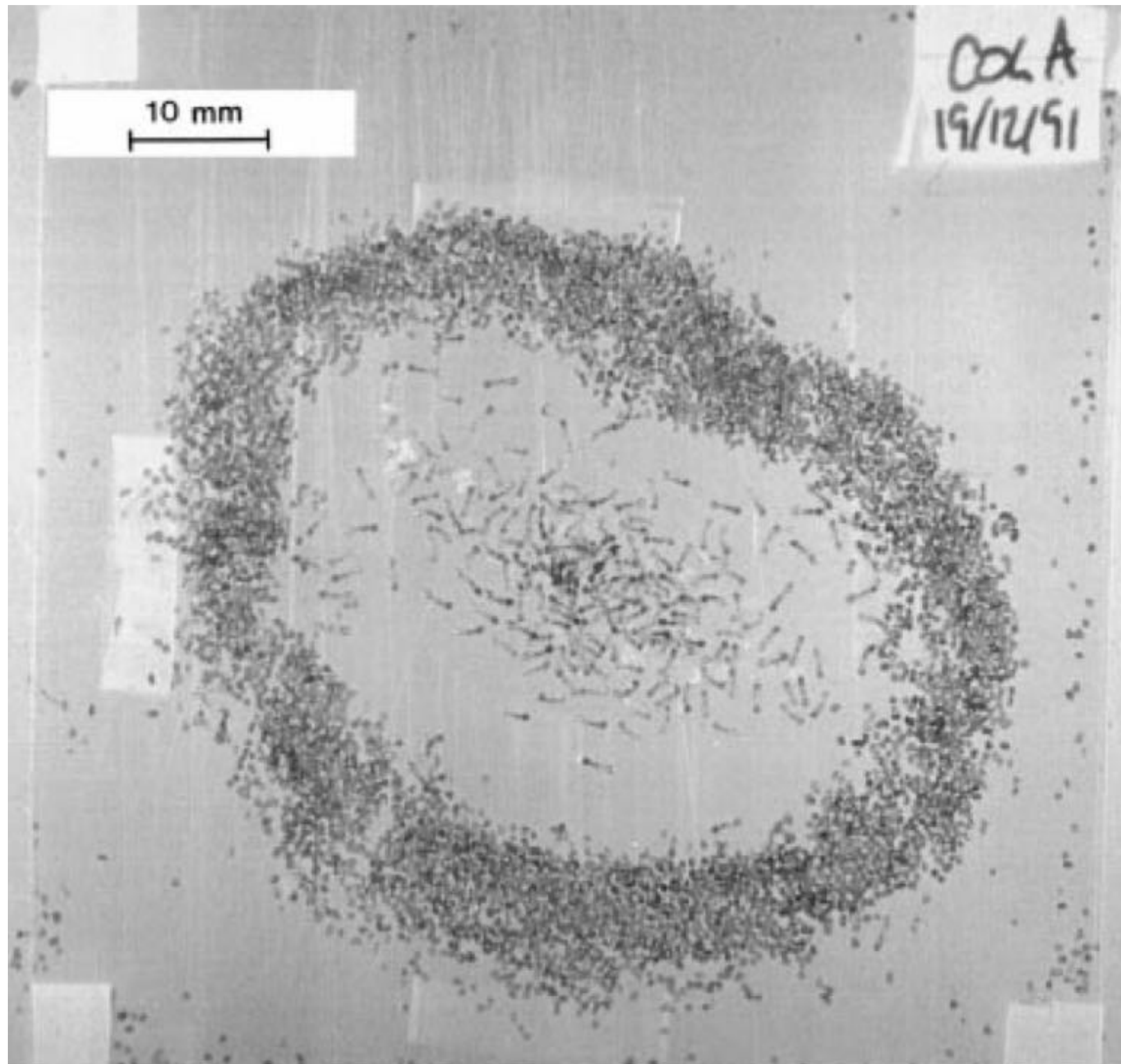


Construction in nature



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

Bulldozer ants - use of templates



Building process (external workers / internal workers)

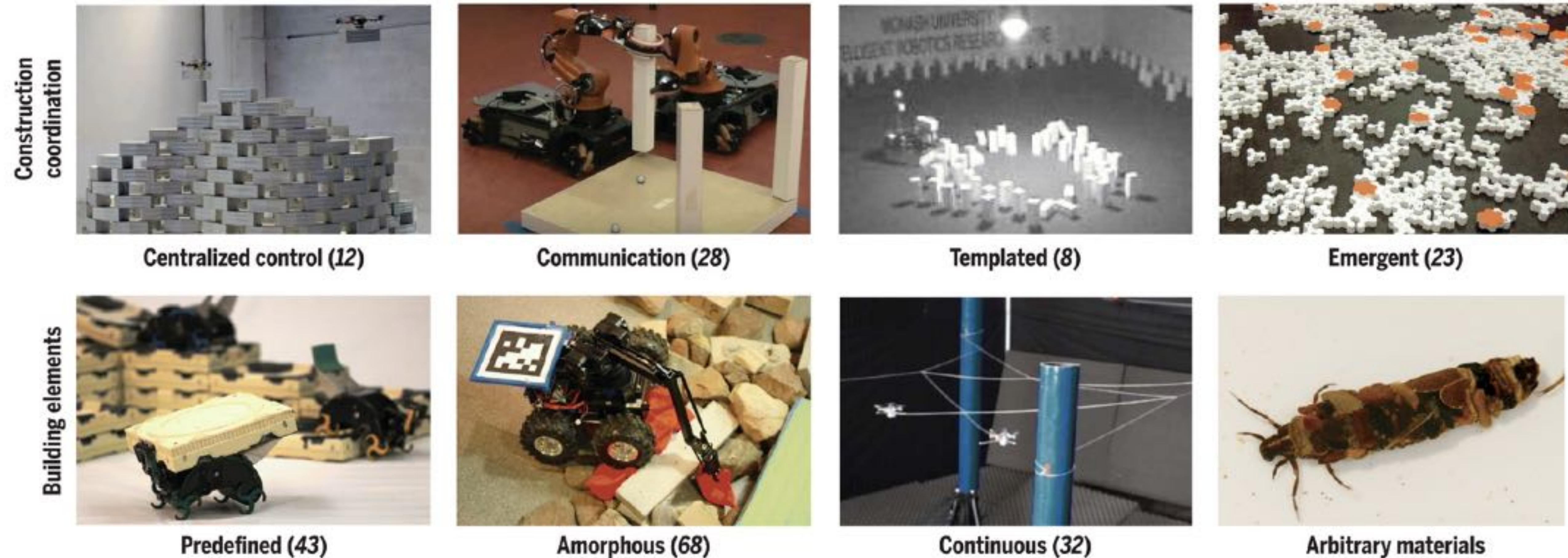
1. External workers collect material and return to nest
2. Enter nest and drop material close to cluster of nest mates (carrying time is constant at 21sec after entry)
3. Drop material after direct contact with a cluster of internal workers or stones previously deposited. Release stone only after feeling 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?

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

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

Bio-inspired construction principles

80



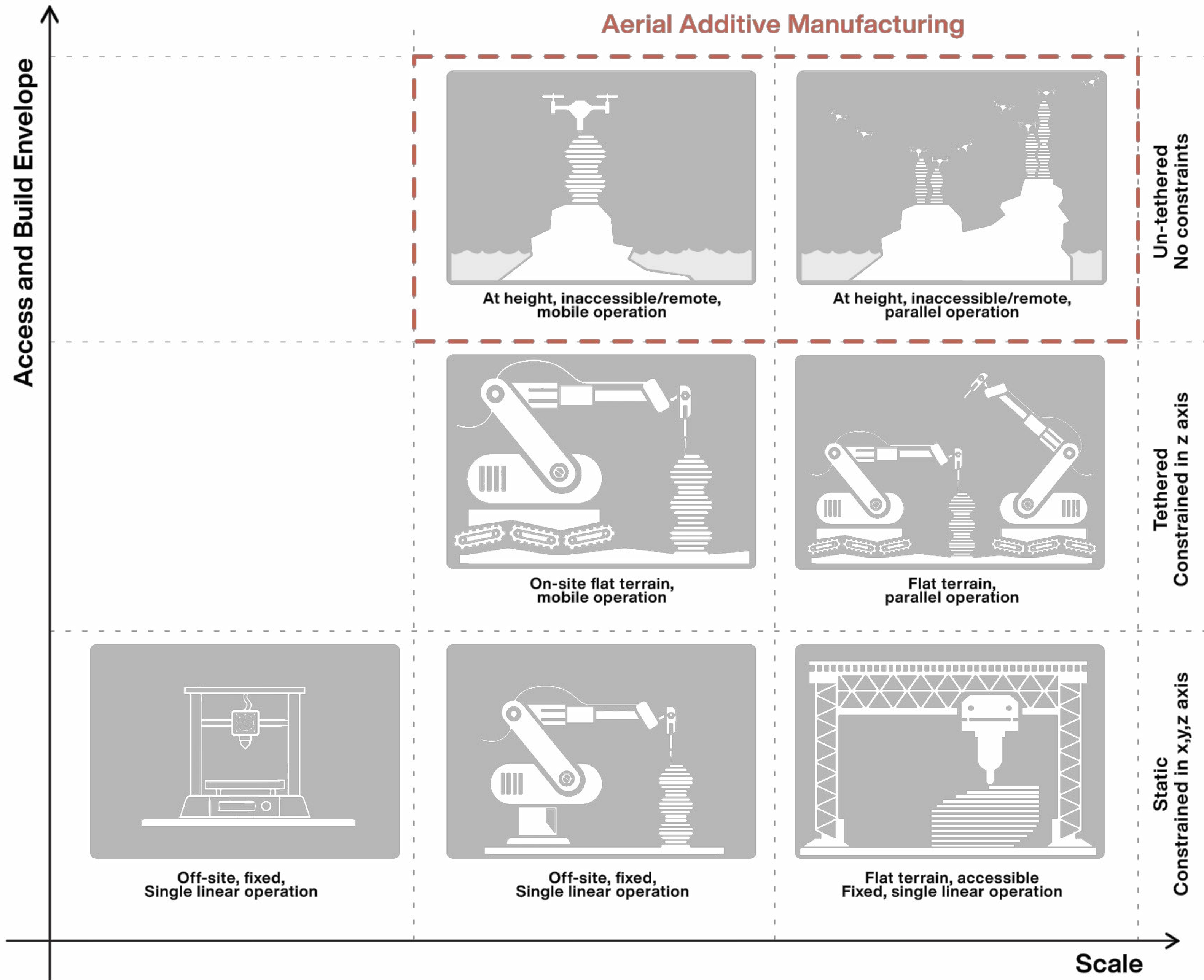
K. H. Petersen, N. Napp, R. Stuart-Smith, D. Rus, M. Kovac,
Science Robotics (2019)

Aerial-AM

AERIAL ADDITIVE MANUFACTURING

3D Printing with Autonomous Aerial Robots

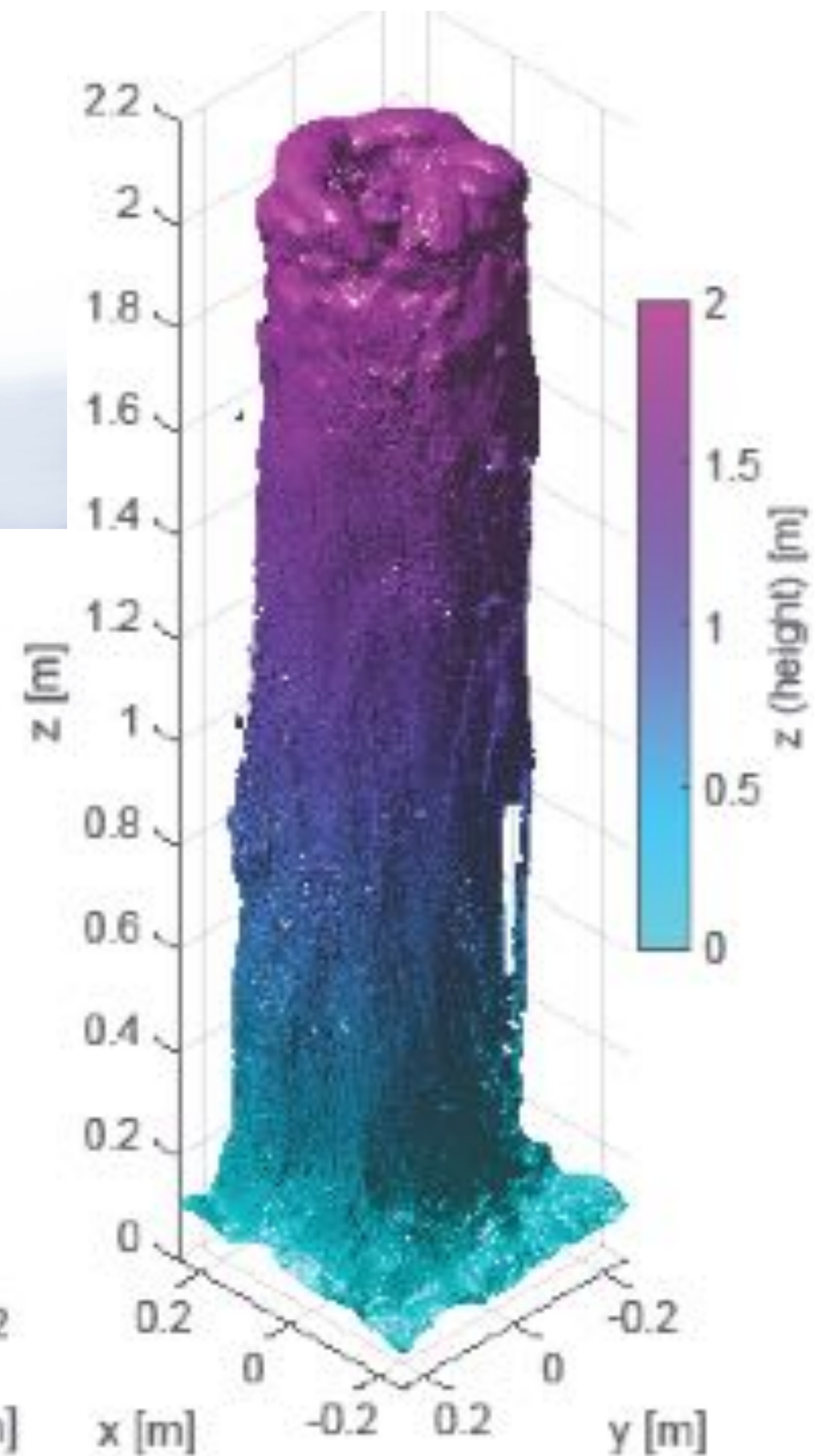
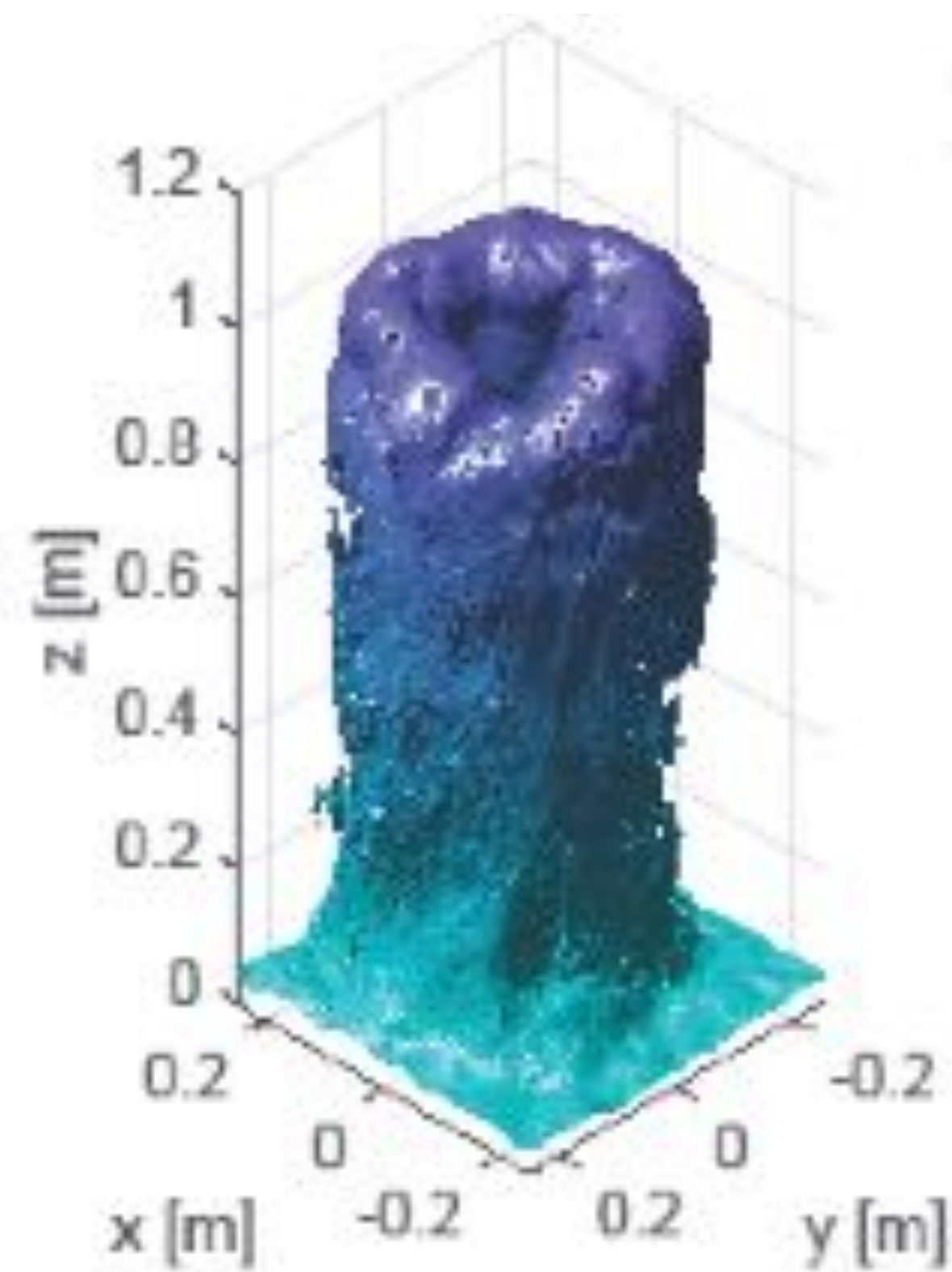
Imperial College London | University College London | University of Bath





Scan-drone

Build-drone



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

Aerial Additive Manufacturing

The international journal of science / 22 September 2022

86

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., Choi, C., Darekar, D.D., Li, W., Hirschmann, S., Soana, V., Ngah, S.A., 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)

Aerial Additive Manufacturing

The international journal of science / 22 September 2022

87

nature



BUILDER DRONES

3D construction using
bee-inspired aerial robots

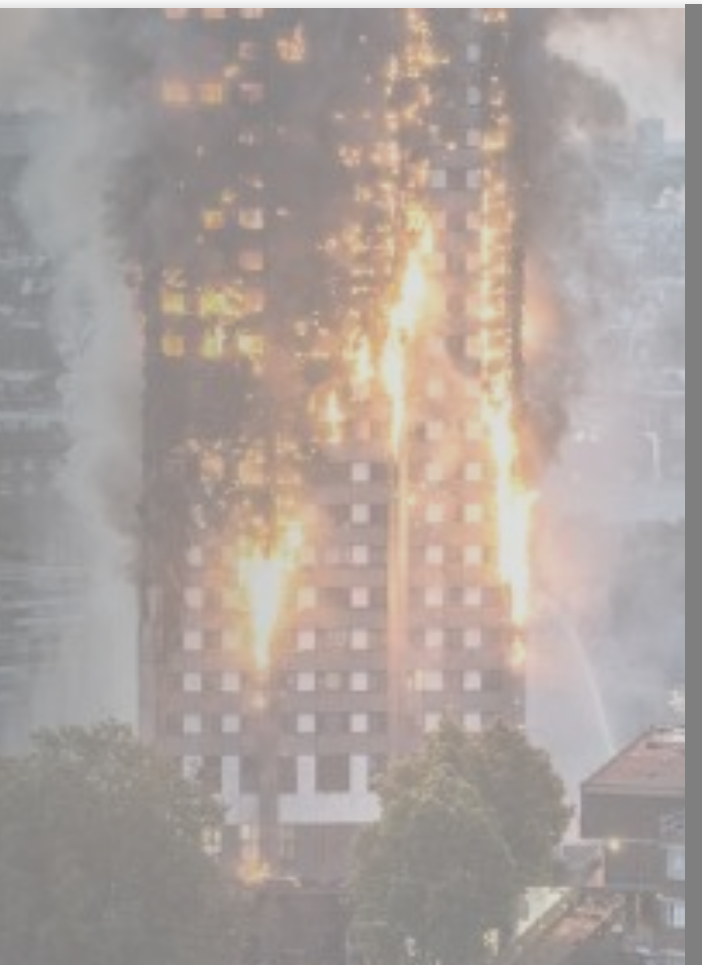
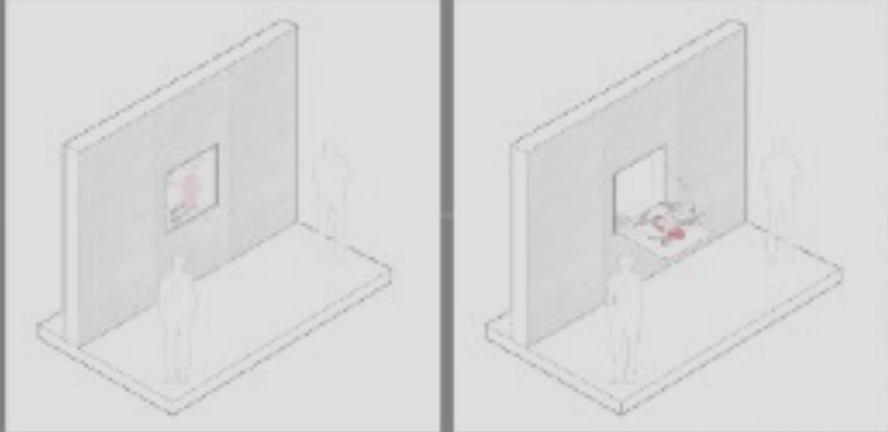
Zhang, K., Chermprayong, P., Xiao, F., Tzoumanikas, D., Dams, B., Kay, S., Kocer, B.B., Burns, A., Orr, L., Choi, C., Darekar, D.D., Li, W., Hirschmann, S., Soana, V., Ngah, S.A., Sareh, S., Margheri, L., Pawar, V., Ball, R.J., Williams, C., Shepherd, P., Leutenegger, S., Stuart-Smith, R., Kovac, M., (2022)

Aerial Additive Manufacturing: 3D Printing with Multiple Autonomous Aerial Robots
Nature 2022 (cover)

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



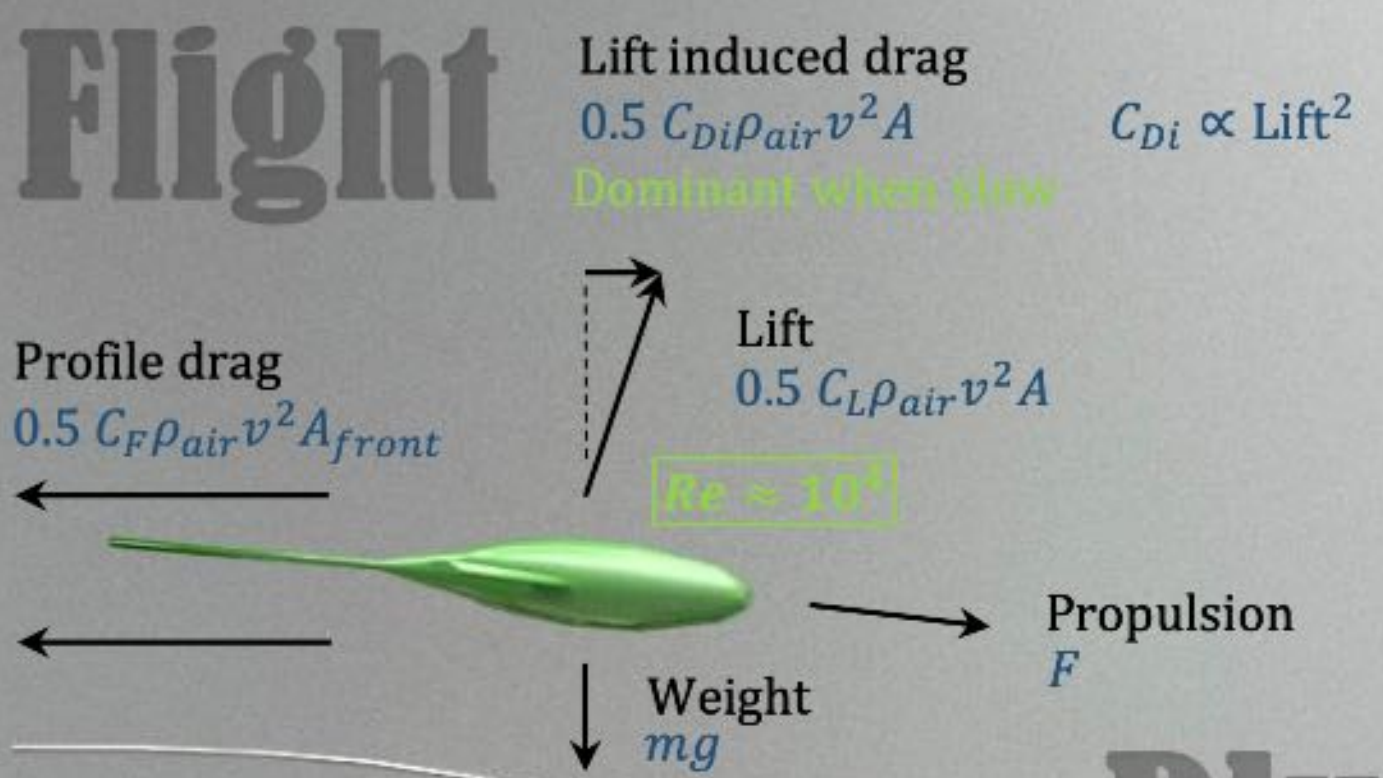


Aerial-aquatic robots to protect aquatic ecosystems



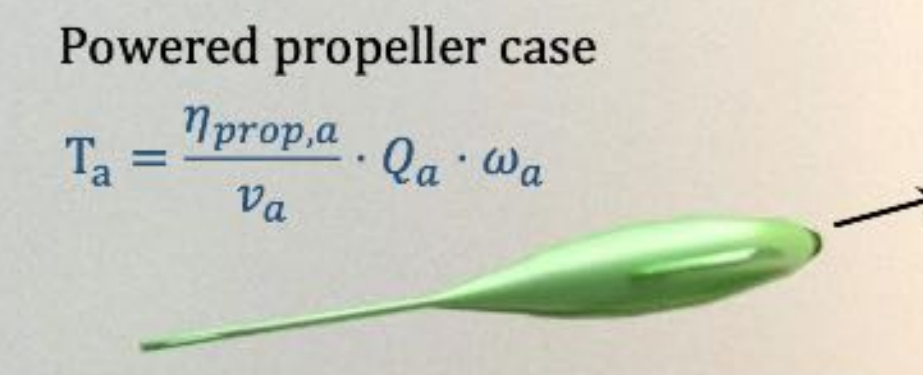
Use cases:
Water health monitoring (Arctic, coral reefs, lakes etc.)
Catchment area modelling (flooding, sewage spills etc)
Environmental DNA and biodiversity monitoring

Flight



- 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

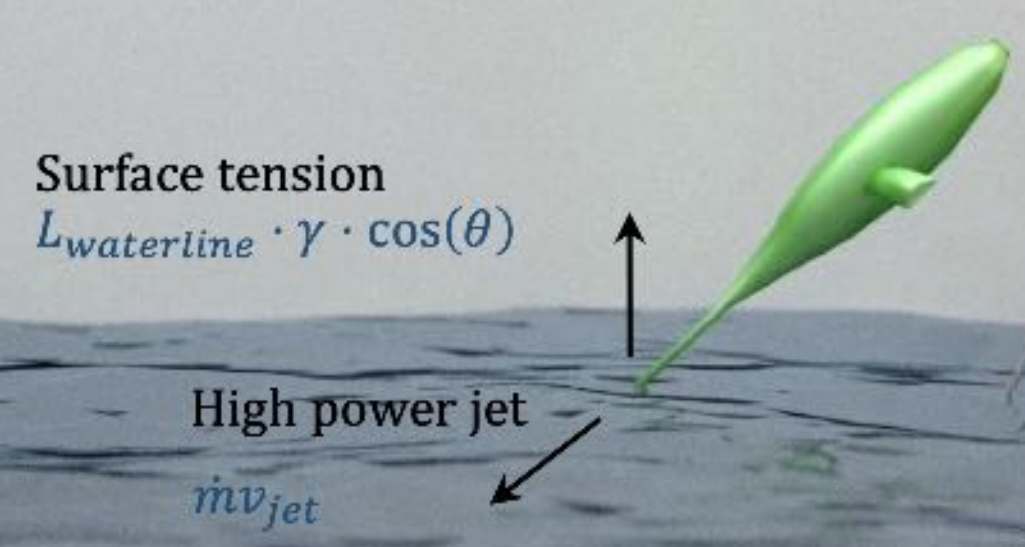
Flight



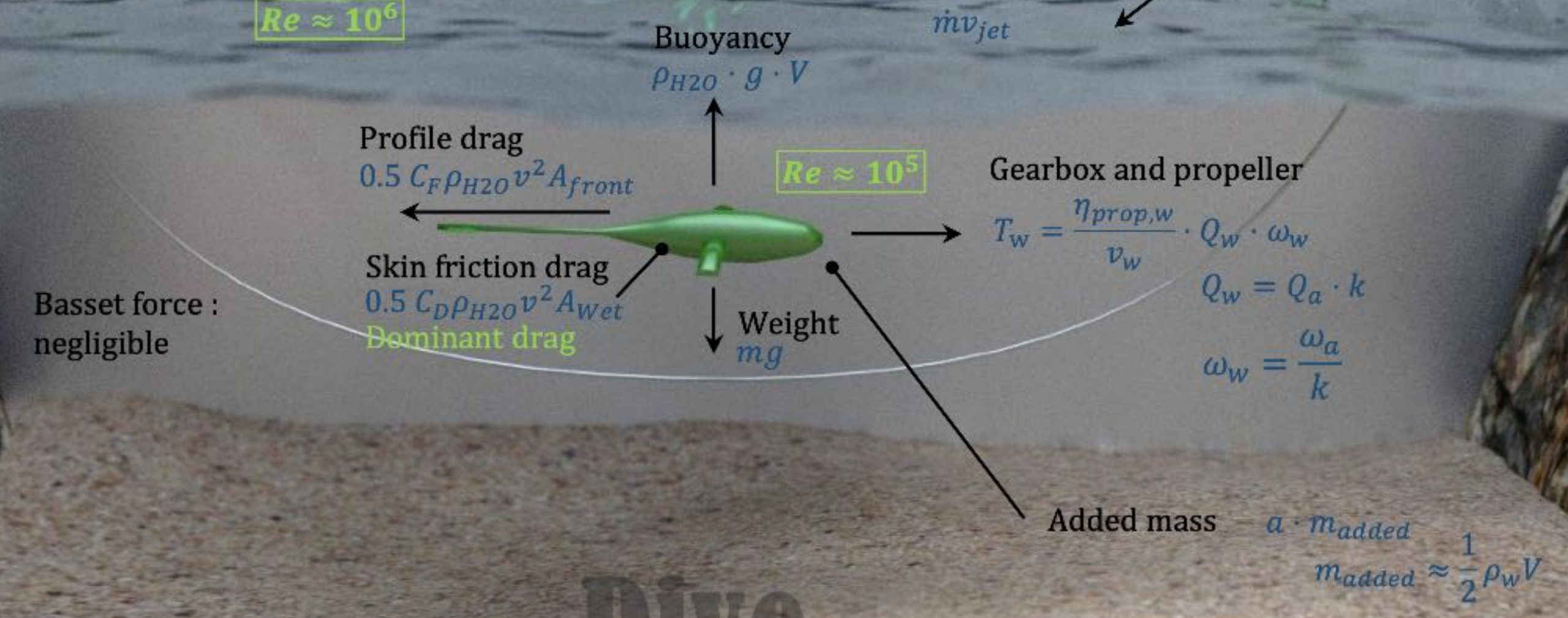
Plunge



Exit



Dive



Aerial-aquatic animals

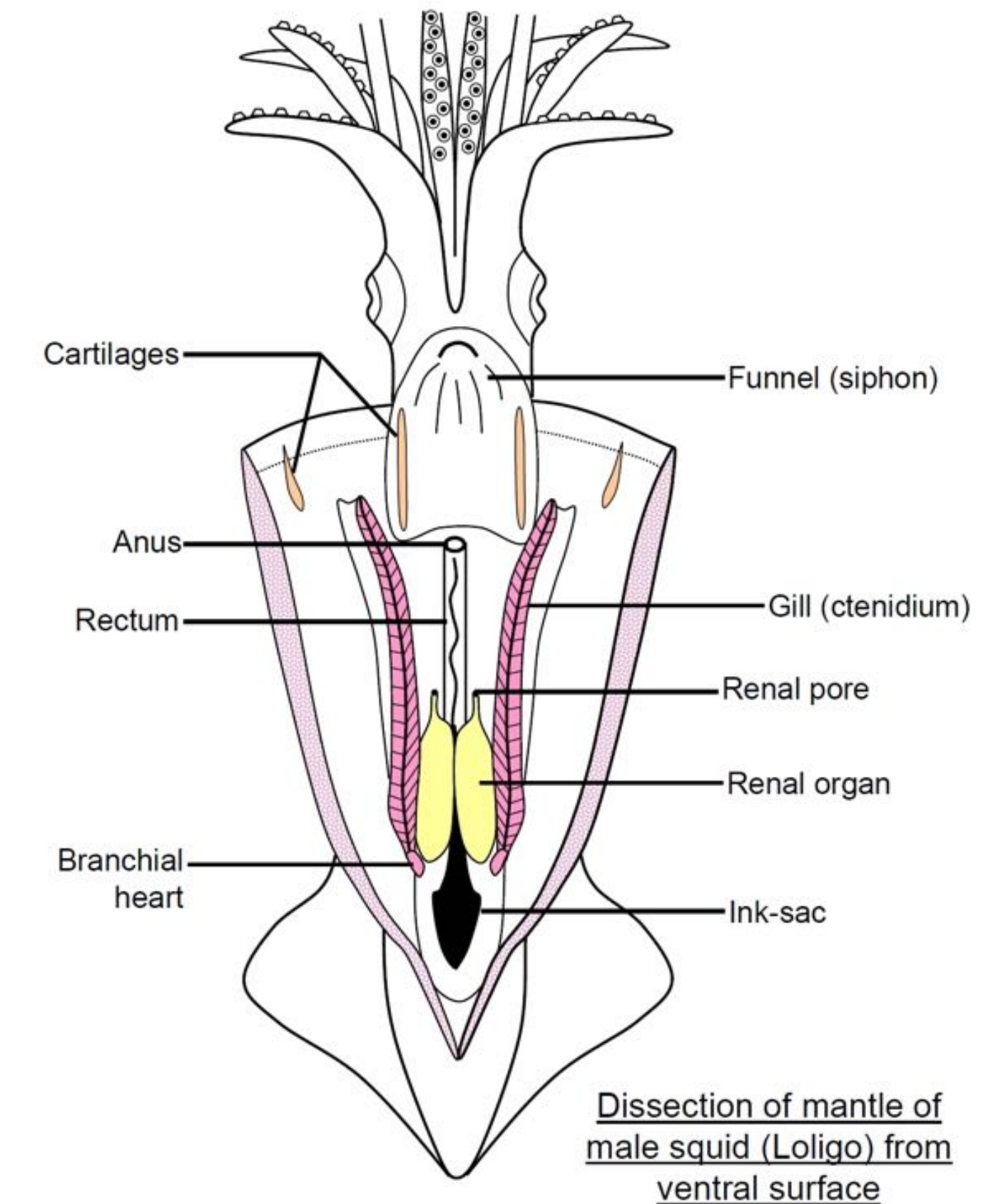
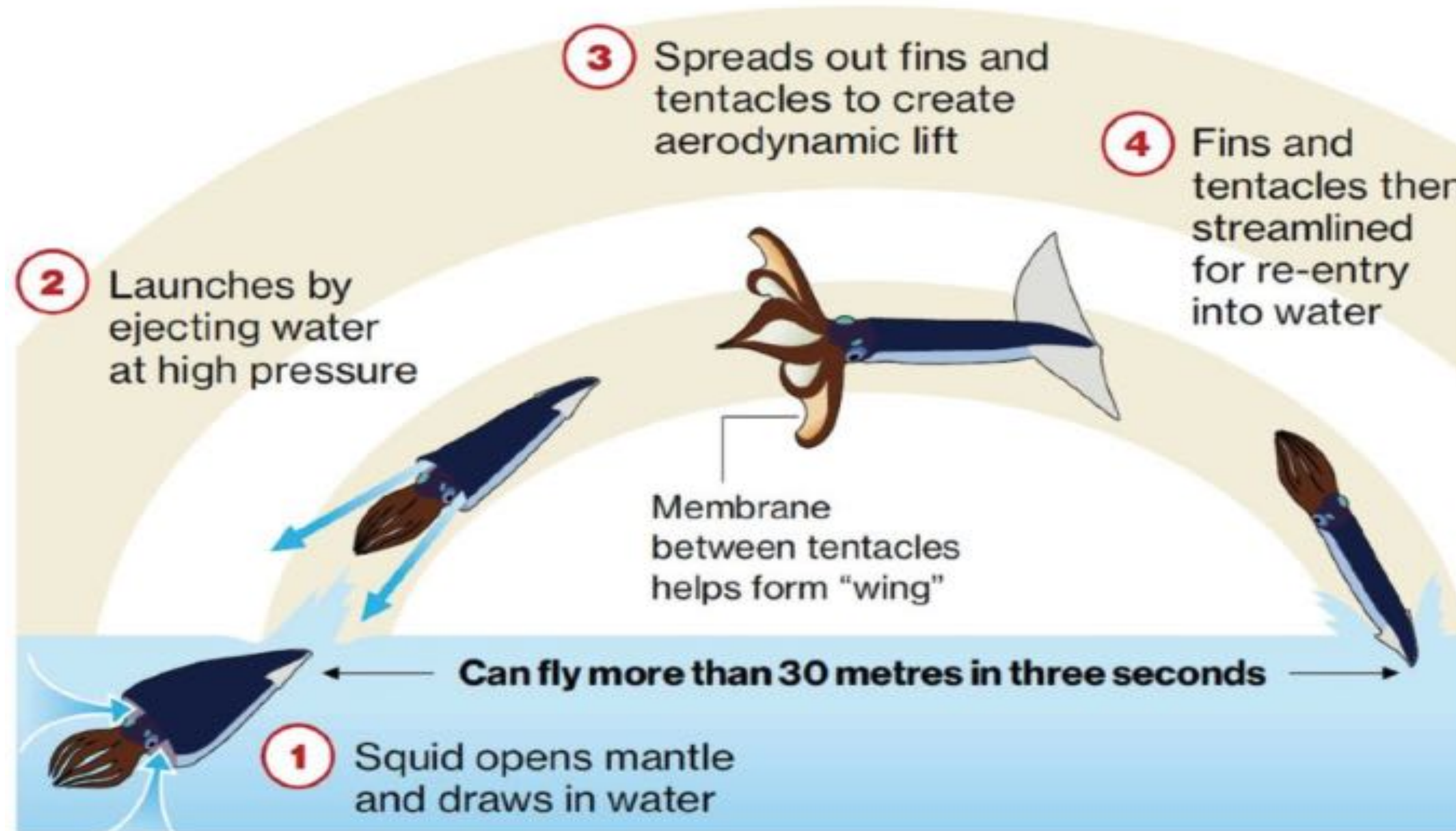
91



“Flight has a clear energy benefit that would aid horizontal migration in addition to being an escape mechanism.”

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

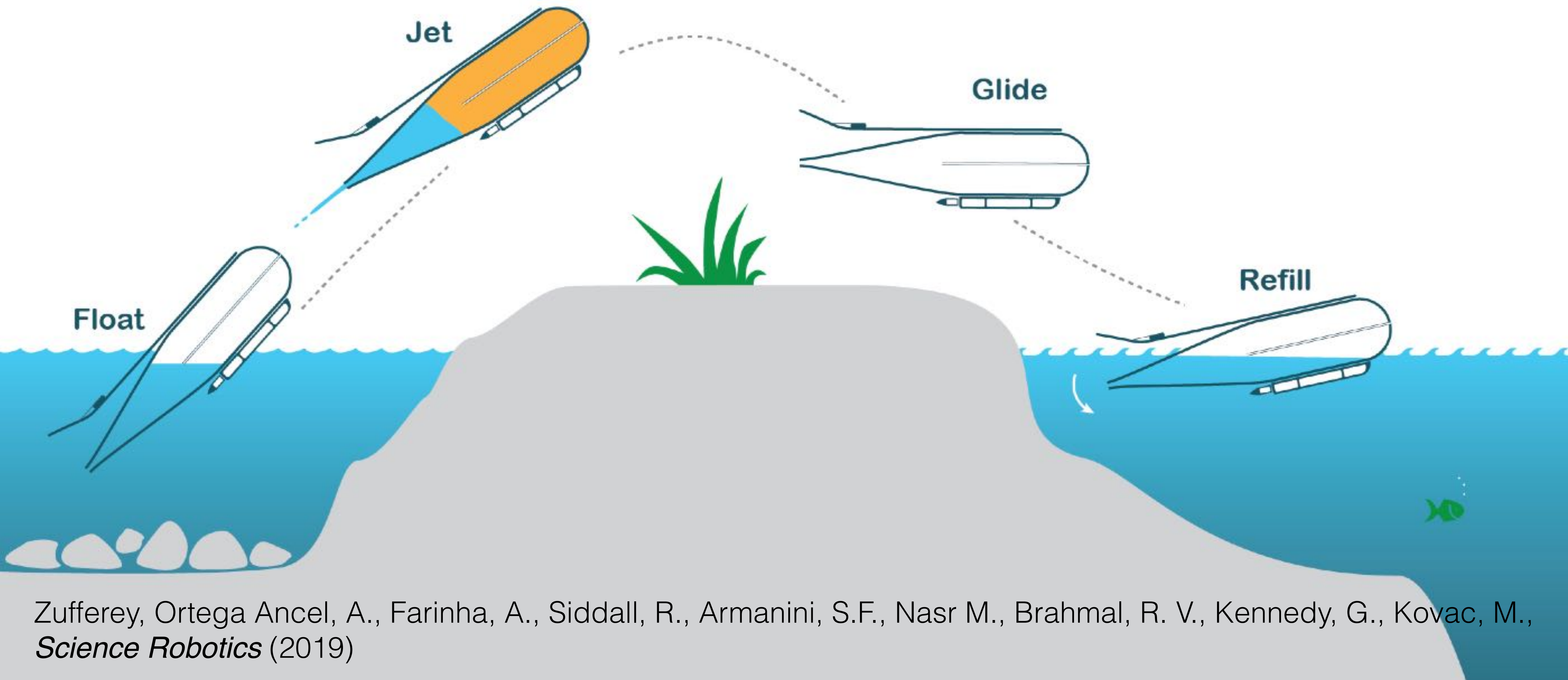


**Mesonychoteuthis
Hamiltoni**

Source: Lee Krystek,
unmuseum.org

Mission Cycle

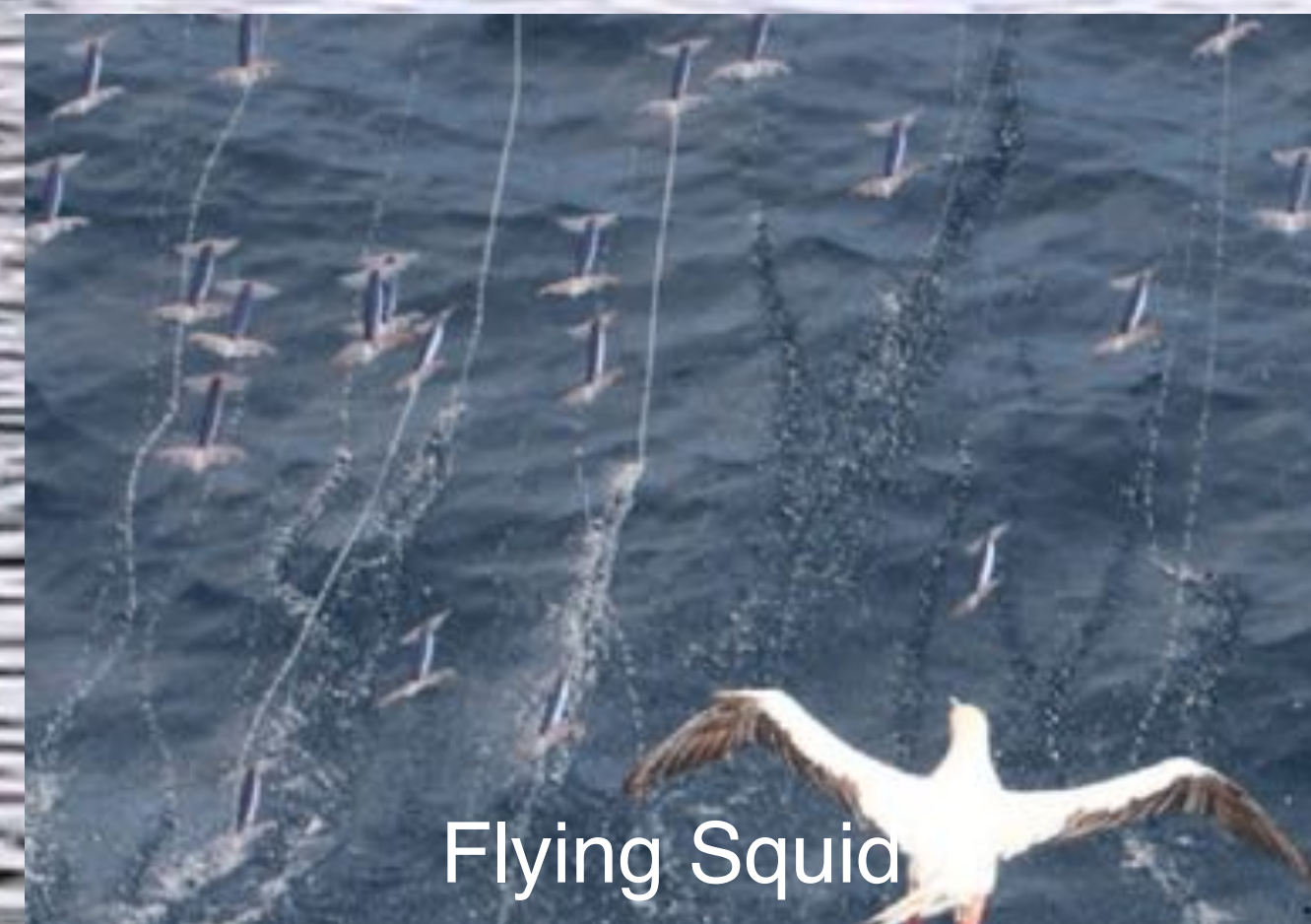
96



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

Aquatic Jump gliding with water reactive fuel

97



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

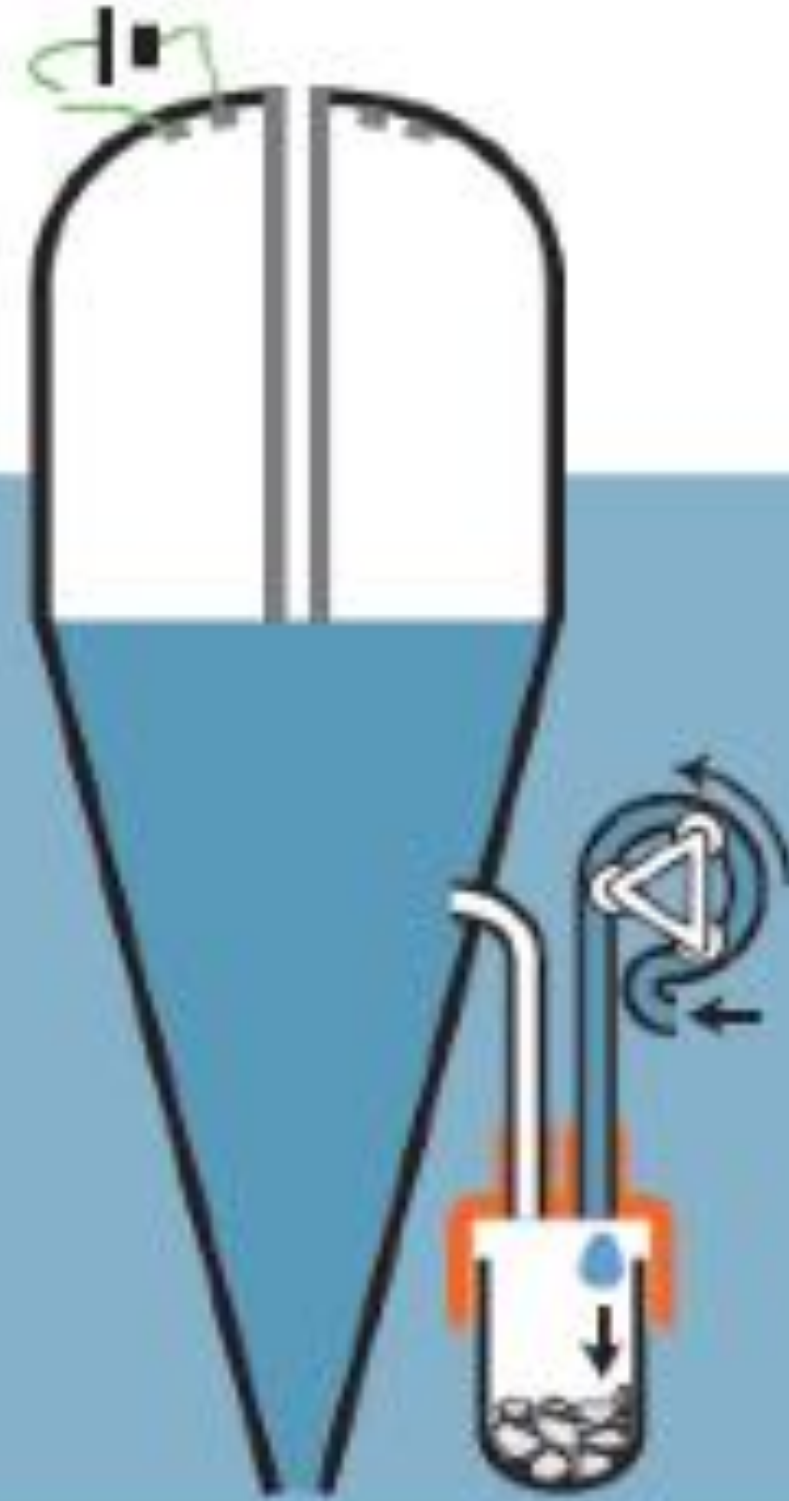
Propulsion System

98

Filling



Water
pumping



Acetylene
production



Ignition



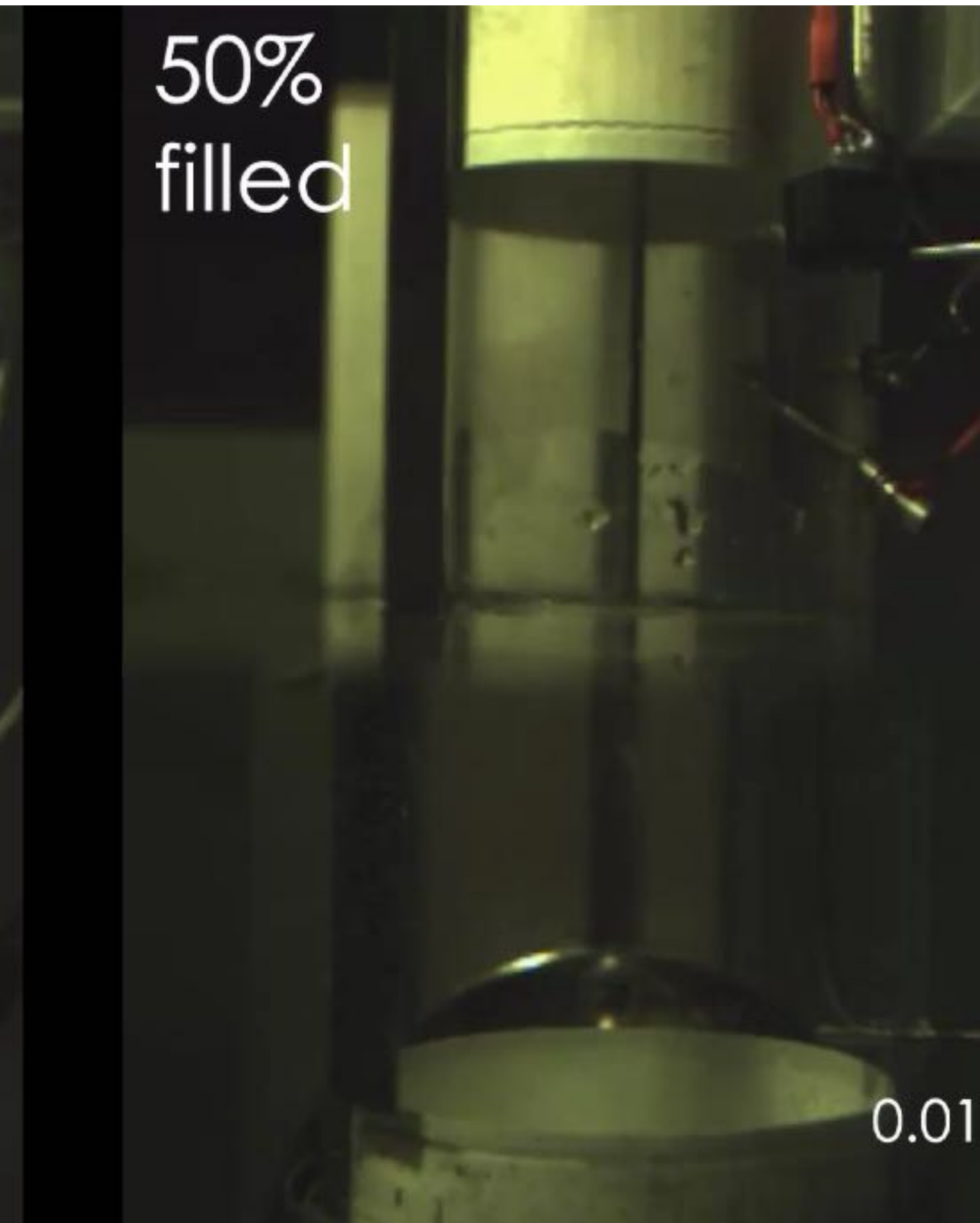
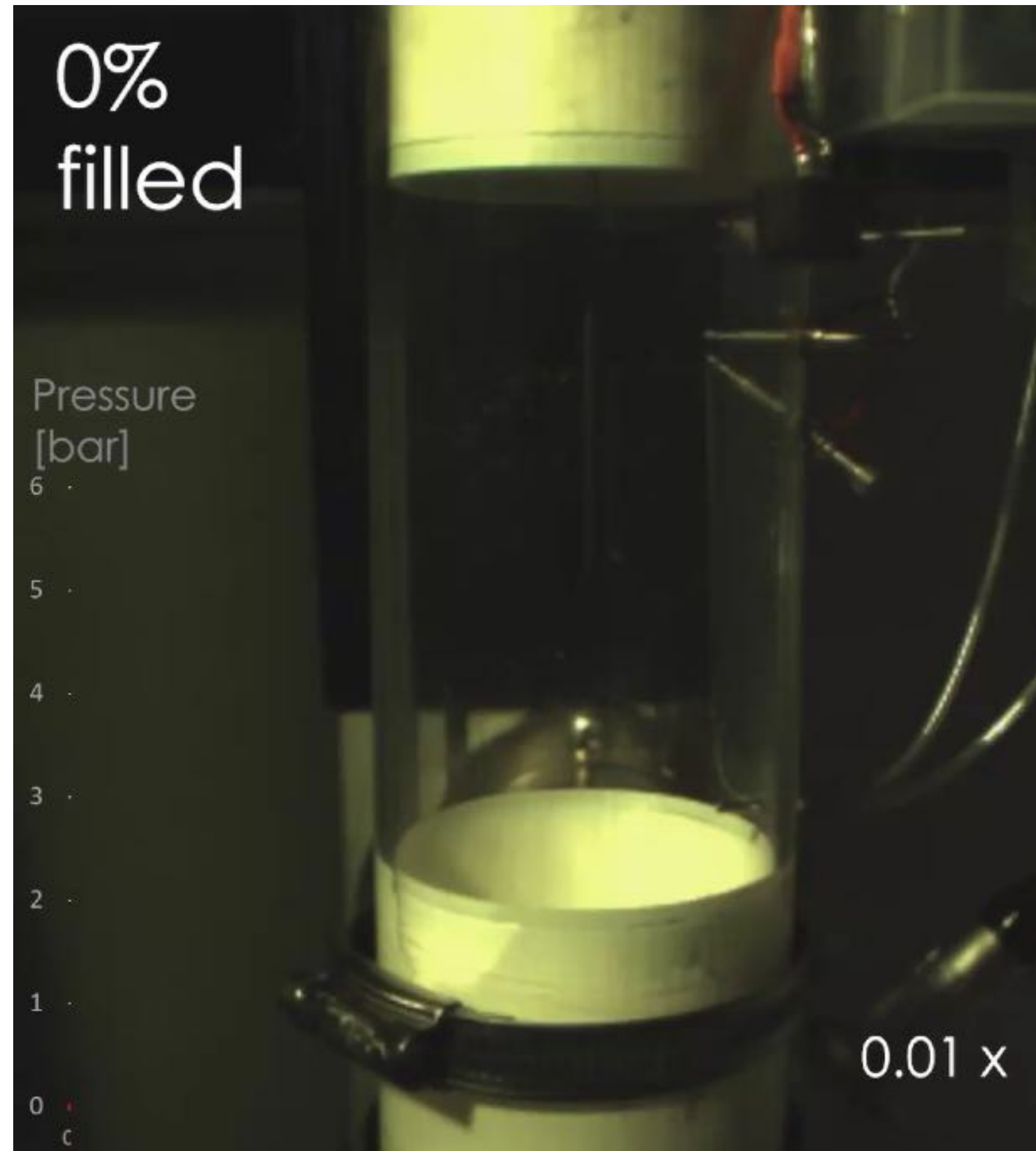
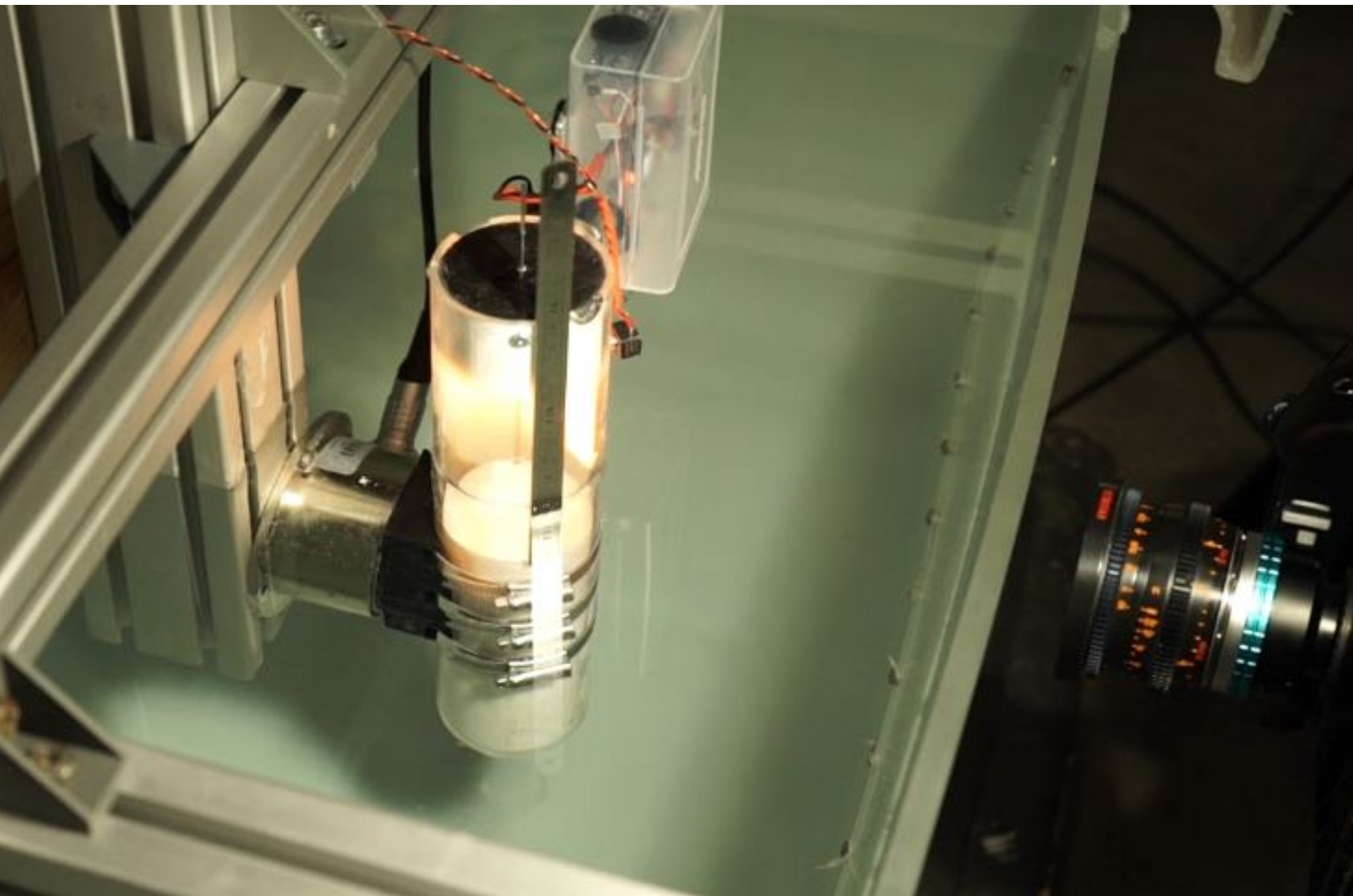
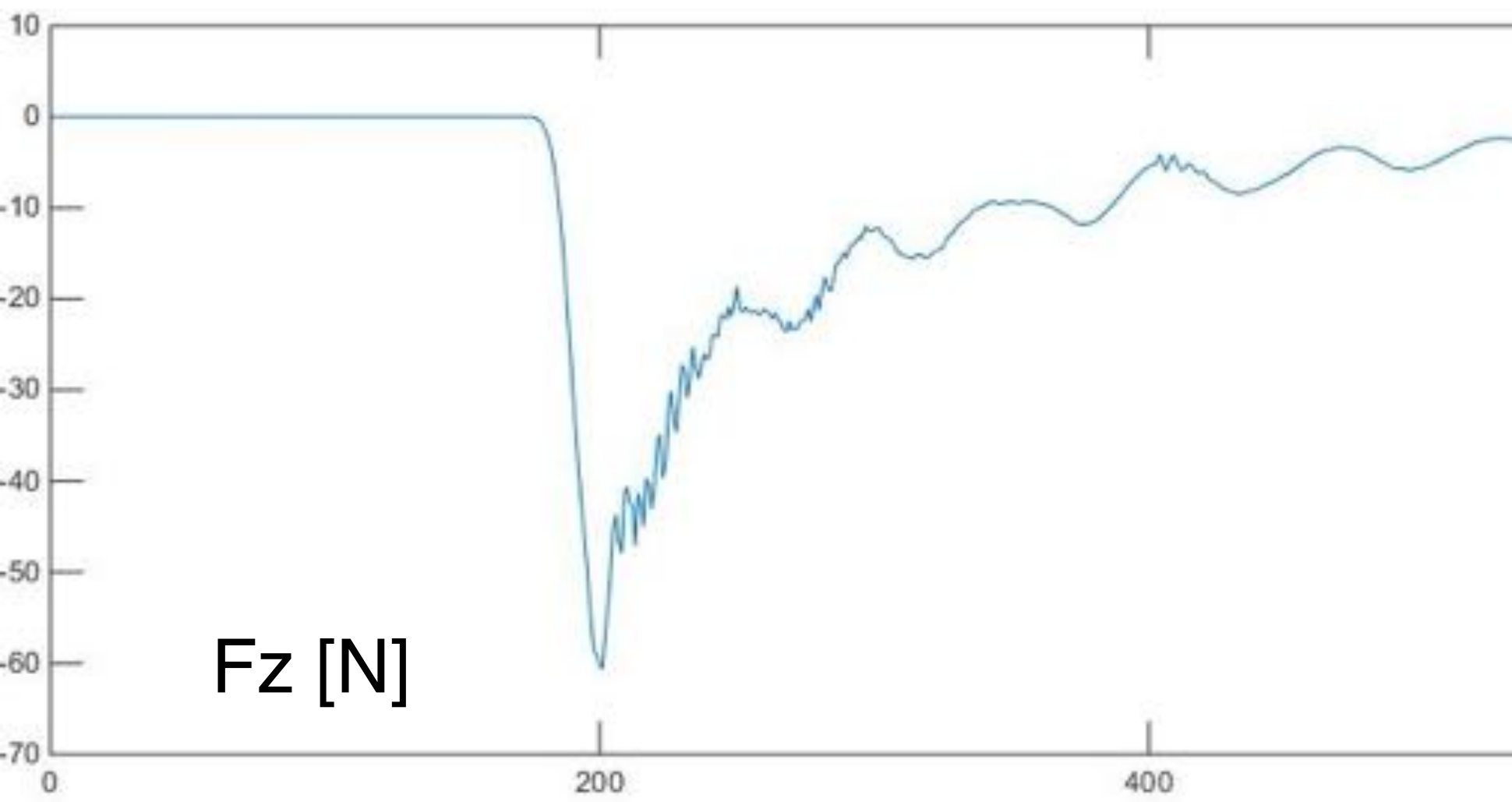
Thrust



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

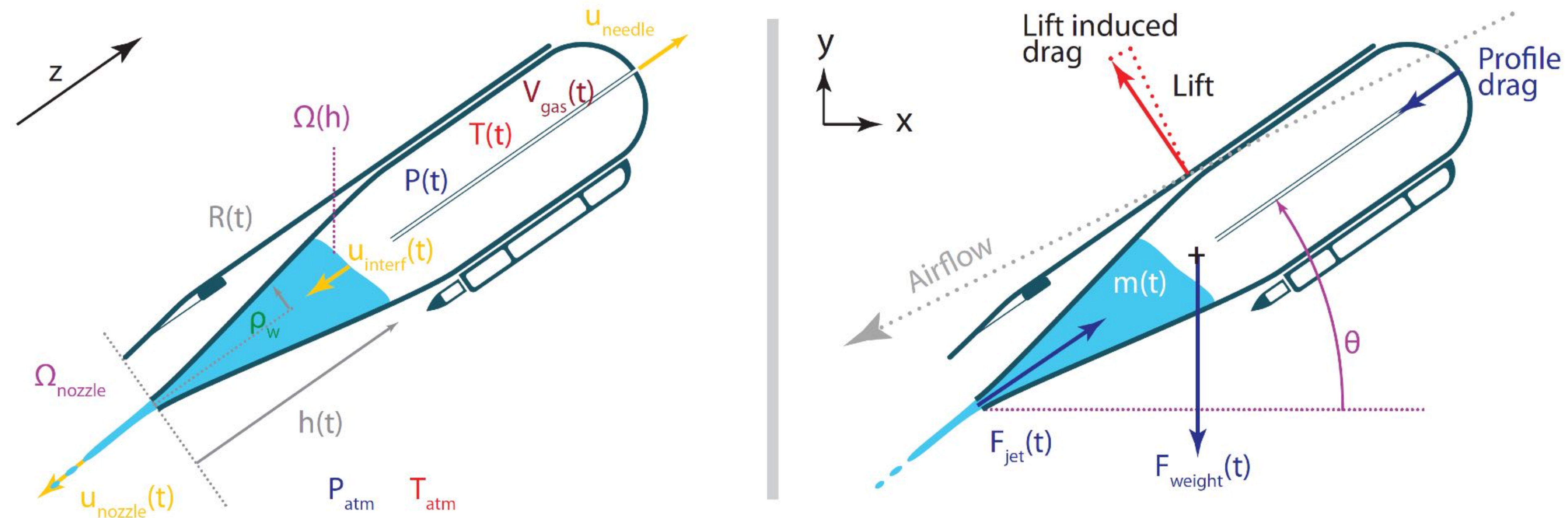
Static Tests

99



Physics-based development

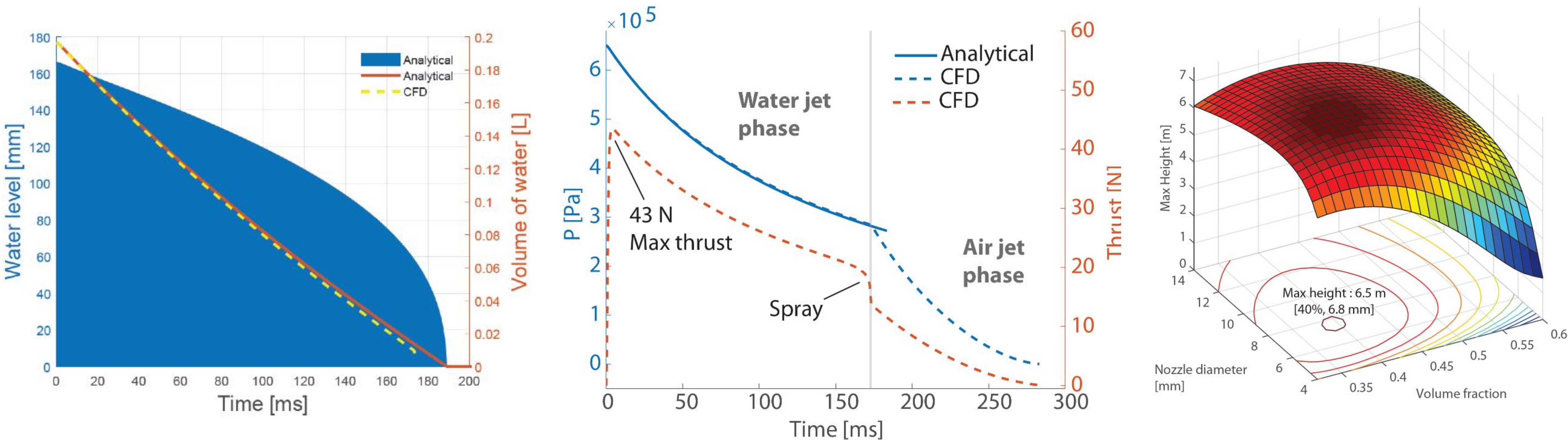
100



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

CFD and model analysis

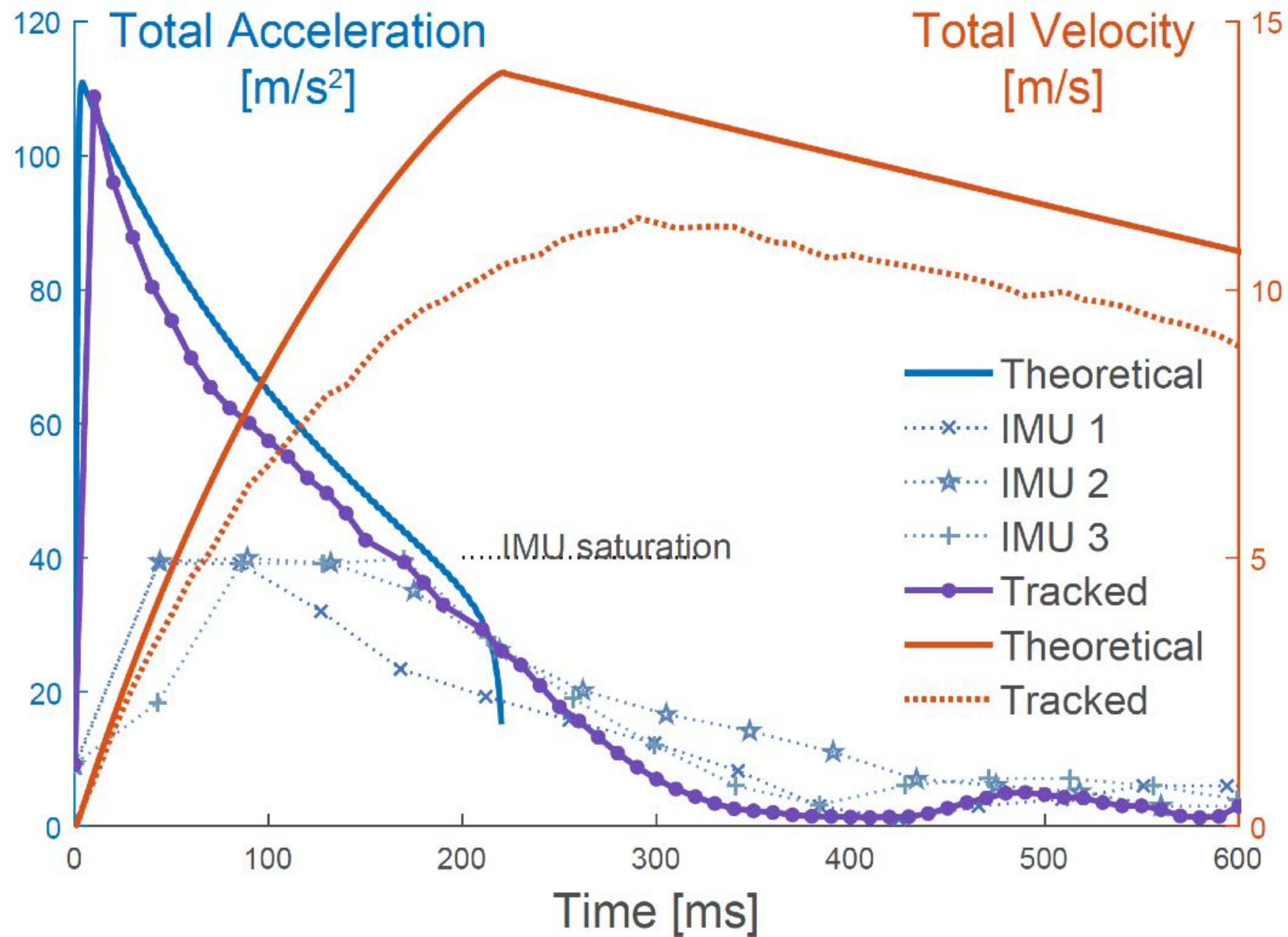
101



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

102



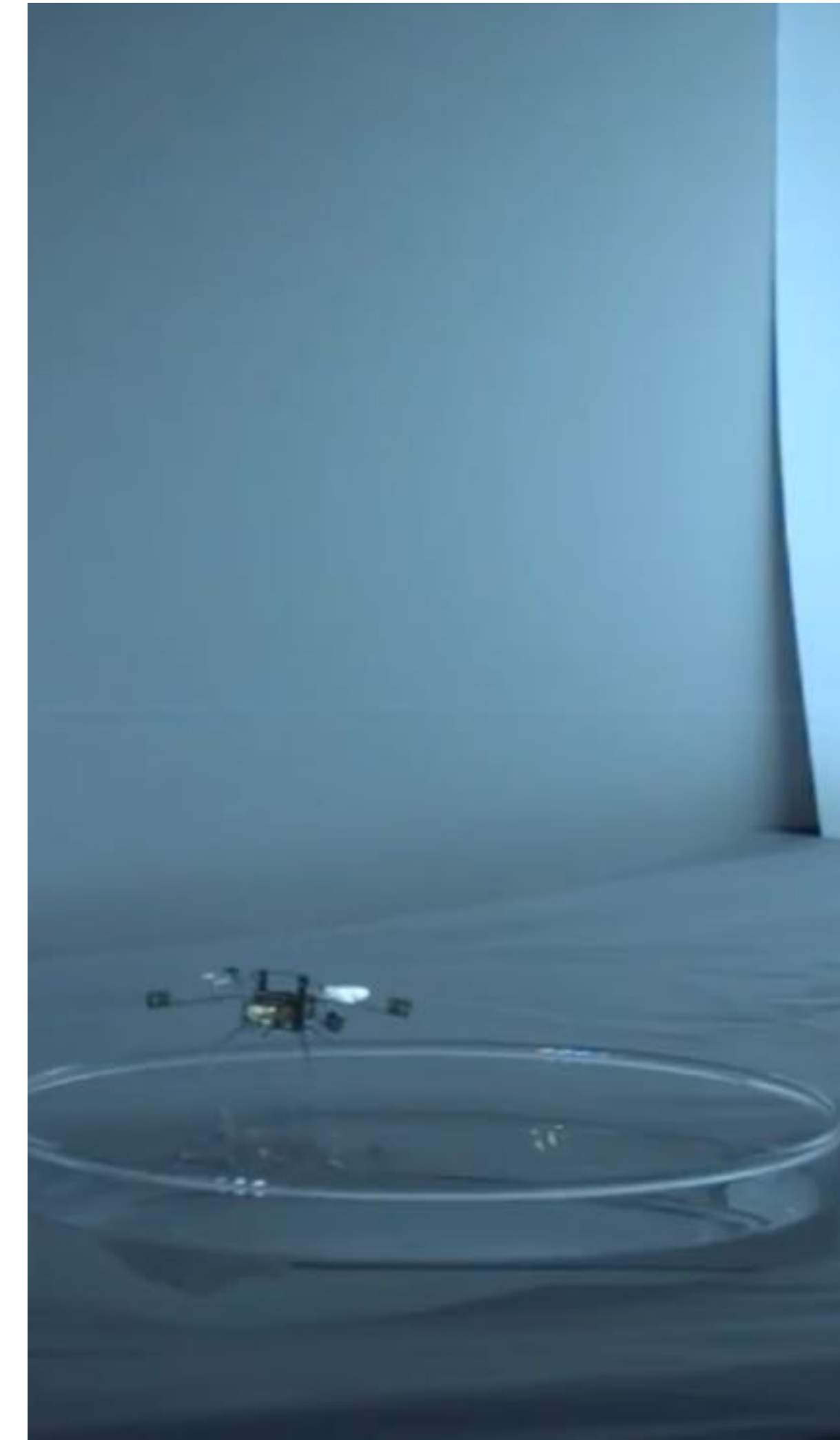
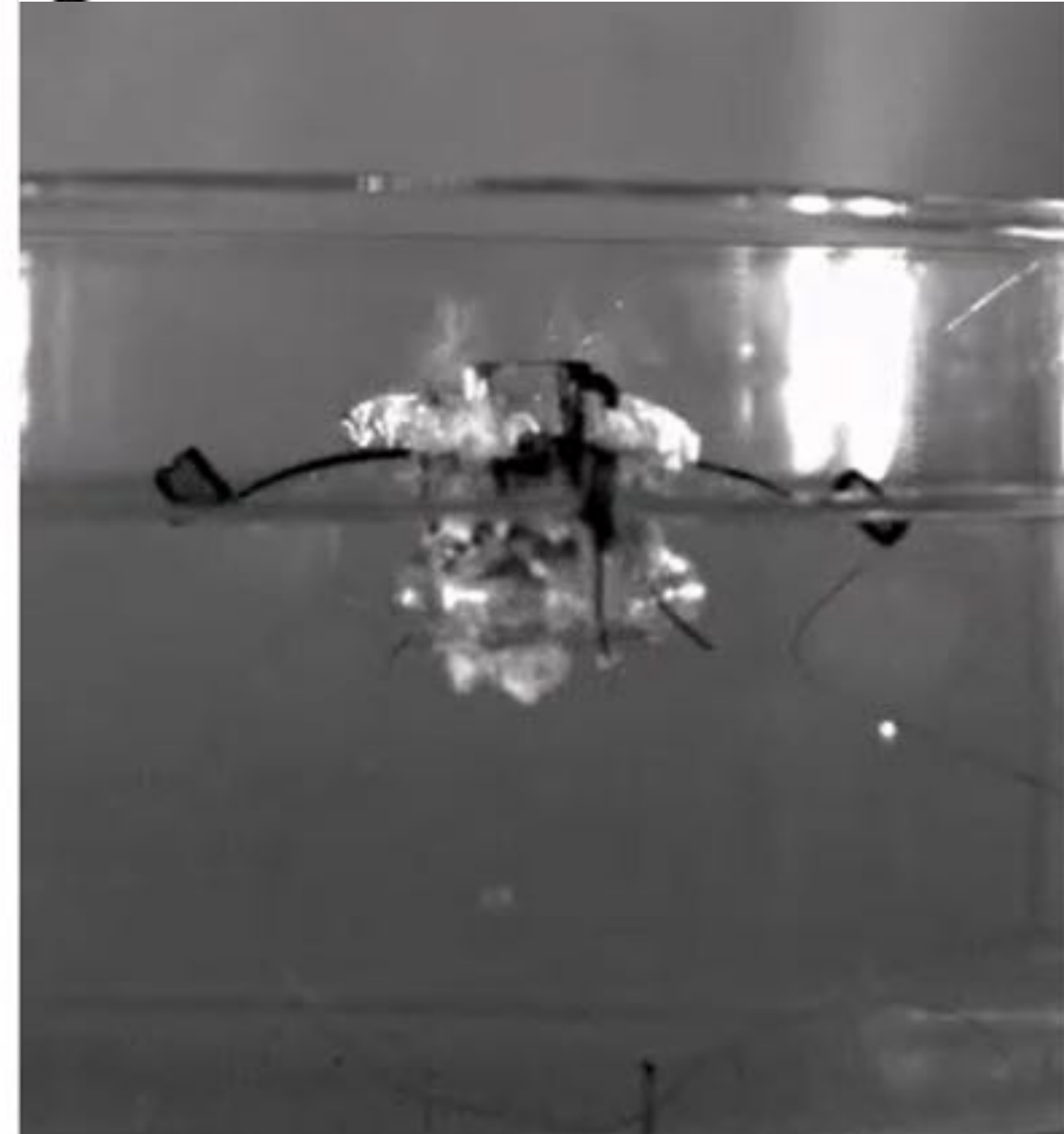
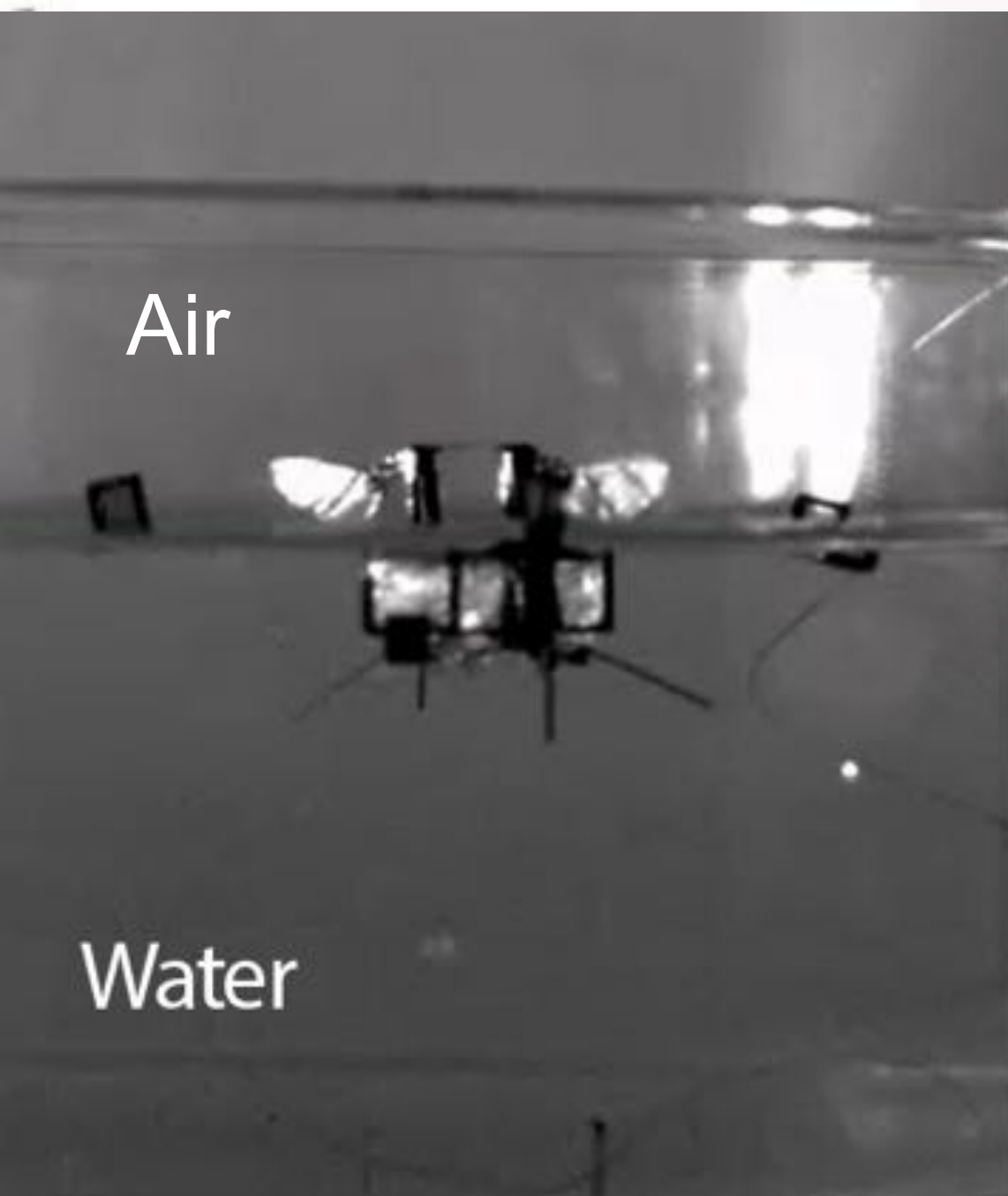
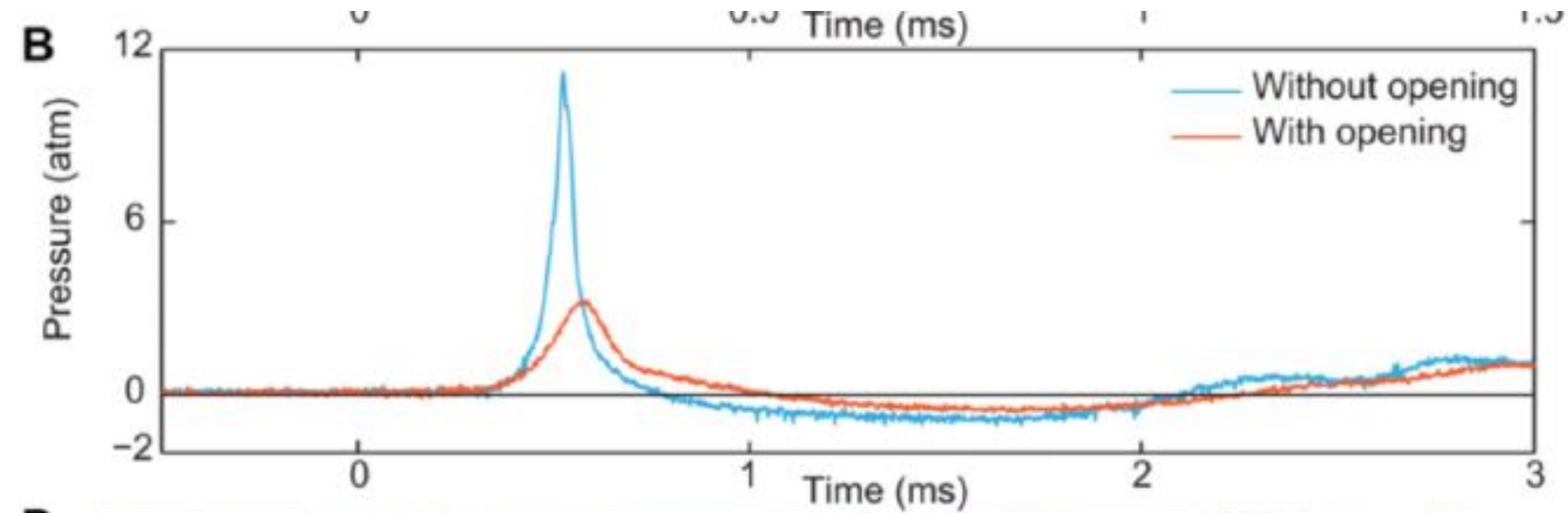
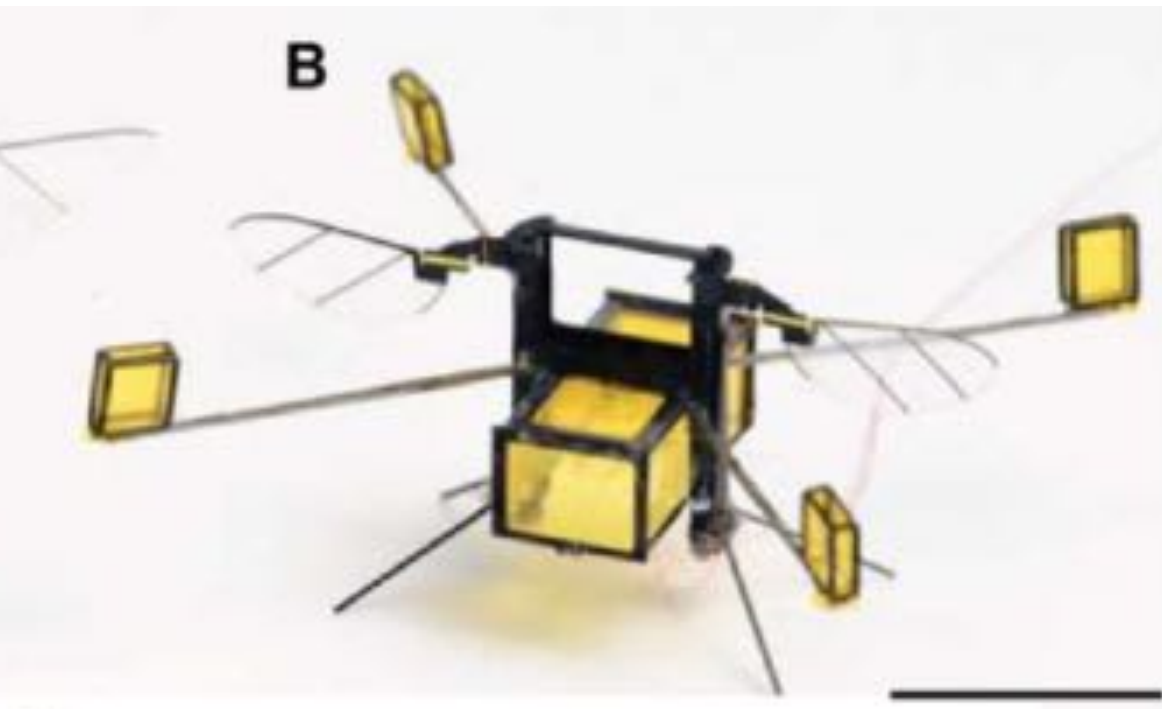
Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahma, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)



Launch

0.03 x

Aerial-aquatic RoboBee



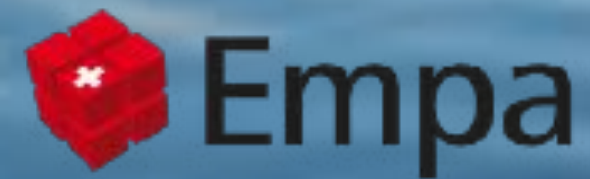
Chen, K., Zufferey, R., Kovac, M., Wood, R. et al.
Science Robotics (2017)

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

Nature (Remora Fish)

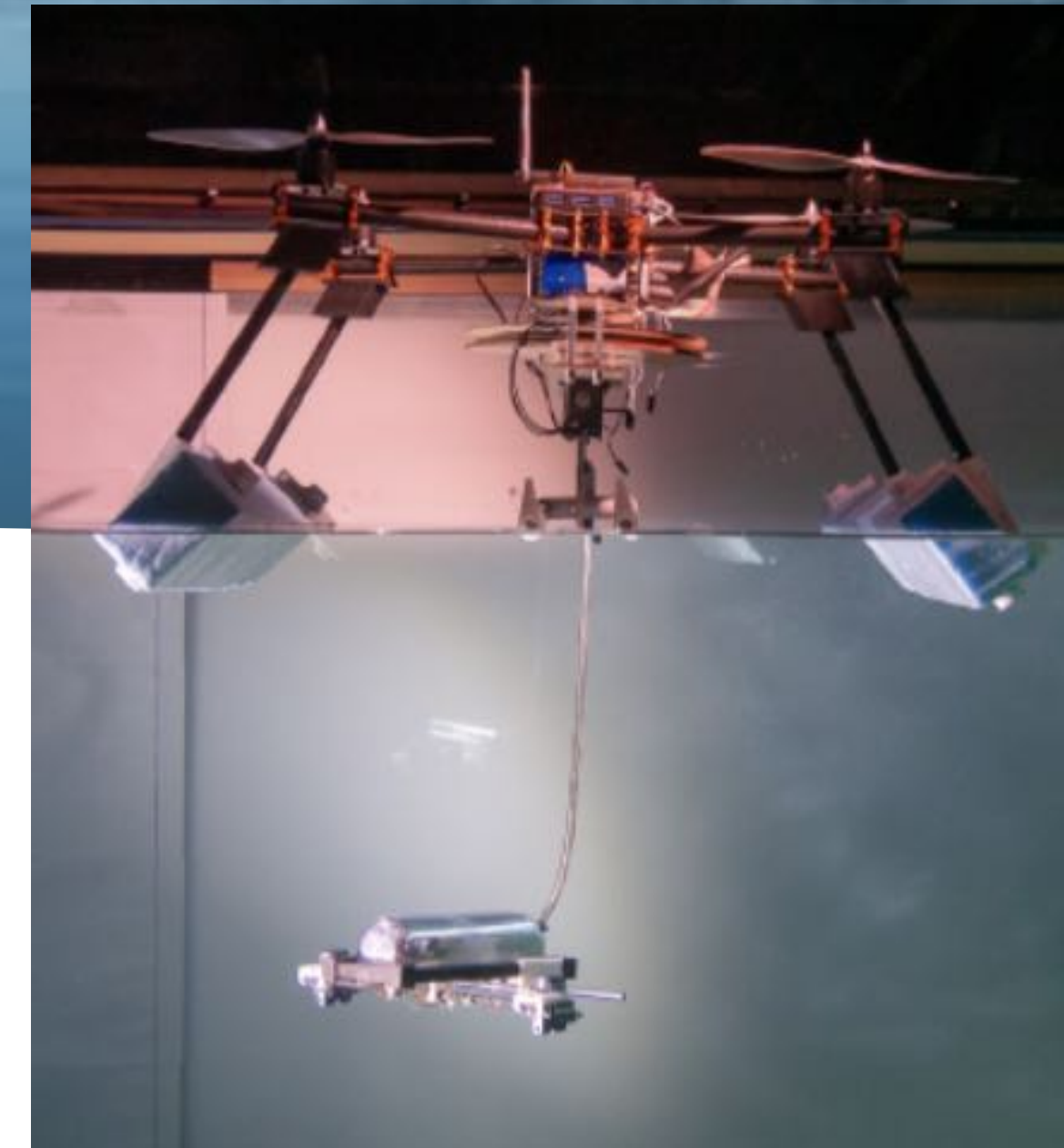
Robot

Aerial - Aquatic platforms for biodiversity

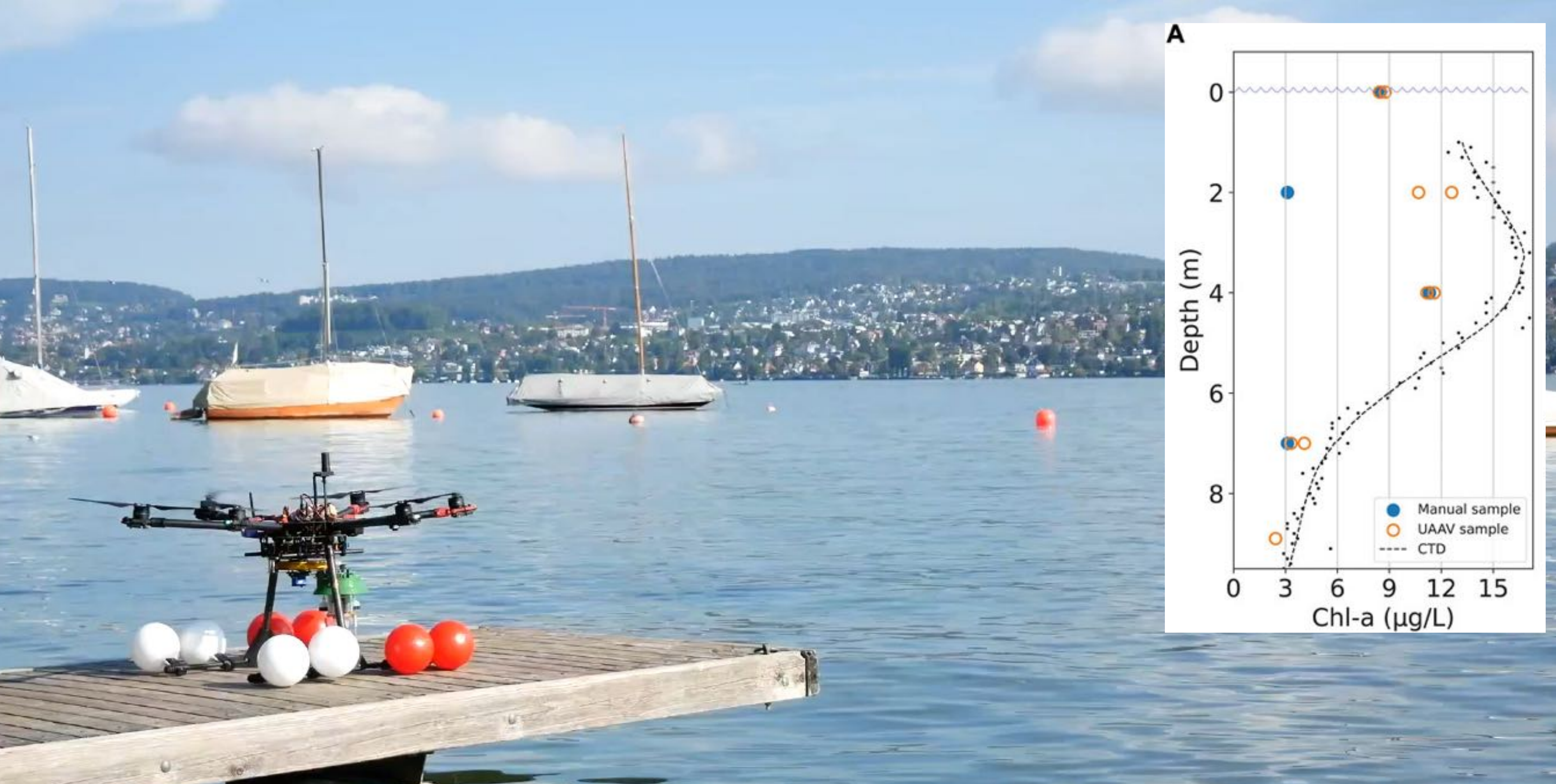


Development of integrated water quality sensing solutions for mobile in-situ sensing

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



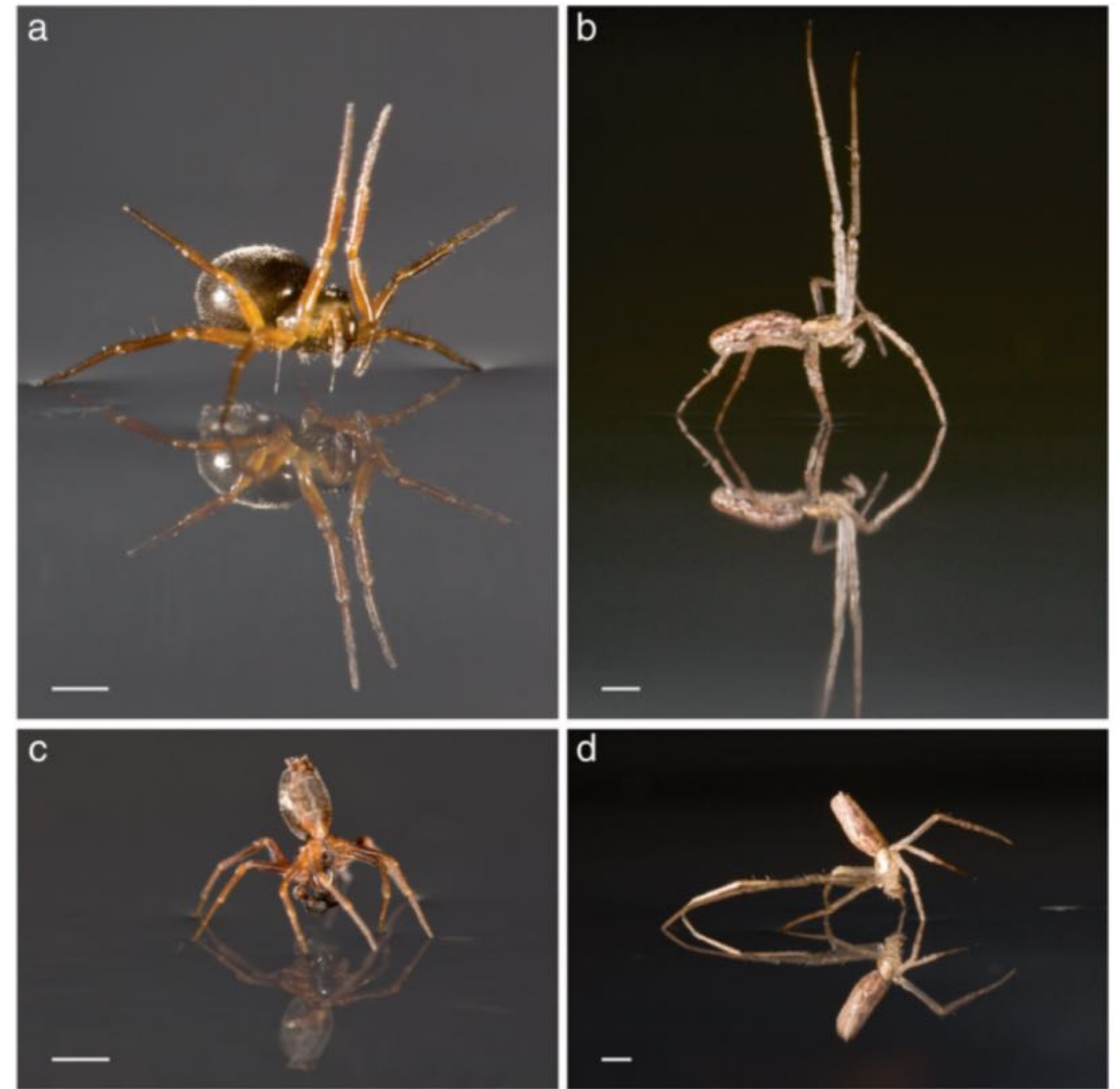
MEDUSA:
a Multi-Environment
Dual-Robot



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

Sailing : Energy efficient locomotion

108

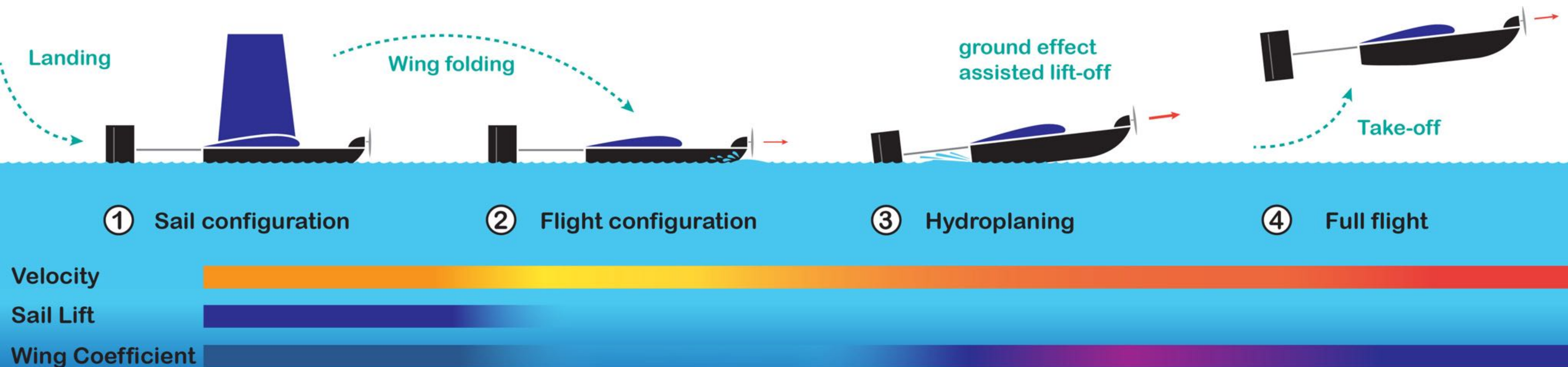


- Terenius. Windsurfing in Mute Swans (*Cygnus olor*). *The Wilson Journal of Ornithology*, (2016)
- Hayashi, Morito, et al. "Sail or sink: novel behavioural adaptations on water in aerially dispersing species." *BMC evolutionary biology* (2015)

Sailing Micro Aerial Vehicles

109

Motivation:
Marine Research
Climate change Research
Innaccessible area Exploration



SailMAV: design and implementation of a novel multi-modal flying sailing robot

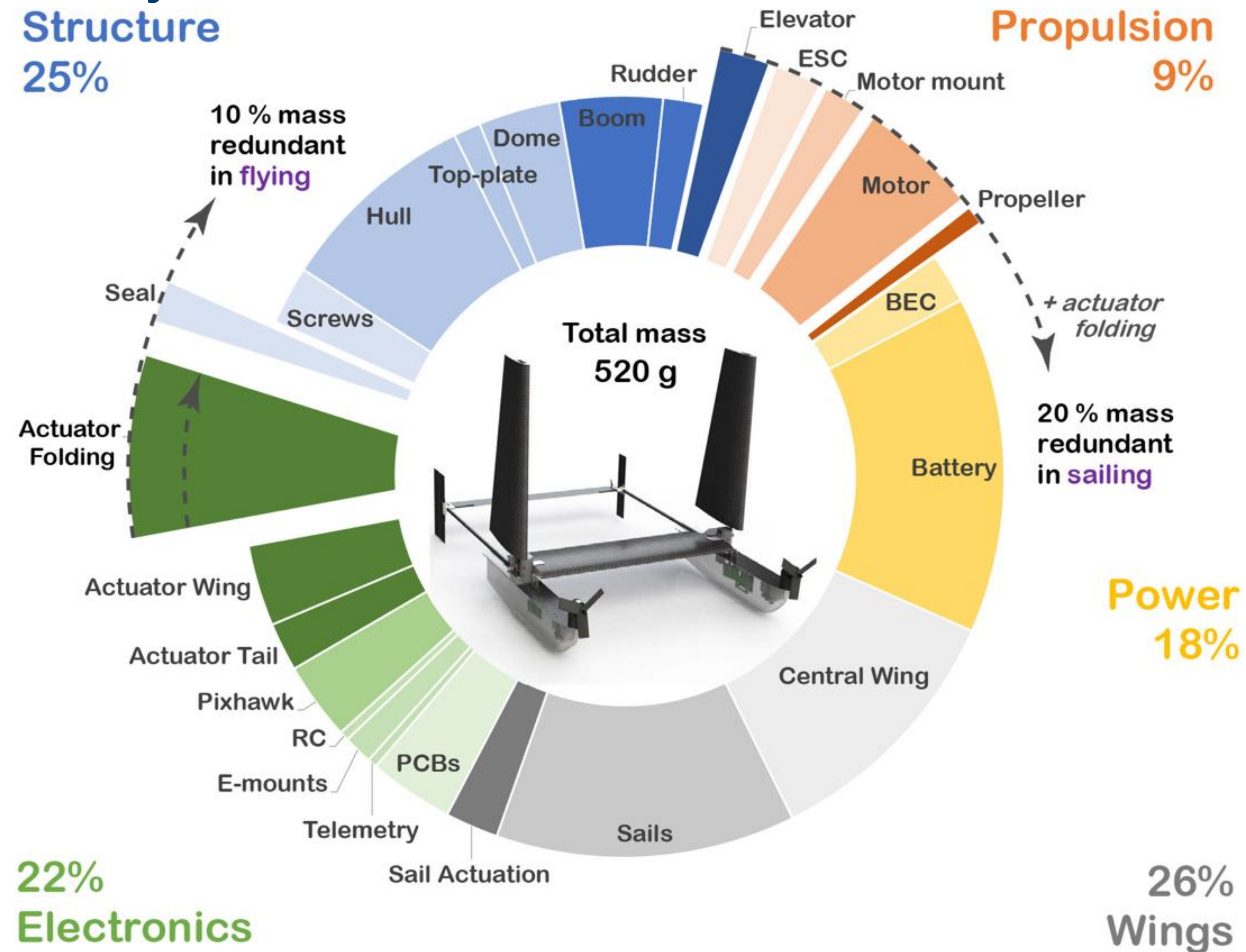
*Raphael Zufferey, Alejandro Ortega, Célia Raposo, Sophie F. Armanini, Andre Farinha,
Robert Siddall, Ion Berasaluce, Haijun Zhu and Mirko Kovac*

Aerial Robotics Laboratory, Imperial College London

Submitted 24.02.2019 to RA-L

Multi-modality cost

111



Aerial - Aquatic SailMAV

Vol. 5 • No. 2 • February 2023

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ADVANCED INTELLIGENT SYSTEMS

Open Access

112

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

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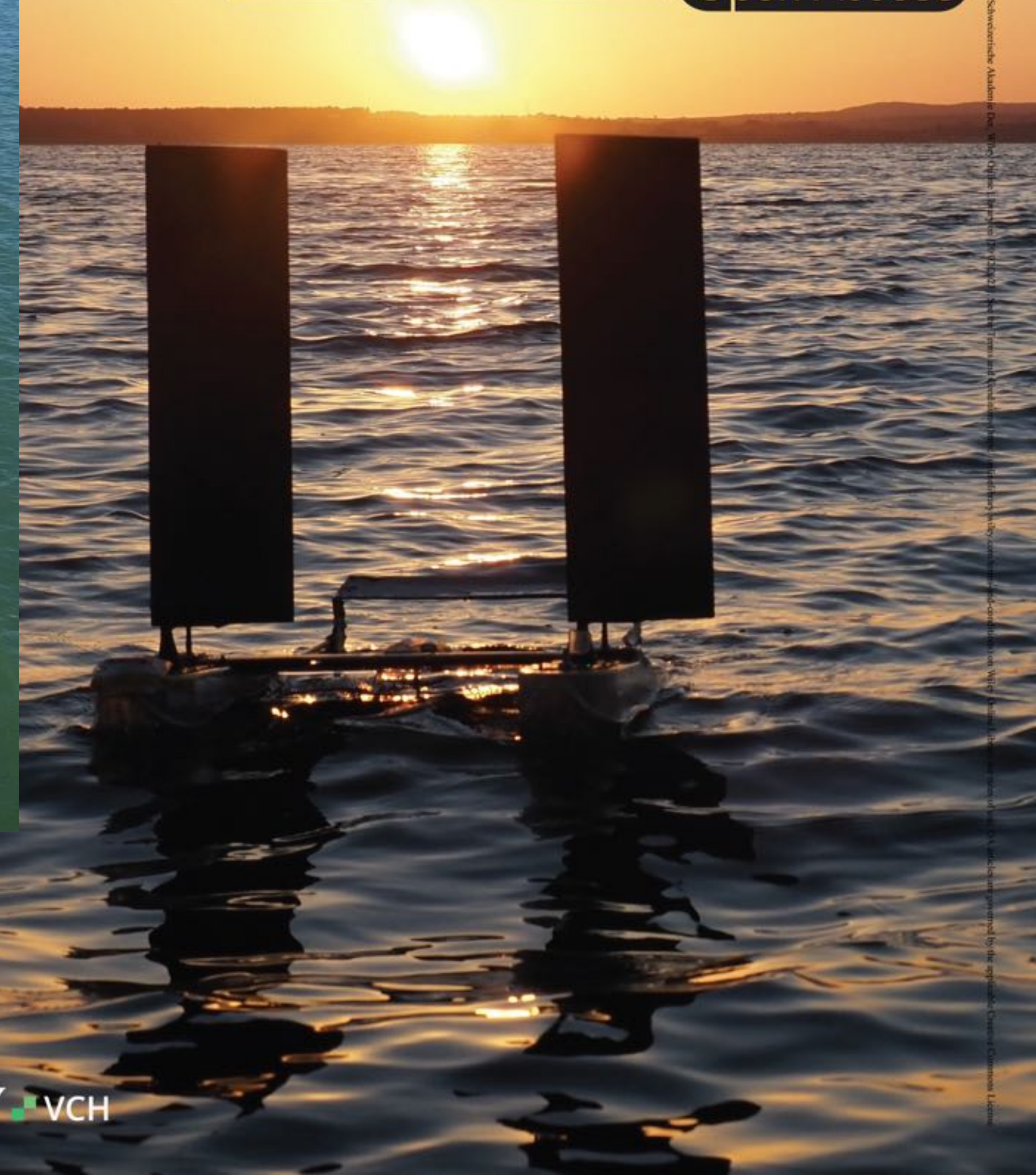
Aerial - Aquatic SailMAV

Vol. 5 • No. 2 • February 2023

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113
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INTELLIGENT
SYSTEMS**

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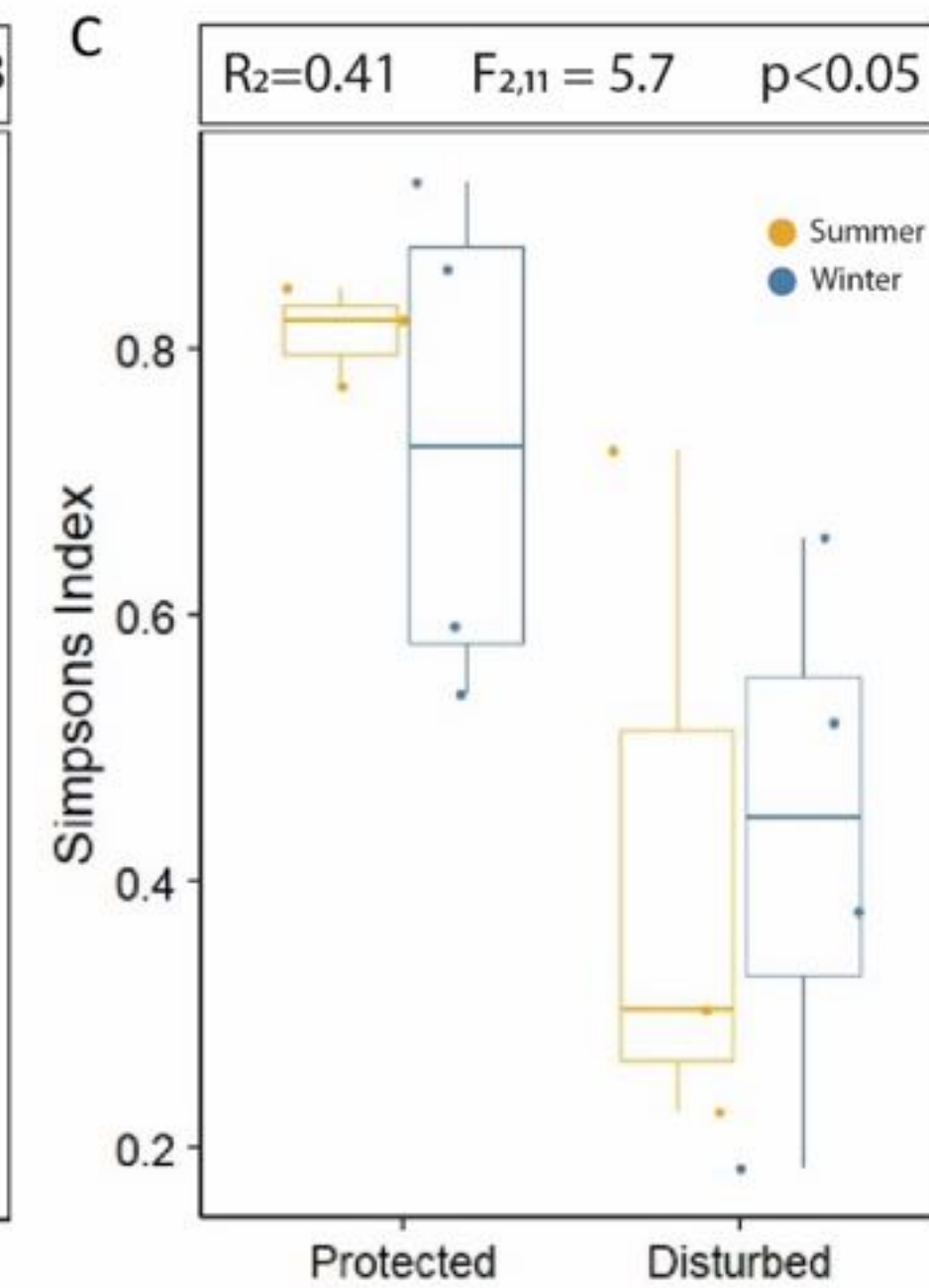
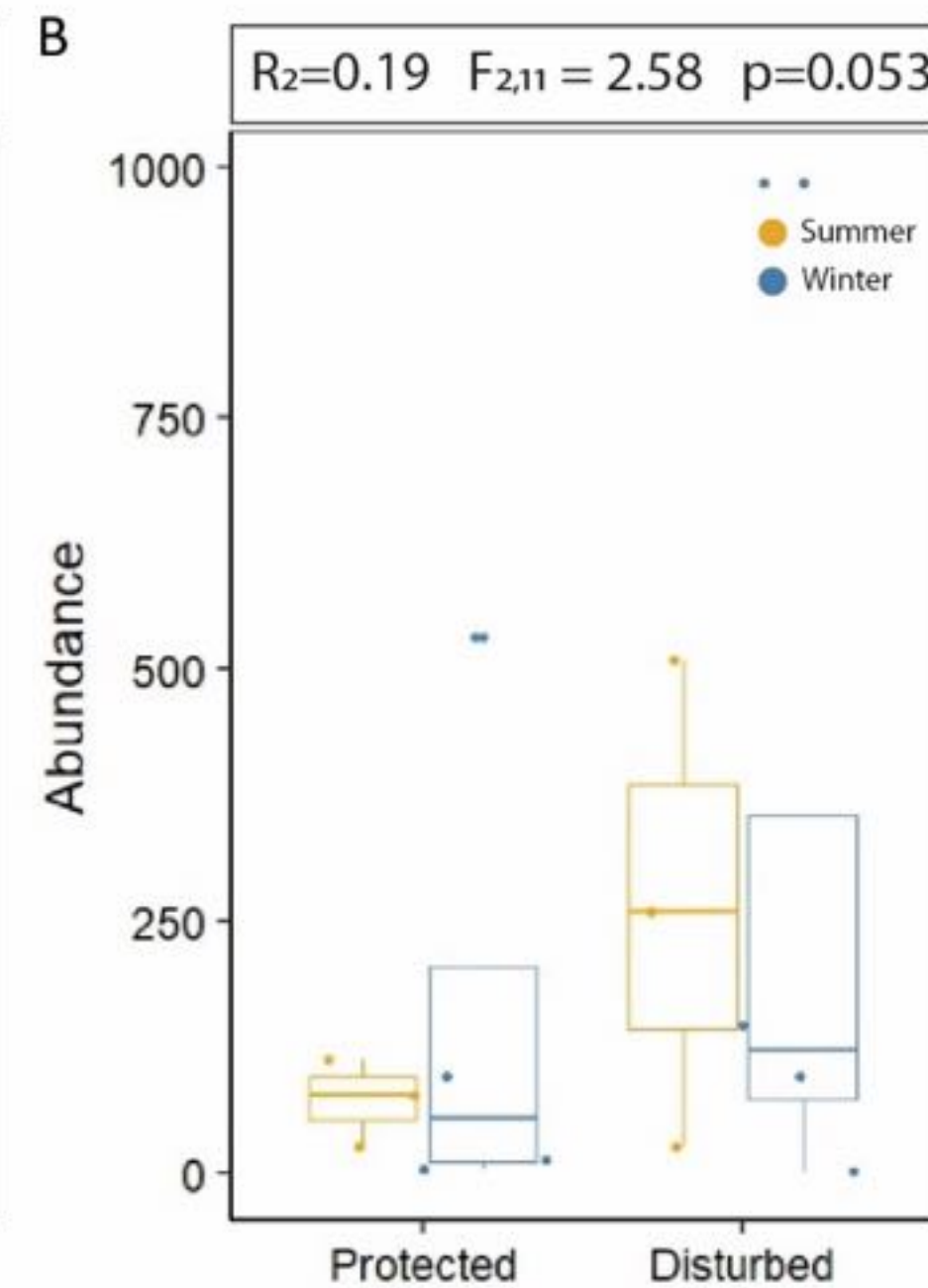
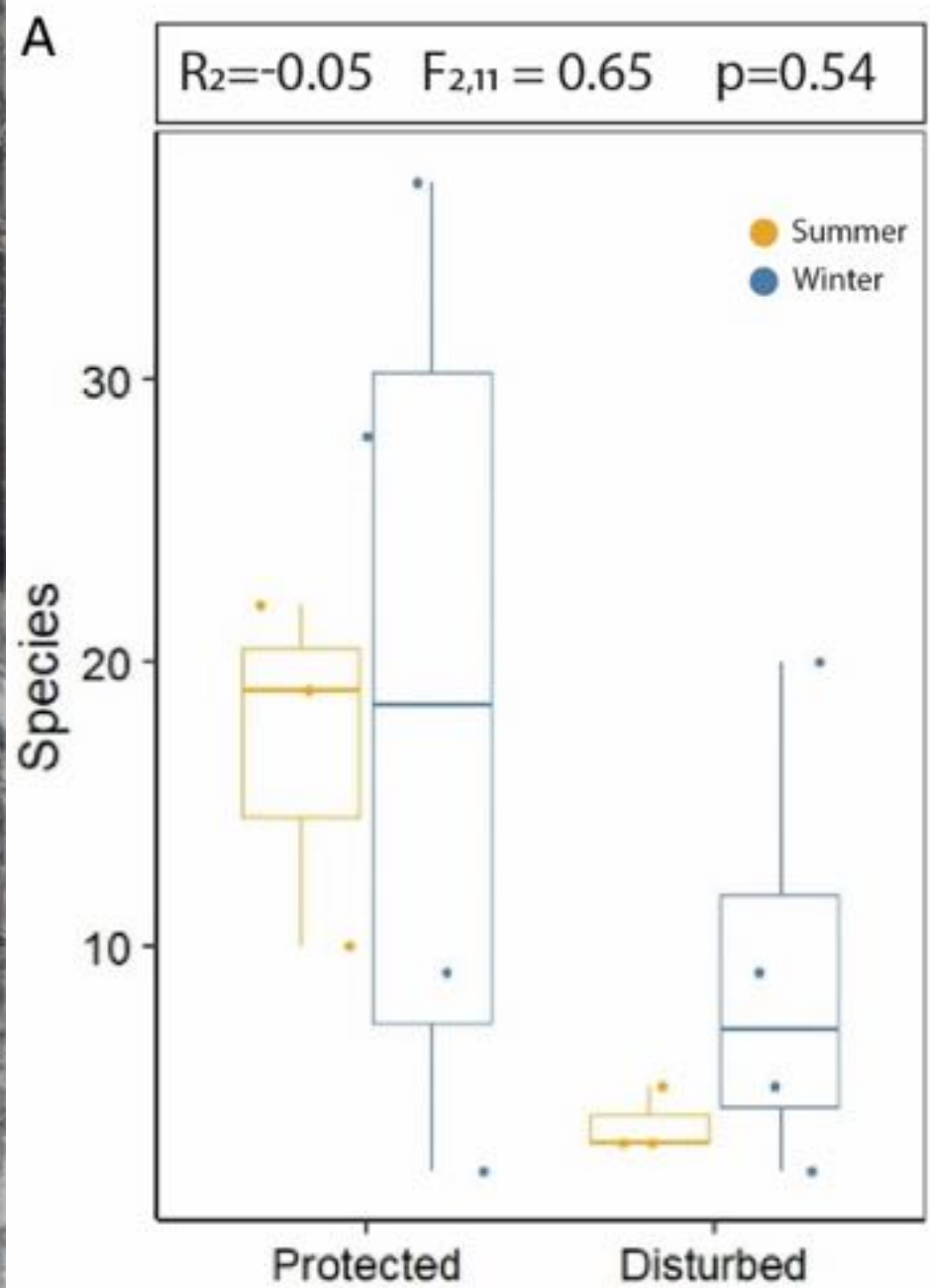


Gortat, D., Ortega Ancel, A., Farhina, A., Zufferey, R., Kovac, M.,
**Use of Superhydrophobic Surfaces for Performance
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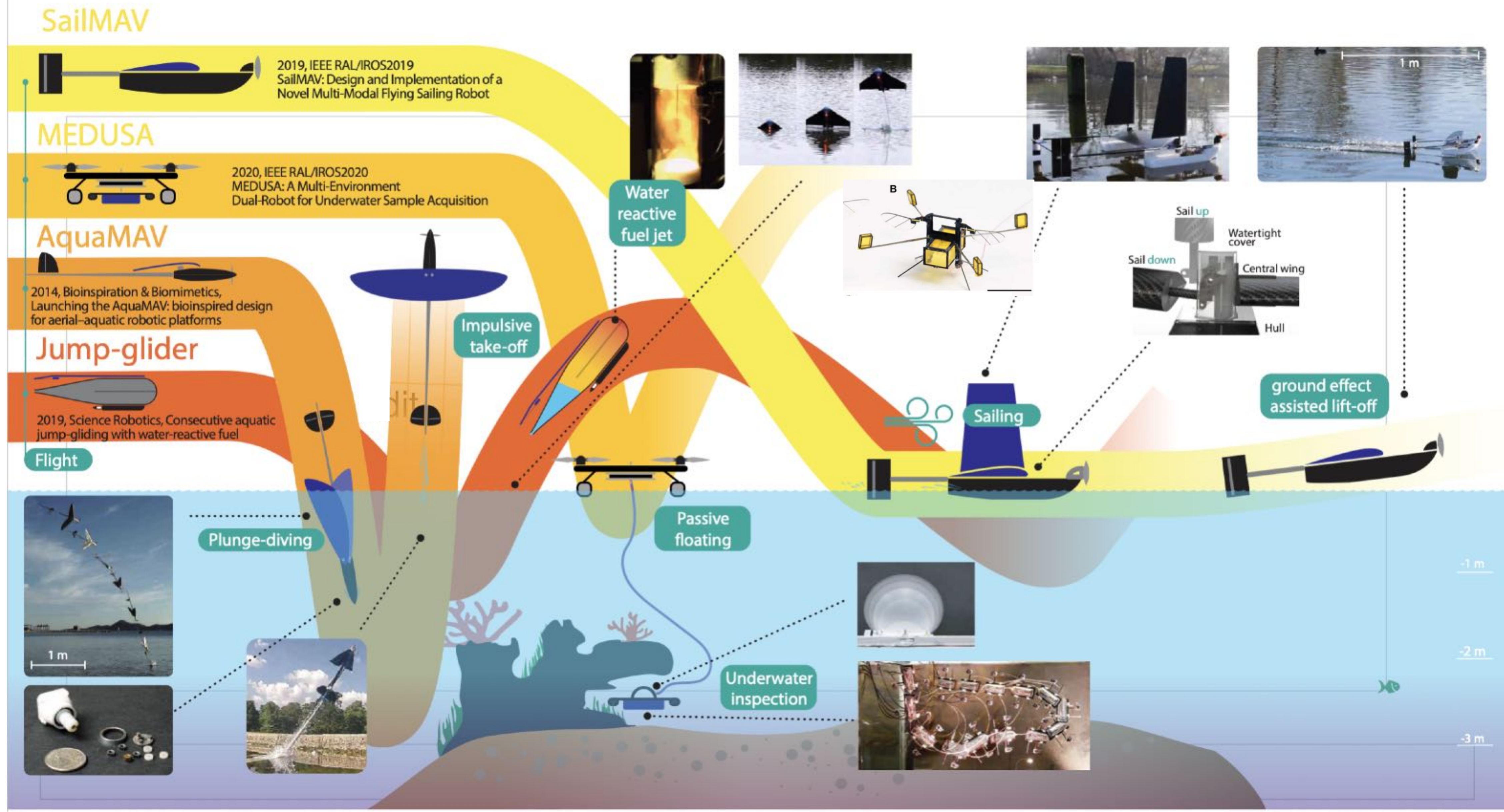
WILEY-VCH

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Field testing campaign



In prep.



Kovac et al. *Science Robotics* 2016, 2019, 2022, *Royal Society Interface Focus* 2x 2017, *ICRA/RA-L* 2016, 2017, 2019, *IEEE TMech* 2016, *Bioinspiration&Biomimetics* 2014, *AIAA* 2019, *IROS* 2019

Best paper/poster awards at AMAM 2019, TAROS 2015, AAAI 2017, QM best PhD thesis award 2018 & 2020

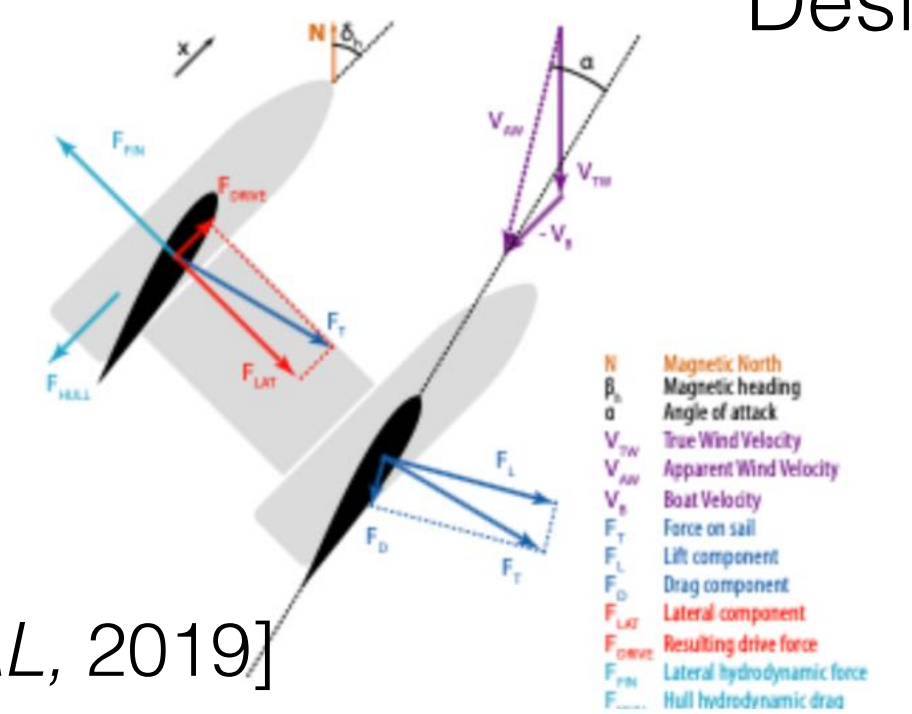
Biosystems & Biorobotics

Raphael Zufferey
Robert Siddall
Sophie F. Armanini
Mirko Kovac

Between Sea and Sky: Aerial Aquatic Locomotion in Miniature Robots

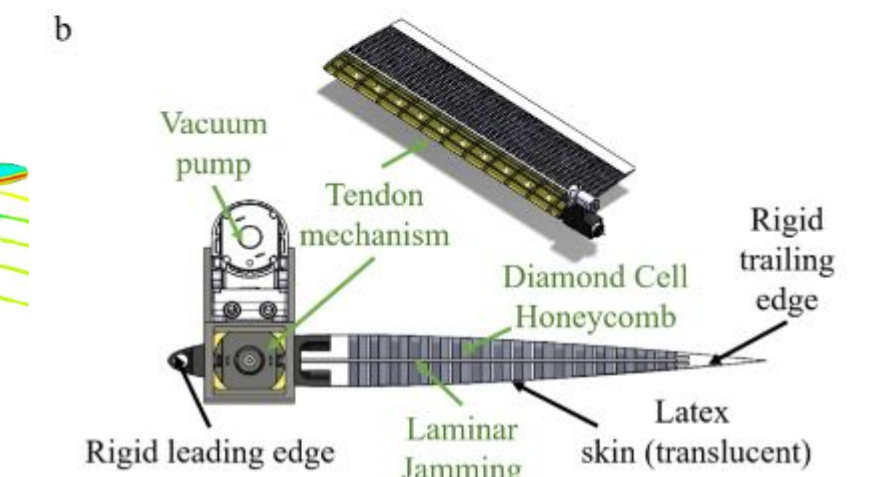
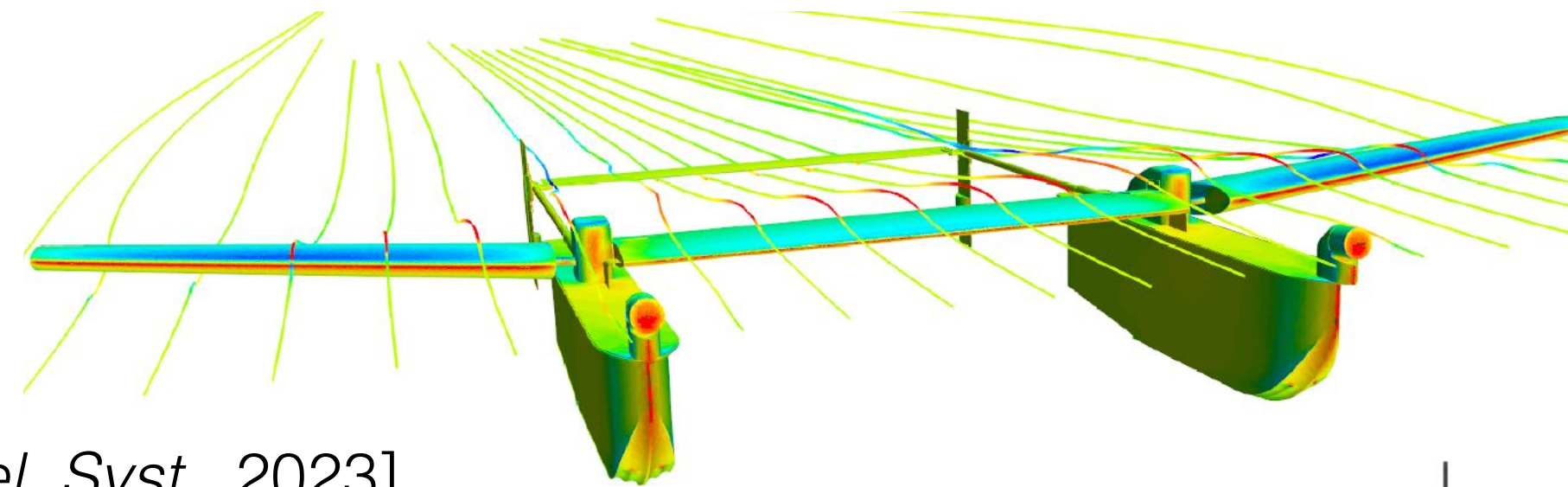
 Springer

Design



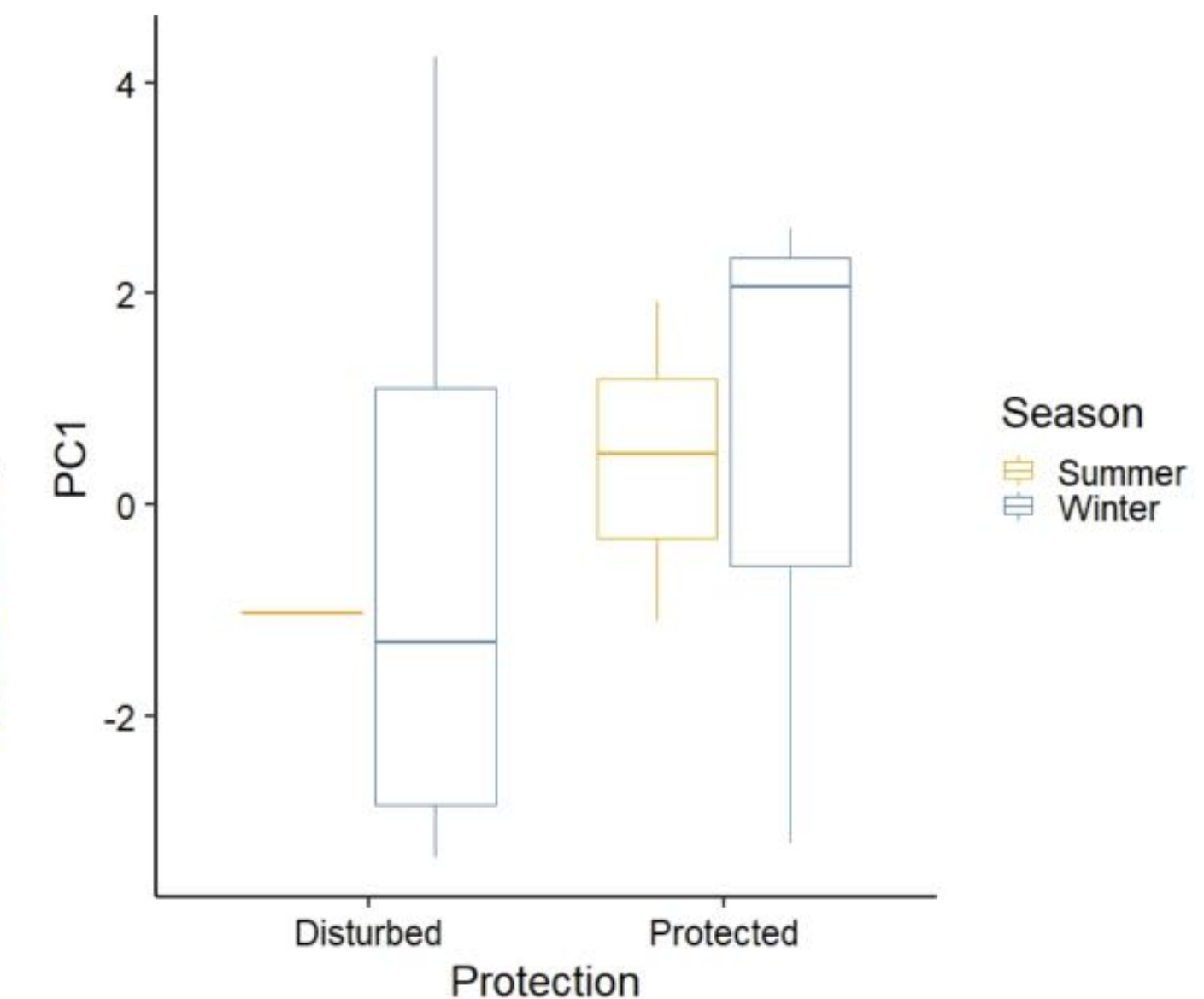
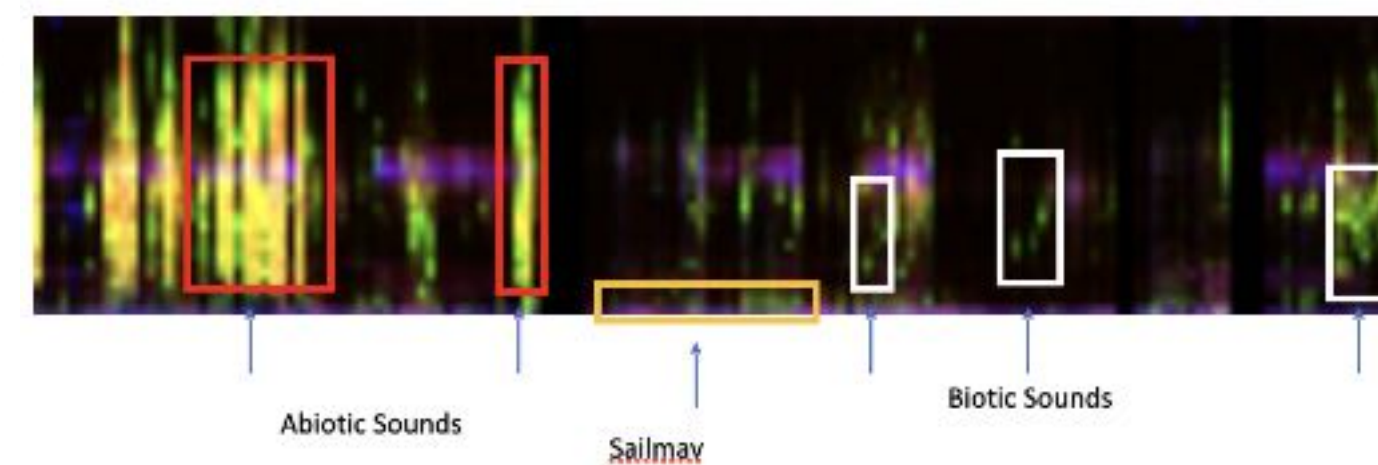
Testing

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



A photograph of a lake with a small boat in the foreground and a grassy hill in the background under a blue sky with clouds.

Soundscape Analysis



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

Proteus: Metamorphic sea god

118



Meta-morphic tri-modal mobility for robotics

119



Consolidator grant 2023-2028
(funded by SERI)

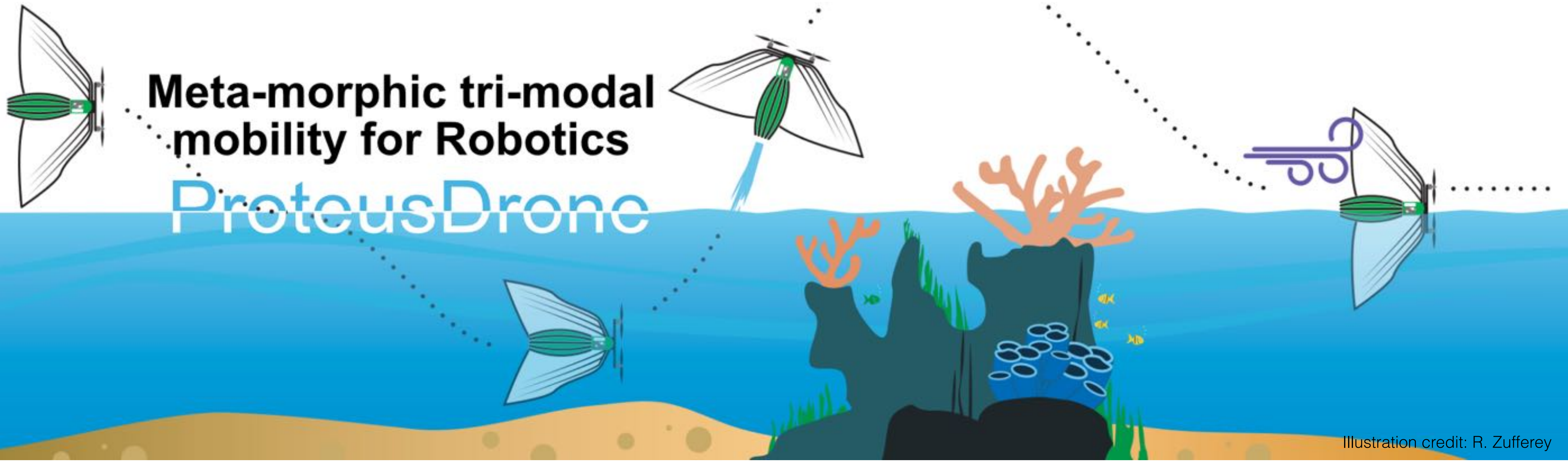
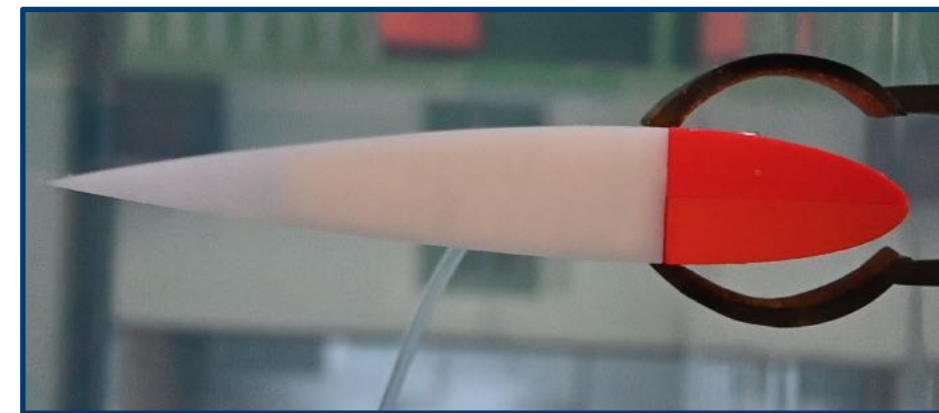
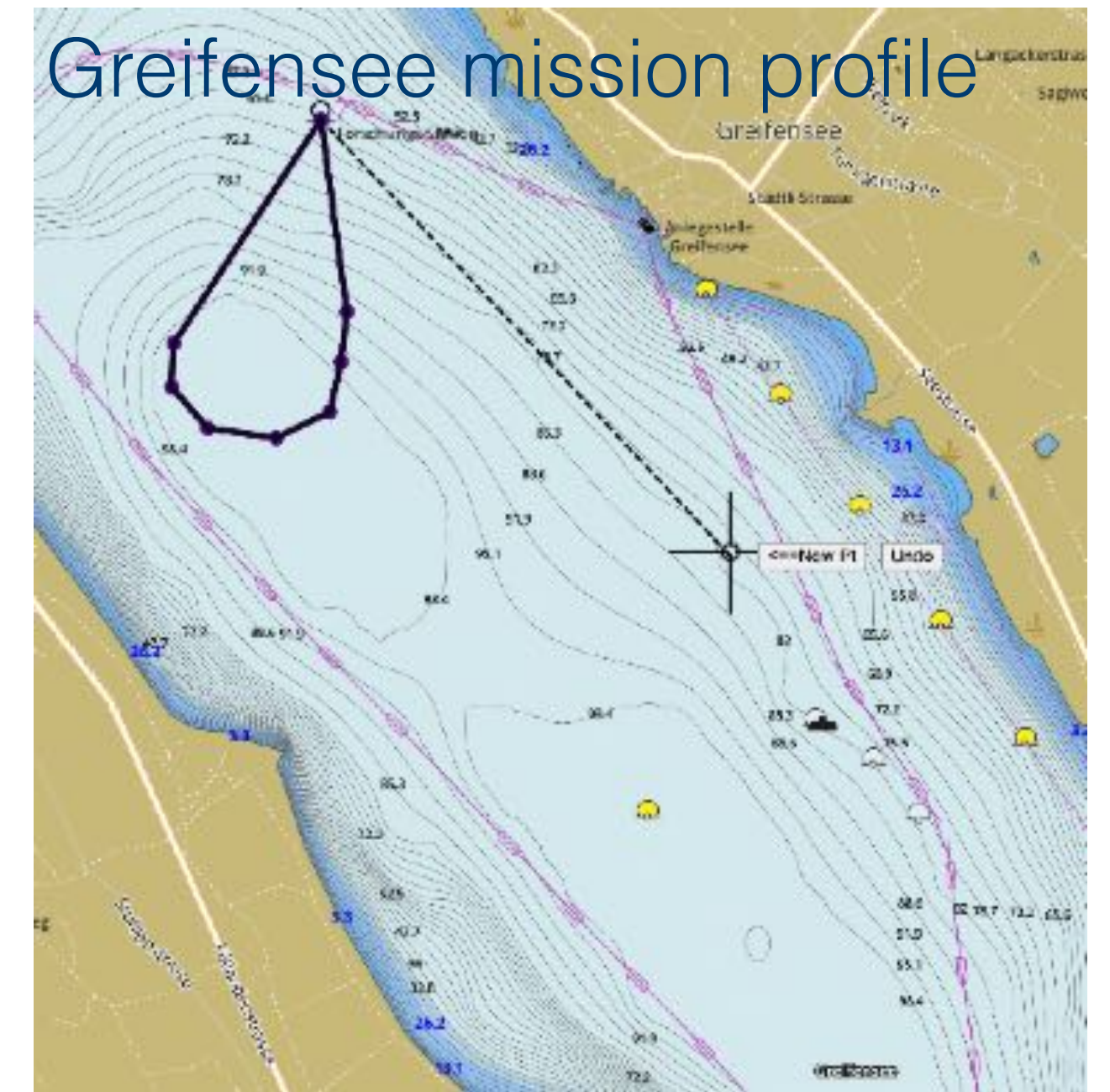


Illustration credit: R. Zufferey

ARIS - Nautilus

- Collaboration with ARIS (Academic Space Initiative Switzerland)
- 20 active contributors, 3 MSc projects
- Development of an Unmanned Underwater Vehicle (Glider) for Planetary Exploration of Icy Moons
- Validation in Greifensee & Aletsch-glacier lake planned



Pixhawk & Raspberry Pi

Battery Pack

Sensor Bay

Direction of Travel

Attitude Control Unit

Soft Wing Control Unit

Hard Wings

Buoyancy Control Unit

Sonar



ETH zürich

eawag
aquatic research

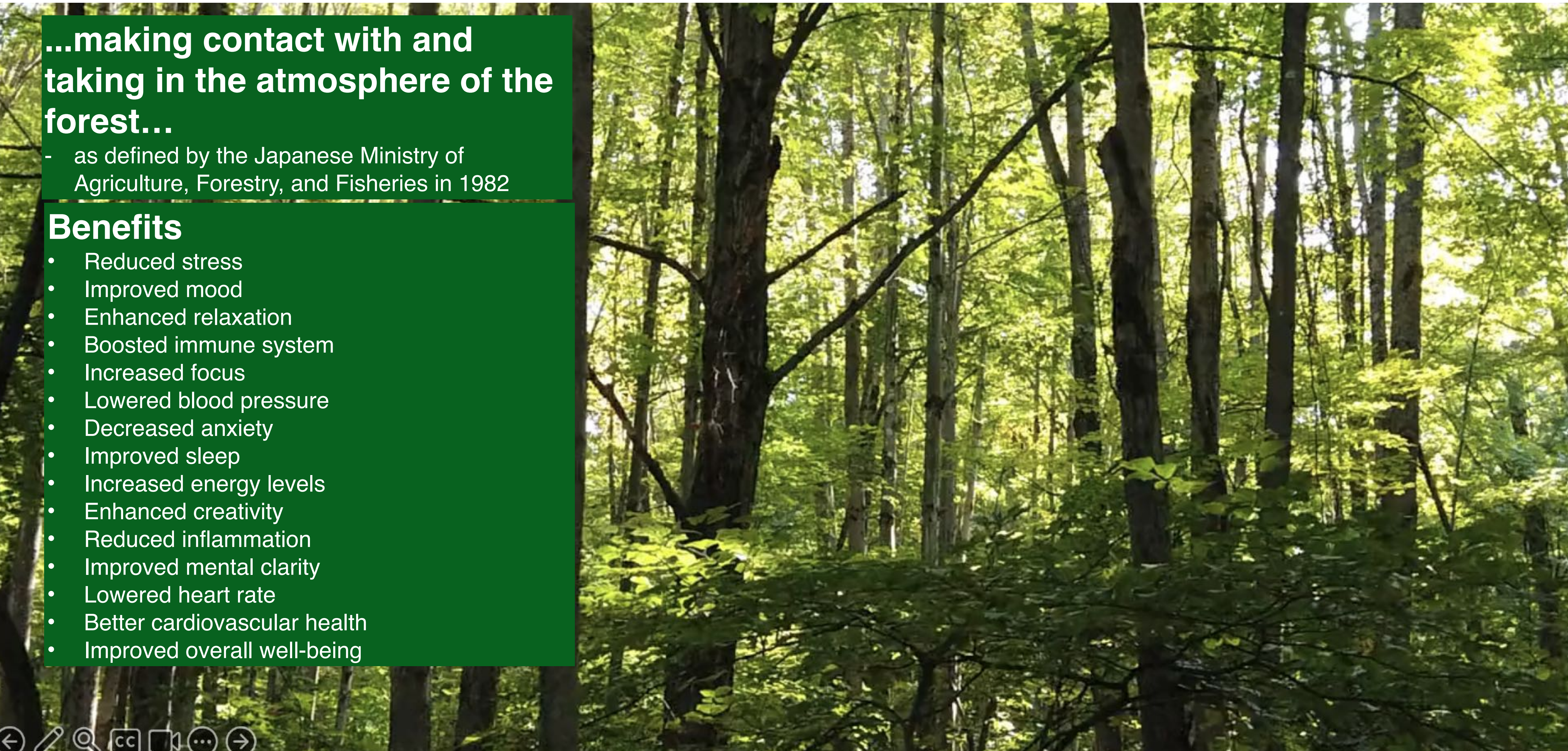
Shinrin-yoku (森林浴) – Forest Bathing

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

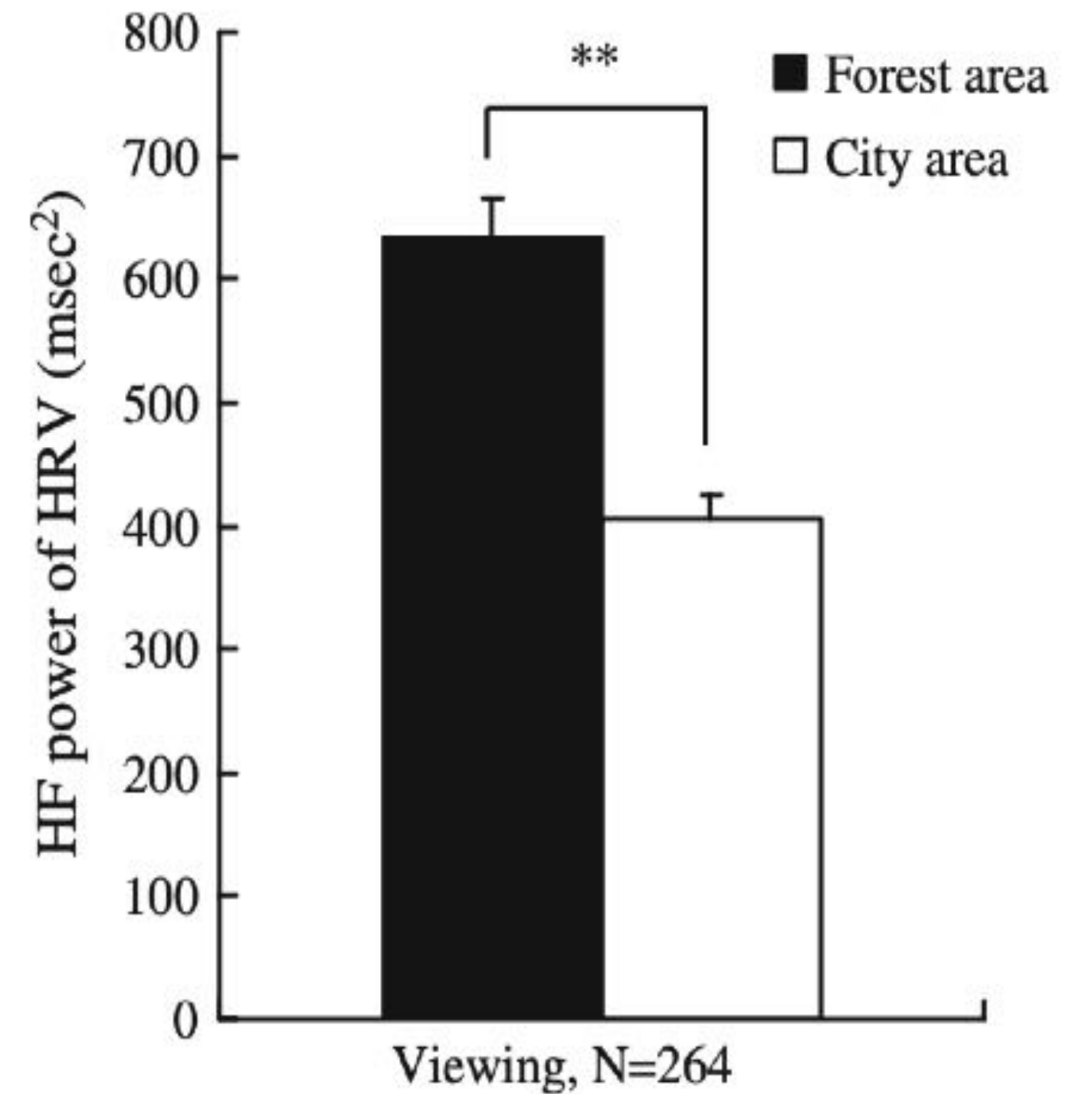
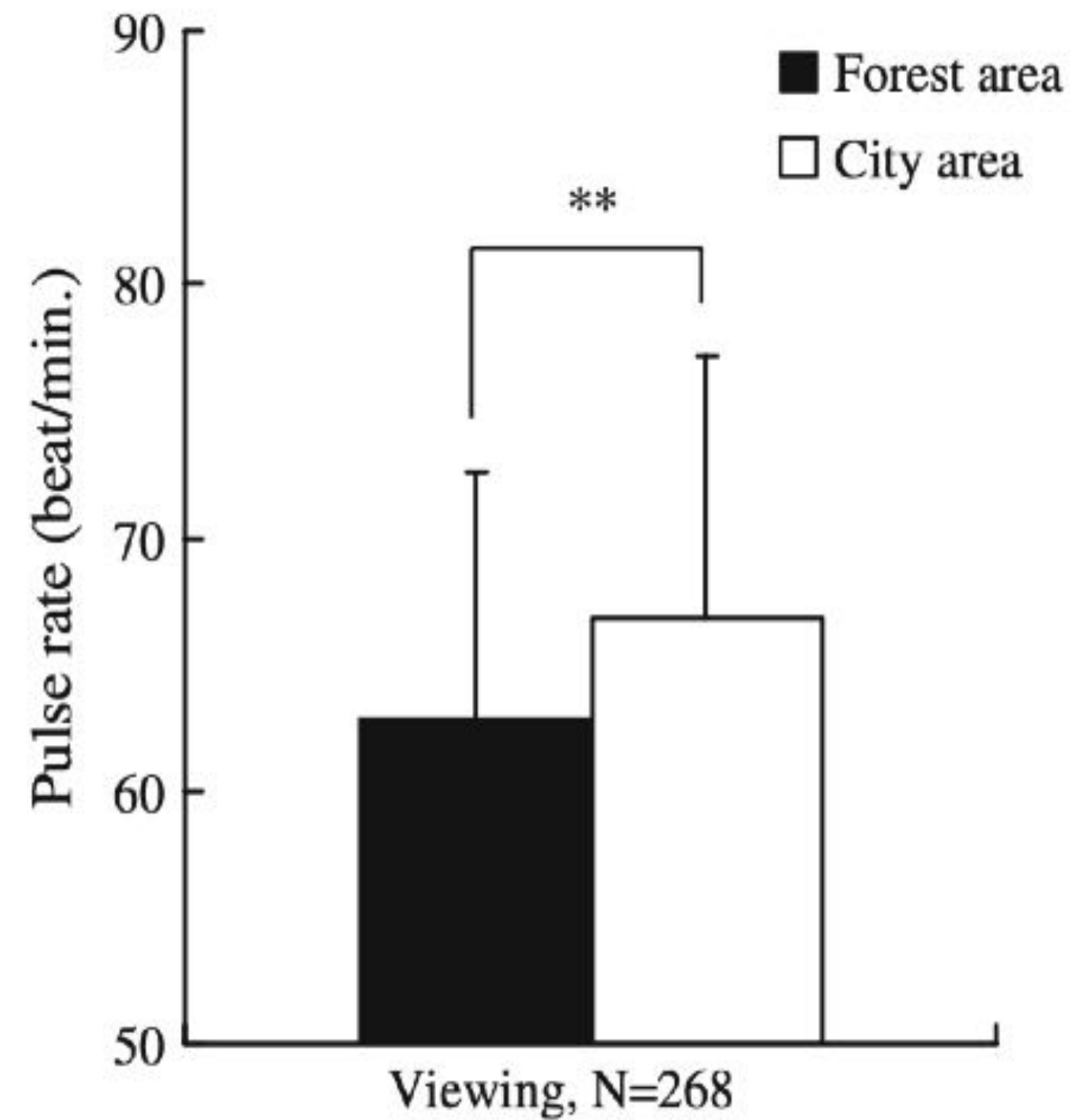
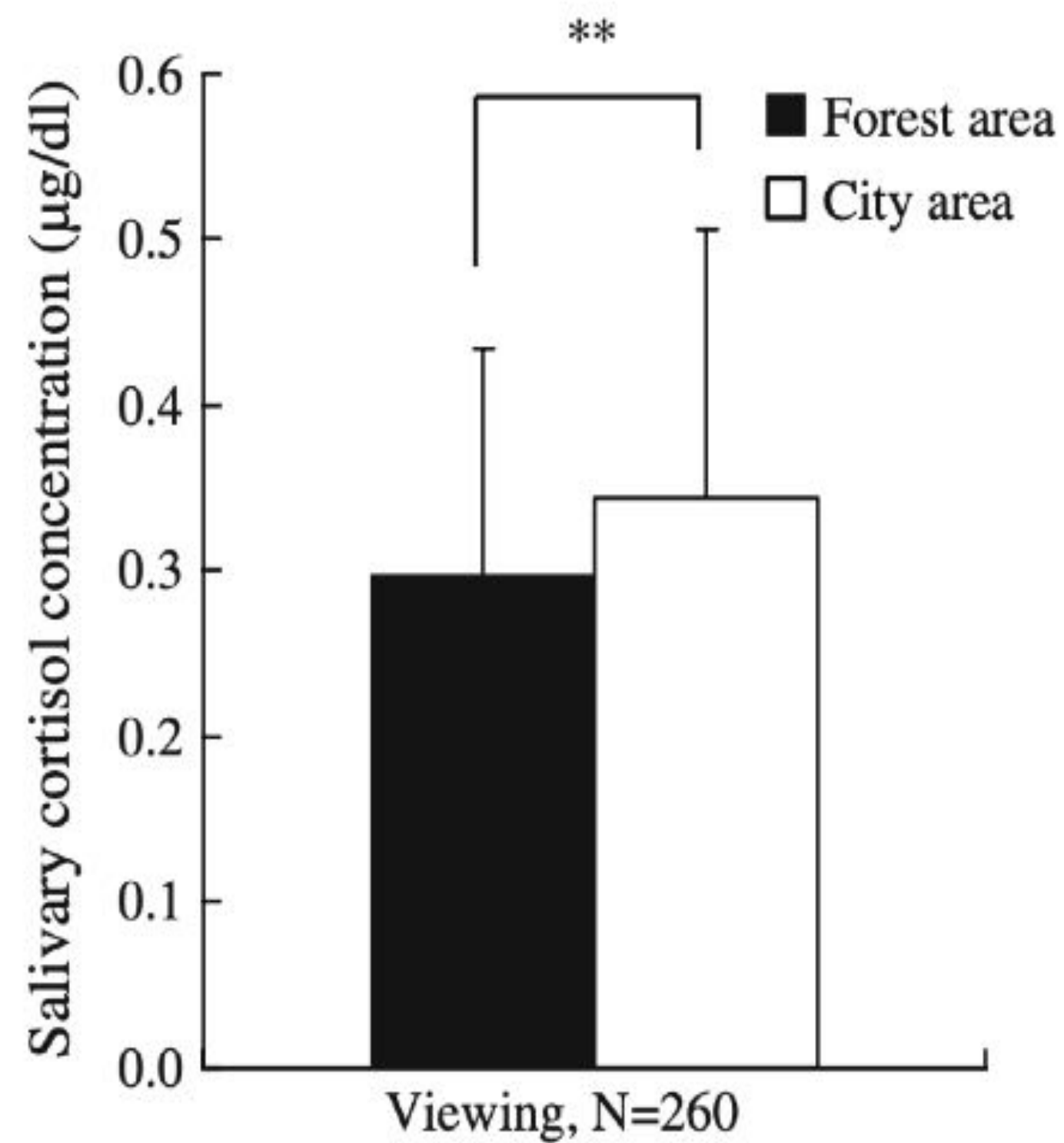
- as defined by the Japanese Ministry of Agriculture, Forestry, and Fisheries in 1982

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

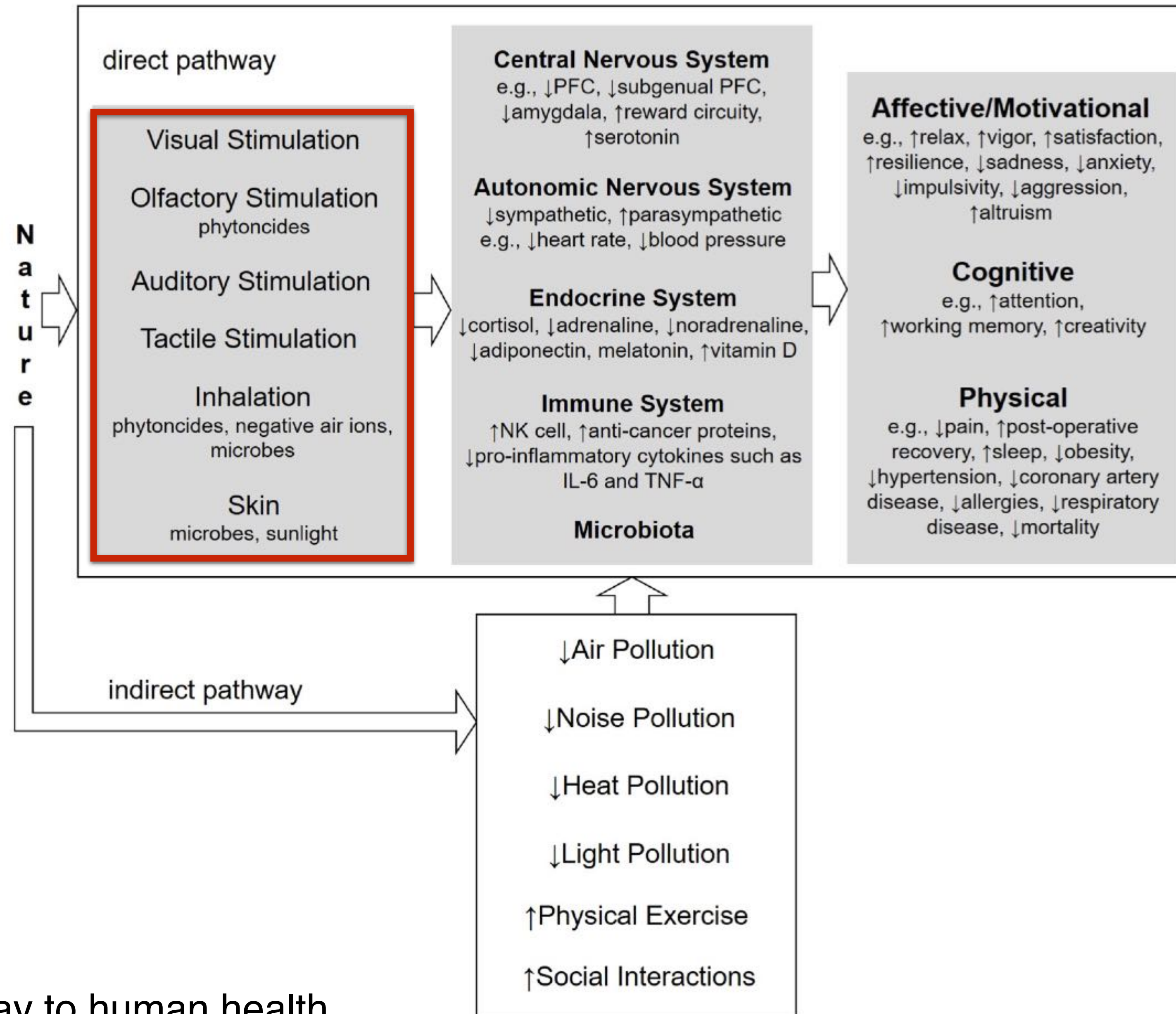


Shinrin-yoku – Health Benefits



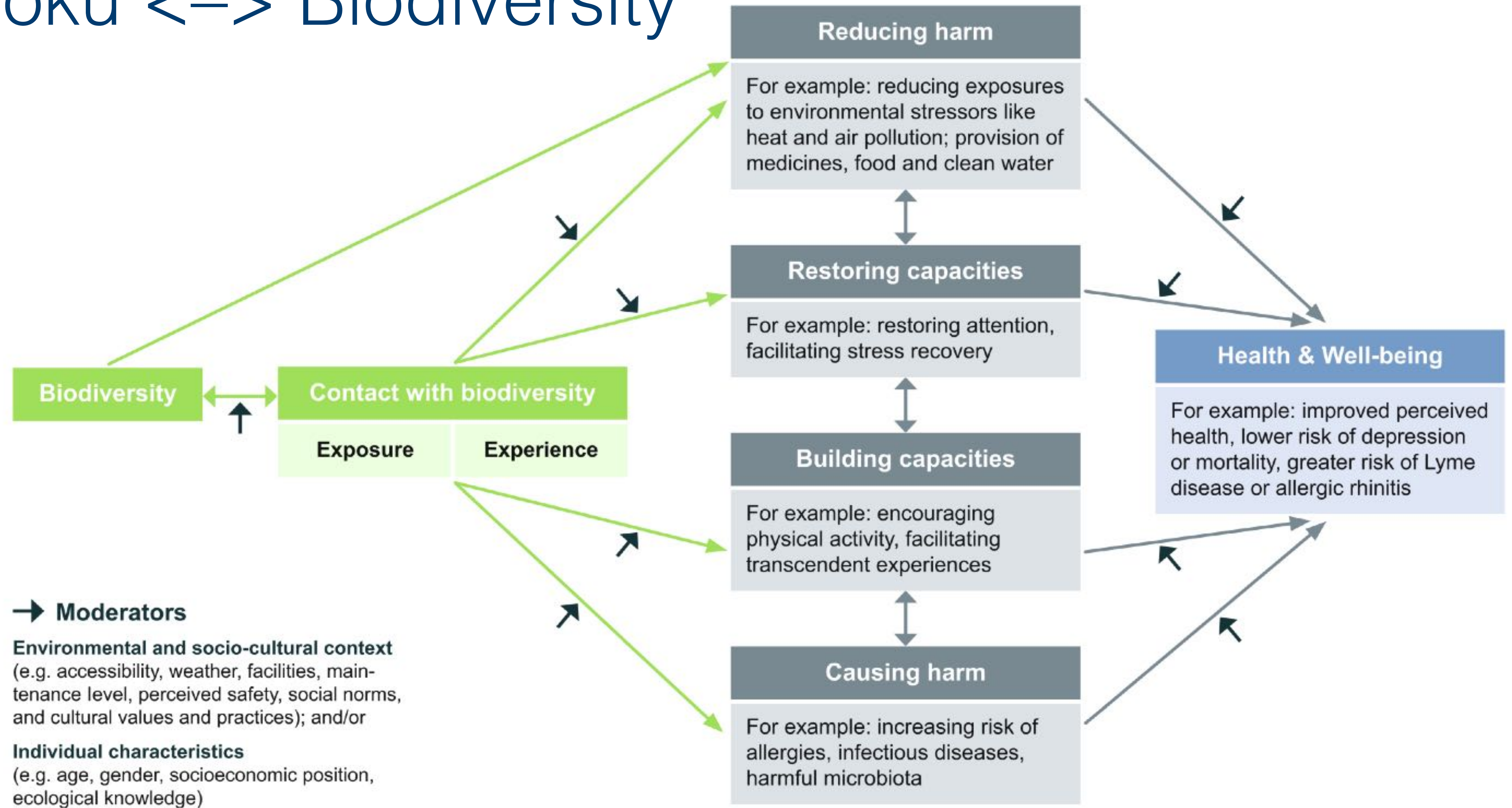
Bum Jin Park, Yuko Tsunetsugu, Tamami Kasetani, Takahide Kagawa, Yoshifumi Miyazaki ***Environ Health Prev Med*** (2010)

Shinrin-yoku



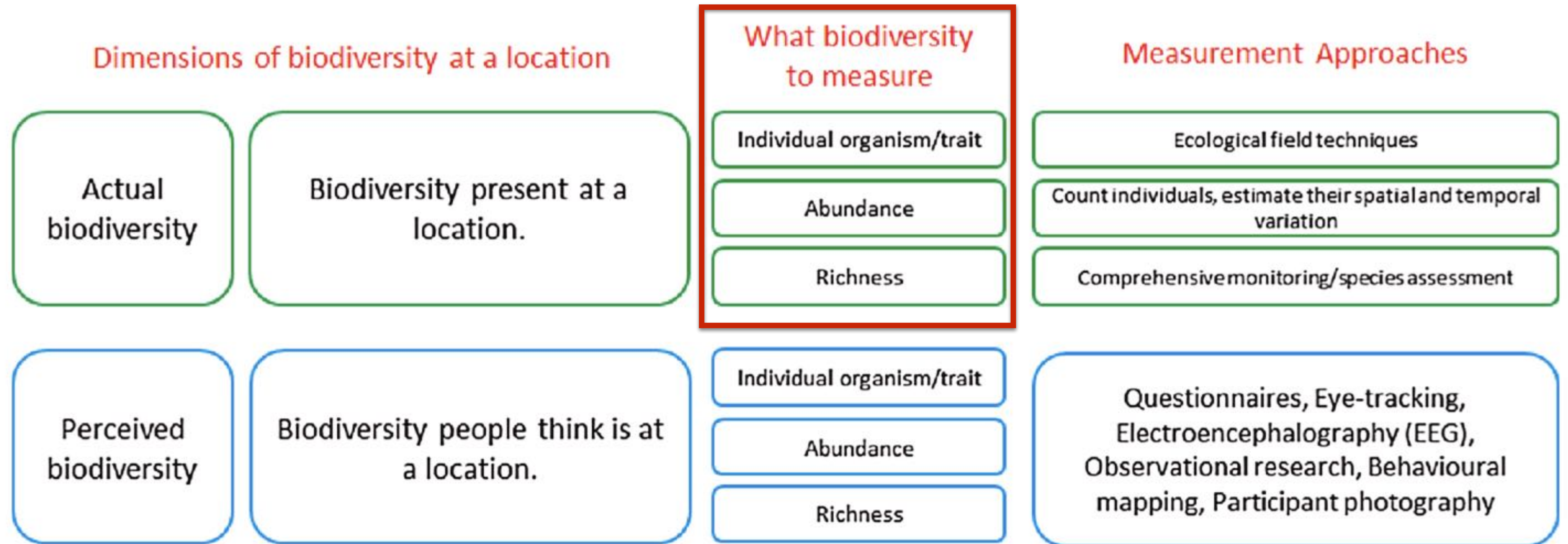
Chen et al. Nature's pathway to human health
International Handbook of Forest Therapy (2019)

Shinrin-yoku <—> 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)

DroneHub

Empowering aerial innovation
for a sustainable future

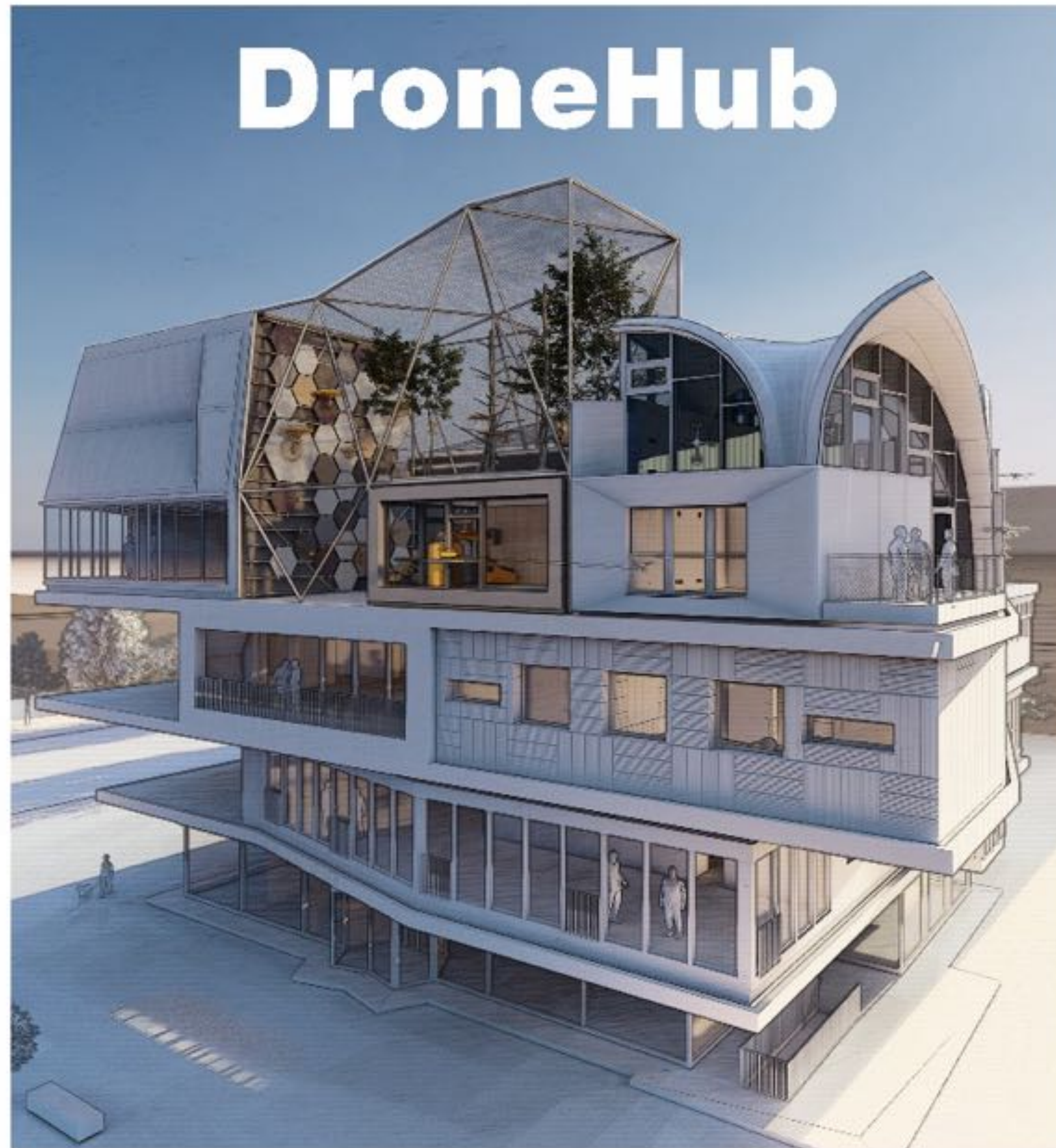


Prof. Mirko Kovač
Aerial Robotics Laboratory at Imperial College London
Sustainability Robotics at Empa Material Science

Empa | **Imperial College
London**



30



Indoor Facilities

Gap for a transitional research facility

Outdoor Facilities

Drone Hub

Building-drone interface for integrated living



Infrastructure Robotics Facade

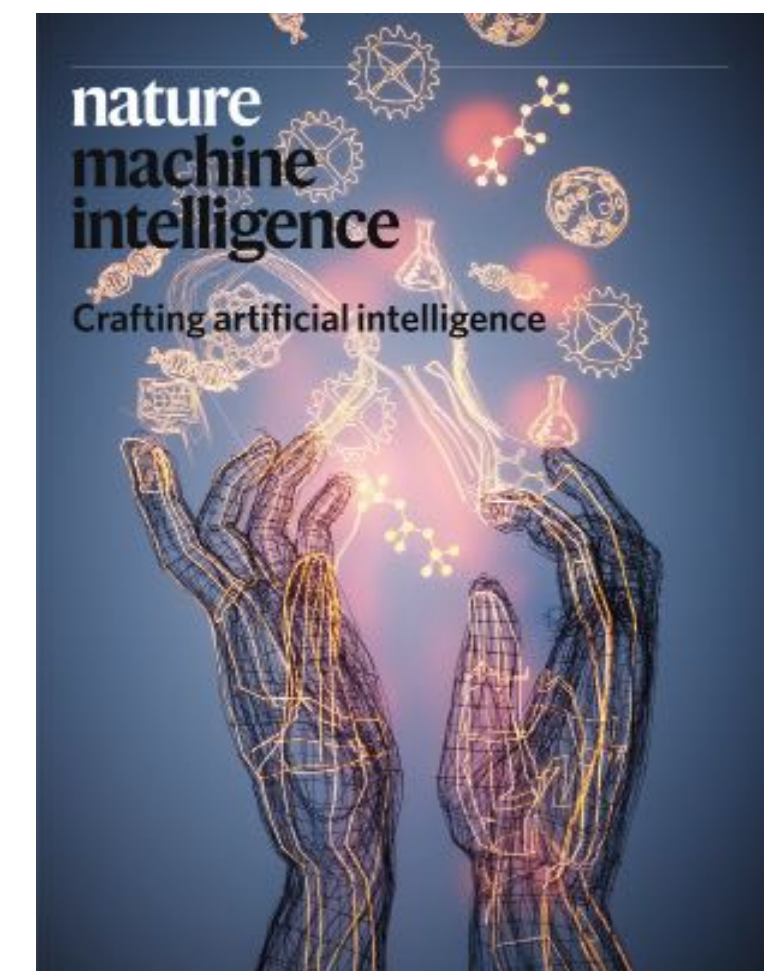
- Building interface for logistics
- Drone based Non Destructive Evaluation
- Autonomous recharging



Empa | Imperial College
London

Biosphere for environmental sensing

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



Aerial Additive Manufacturing

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



Infrastructure Drones Testbed @ Empa



The 1000m³ flight arena universal drone testbeds

Infrastructure Drones Testbed @ Empa

Wind blade tip (7m)



Wind blade base (6m)



Bridge element (8m)



Water tunnels



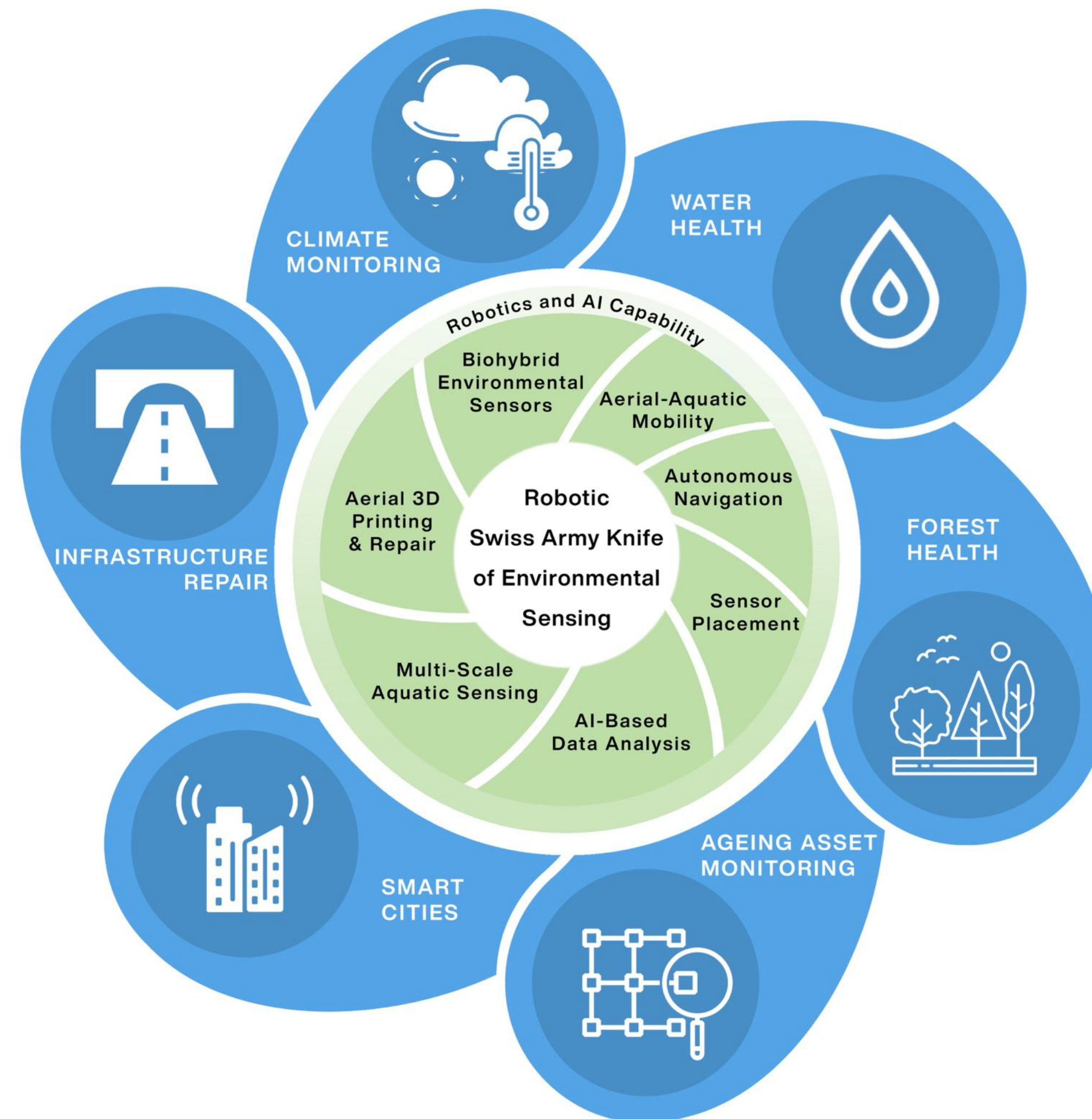
Mission statement

Novel Robotics and AI technologies to measure and modify environments and deliver sustainable outcomes



Mission statement

Novel Robotics and AI technologies to measure and modify environments and deliver sustainable outcomes



2005

2010

2012

2019

2024

Diploma (BSc/MSc)

PhD

Post Doc

Full Professor

ETH Zürich


ÉCOLE POLYTECHNIQUE

FÉDÉRALE DE LAUSANNE

HARVARD

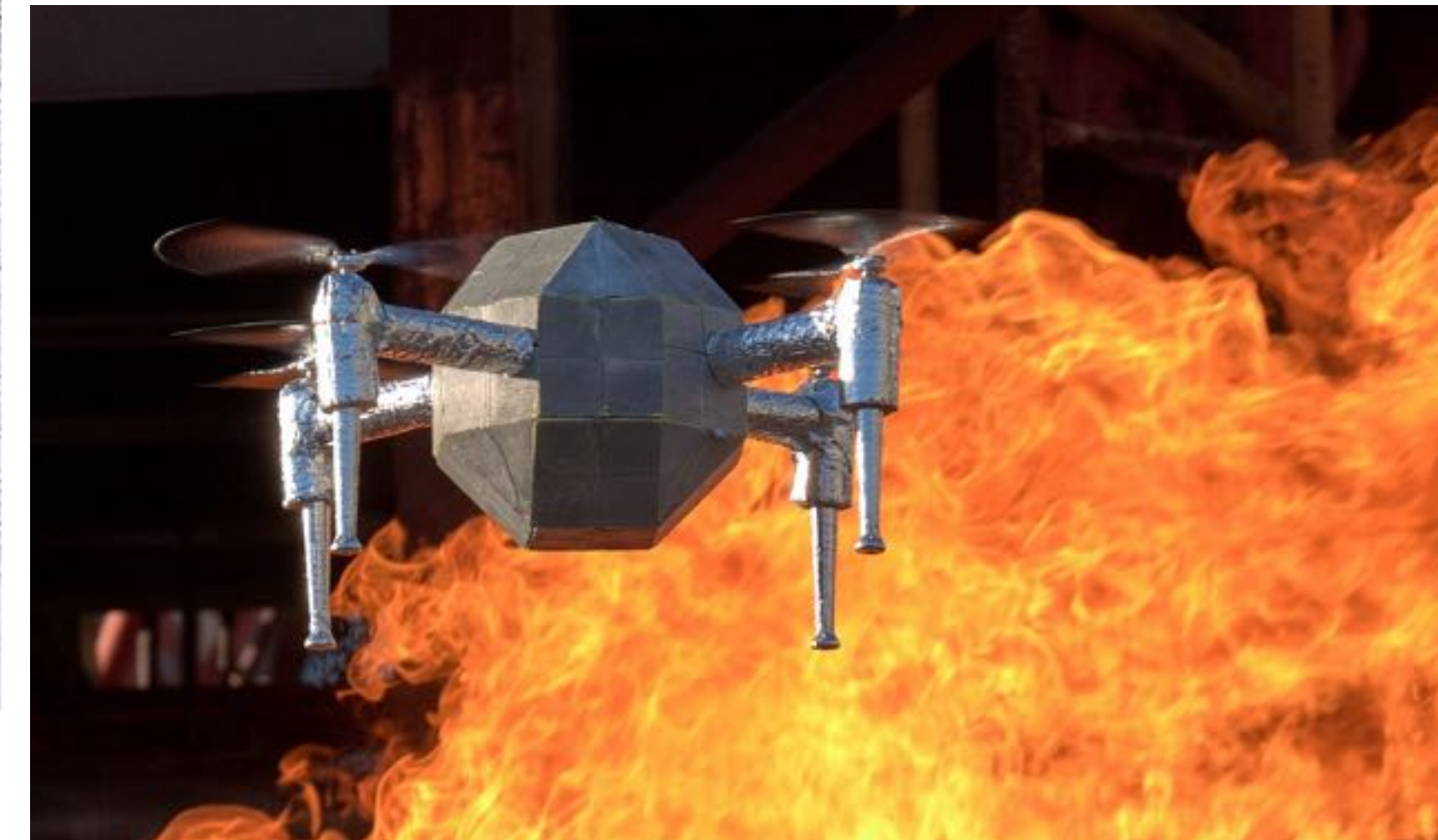
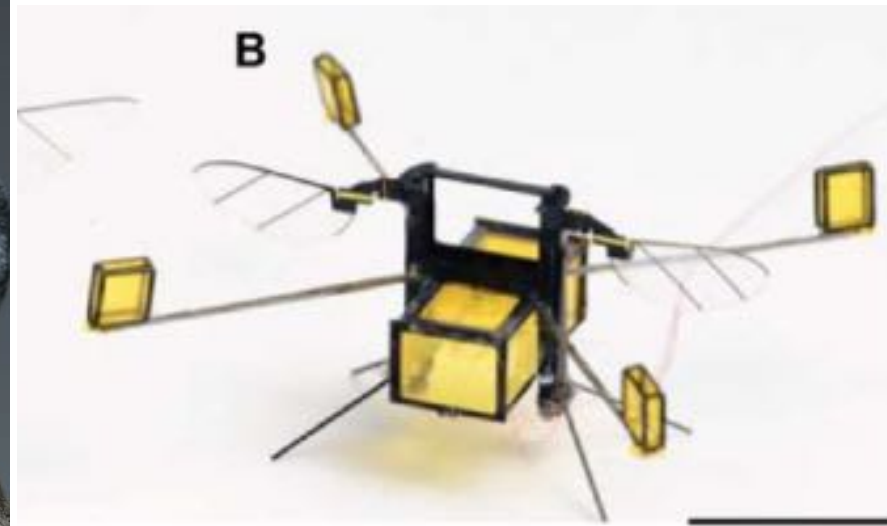
UNIVERSITY

Imperial College

London

Lab Head


Empa

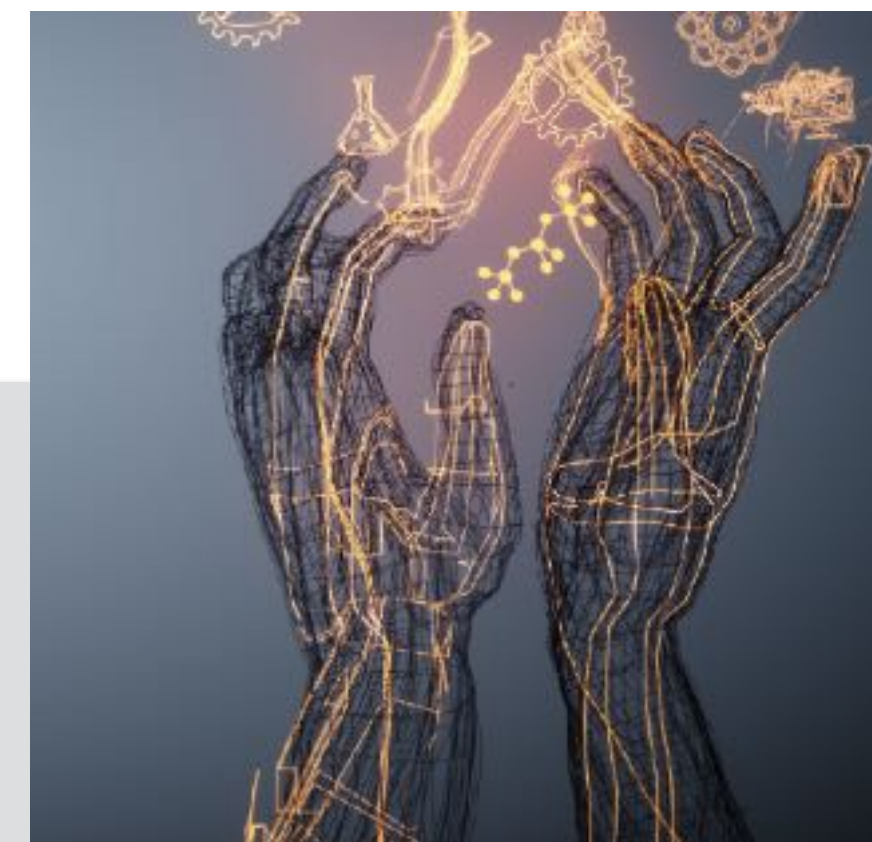
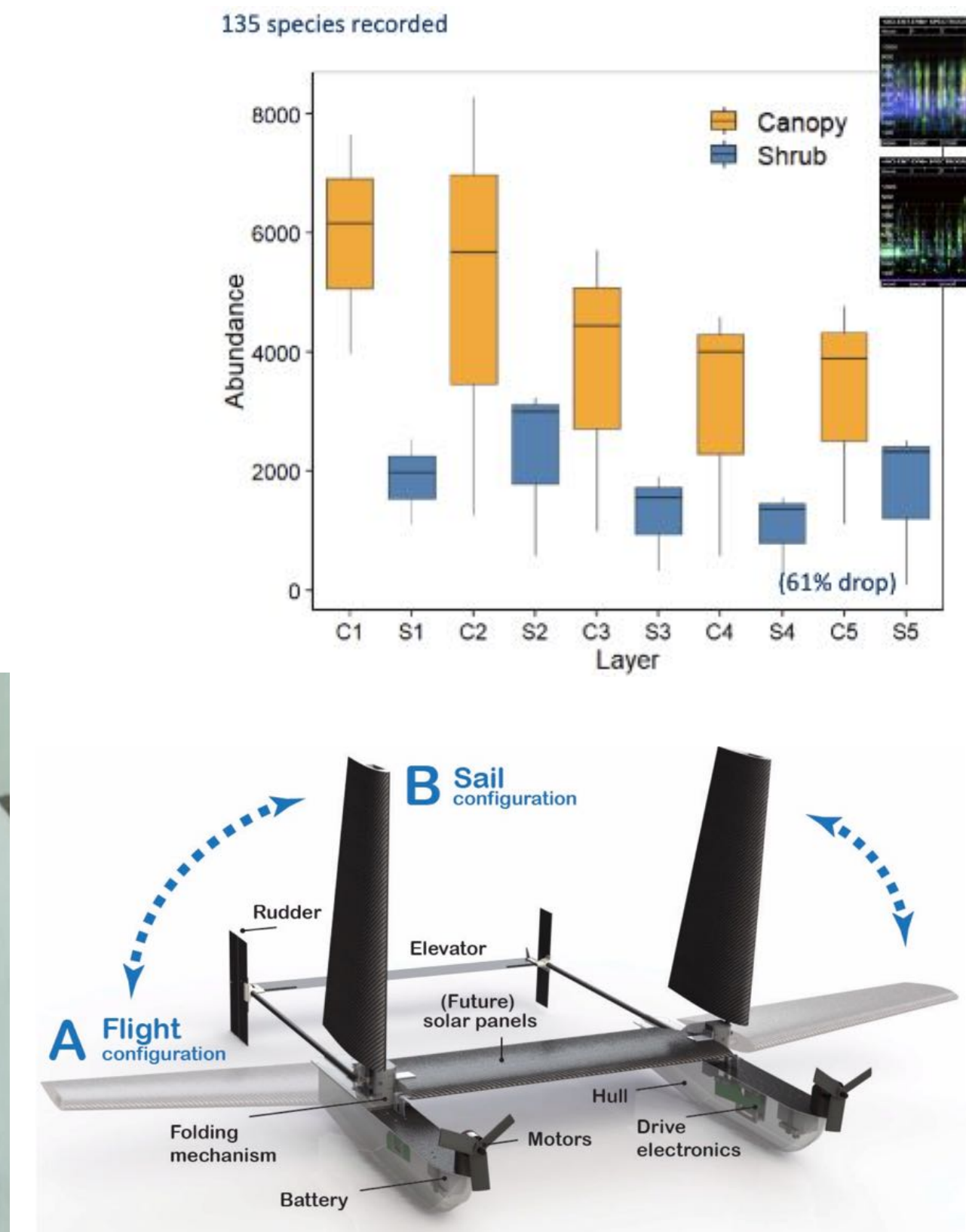
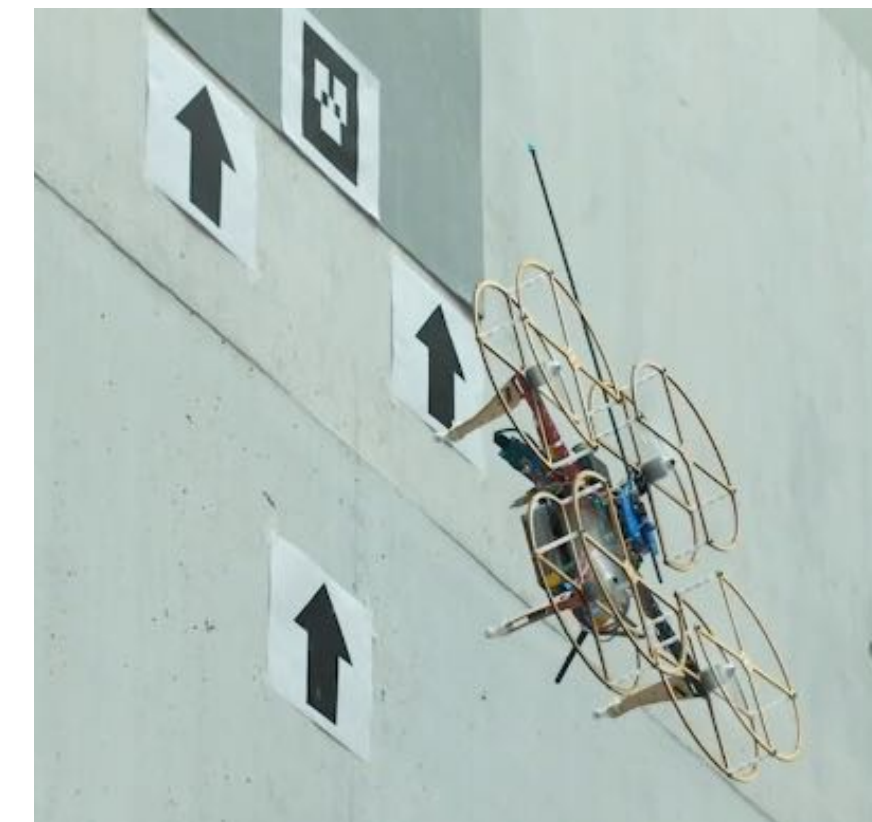
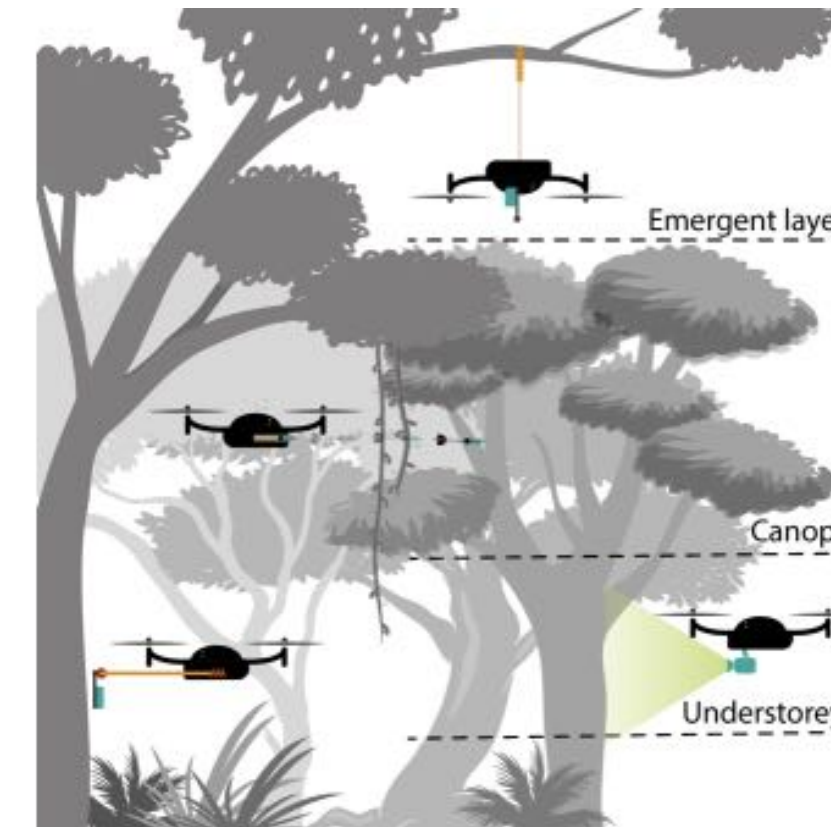
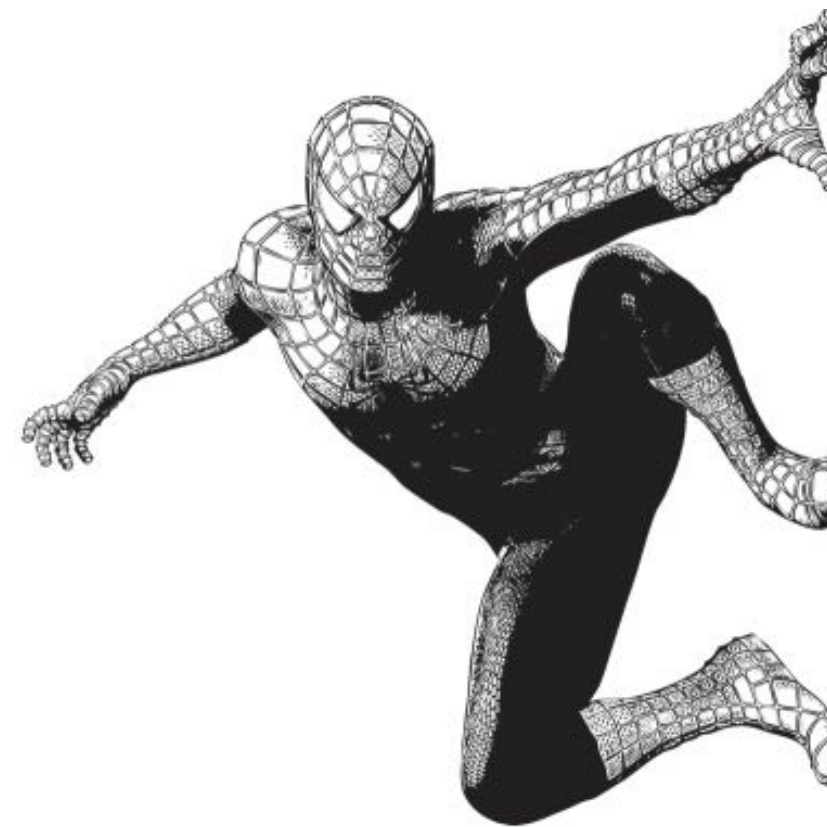
Materials Science and Technology
 
ETH DOMAIN
EPFL


Multi-modal platform development. From Nature to Robotics and Back

Sustainability Robotics

138

- ✓ Autonomous drones can quantify biodiversity
- ✓ Bio-inspired methods can increase robustness and multi-terrain capabilities
- ✓ Meta-morphosis can increase functionality
- ✓ Physical AI: Co-eveolution of disciplines for lifelike robots
- ✓ DroneHub: Physical AI testbeds for future robotics
- ✓ Sustainability Robotics - join us!



Prof. Mirko Kovac
Aerial Robotics Laboratory at Imperial College London
Sustainability Robotics Laboratory at Empa - EPFL

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.

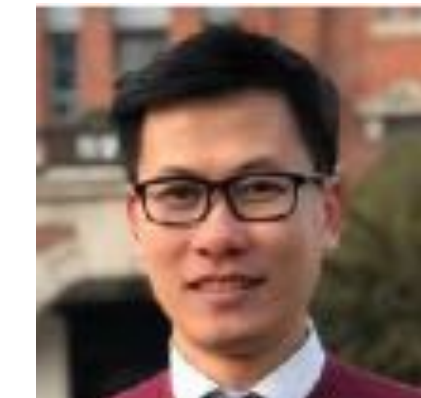
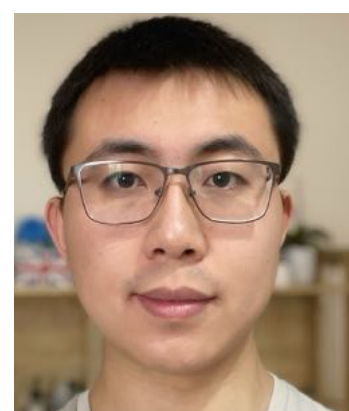
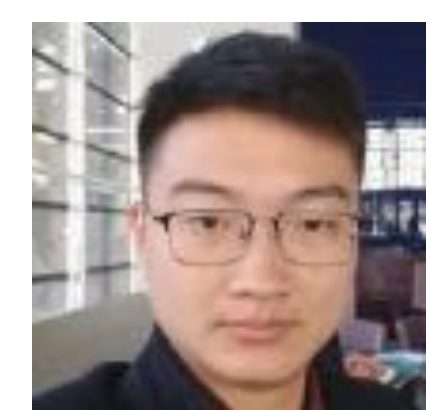
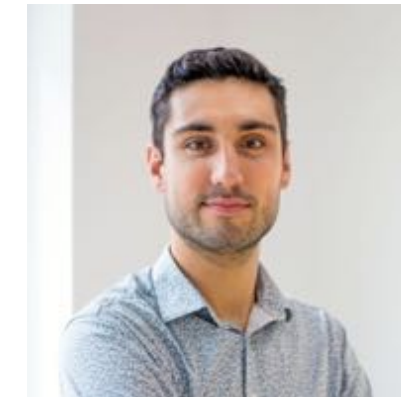
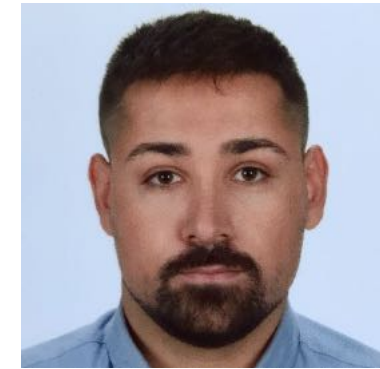
npj Robotics aims at stimulating the publication of research that adopts a **holistic stance**, taking the physical nature of robots and their relation and interaction with the world as a departure point.

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

12 years celebration @ Imperial College London & Empa



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LAB
ALUMNI

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Salua Hamaza, Asst.Prof. Delft University
Sophie Armanini, Asst.Prof. TU Munich / Imperial
Pooya Sareh, Asst.Prof.(Lecturer) U. Liverpool
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