Sustainability Robotics

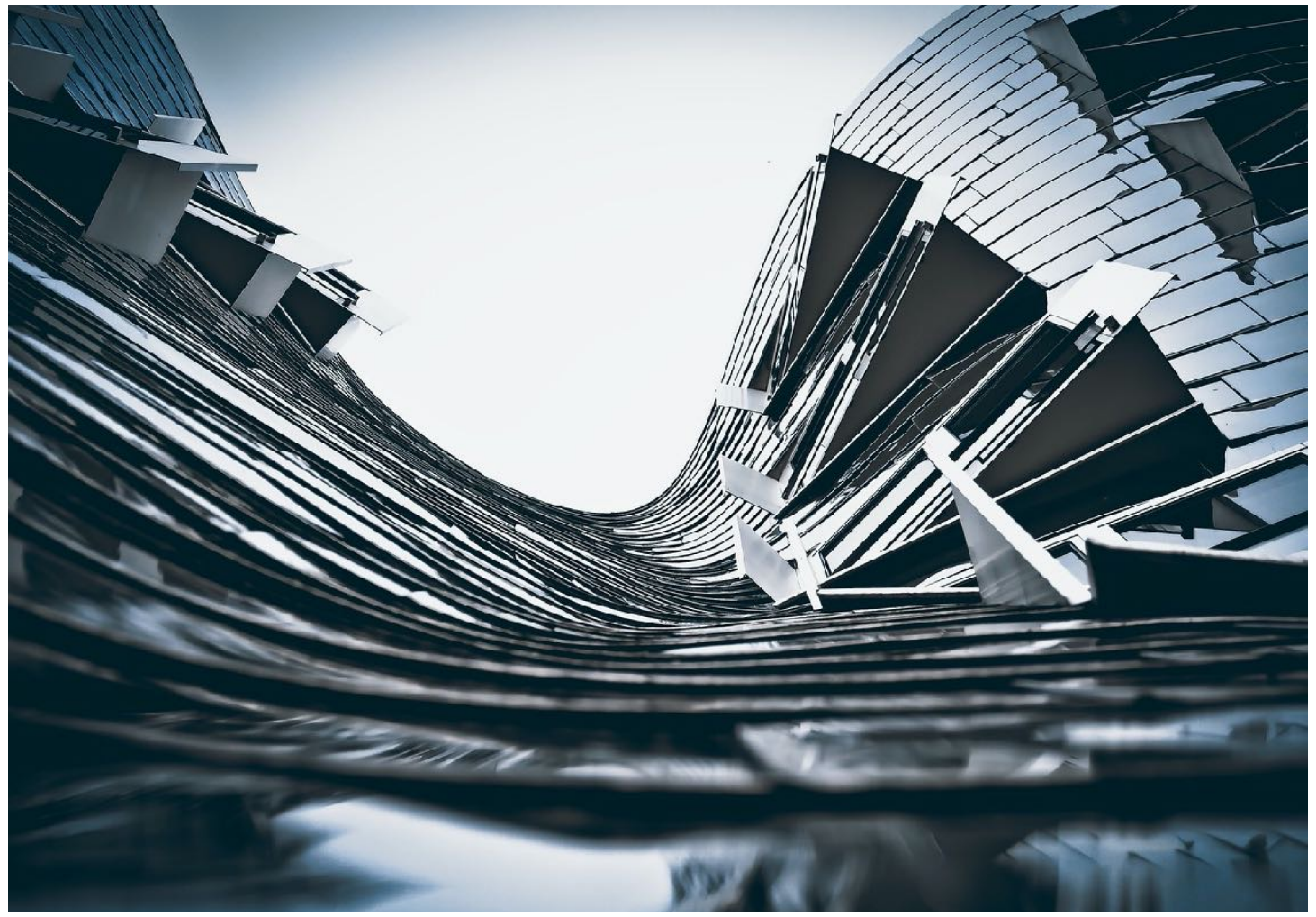
Prof. Mirko Kovac
Aerial Robotics Laboratory at Imperial College London
Laboratory of Sustainability Robotics at Empa Material Science

Drones for digitalisation

Built environment

Off-shore infrastructure

Ecology



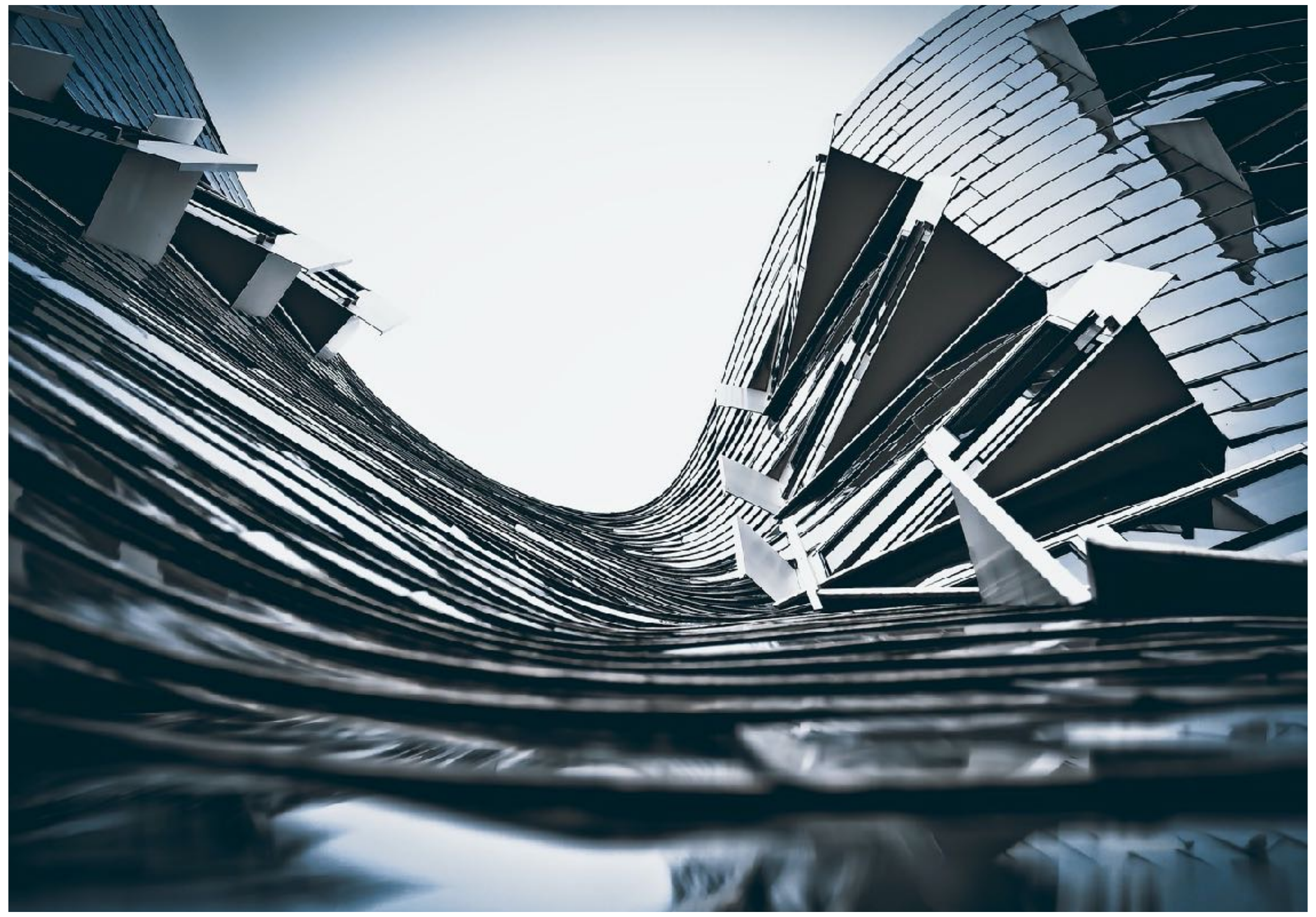
Construction

Mining/tunnel infrastructure

Polar regions

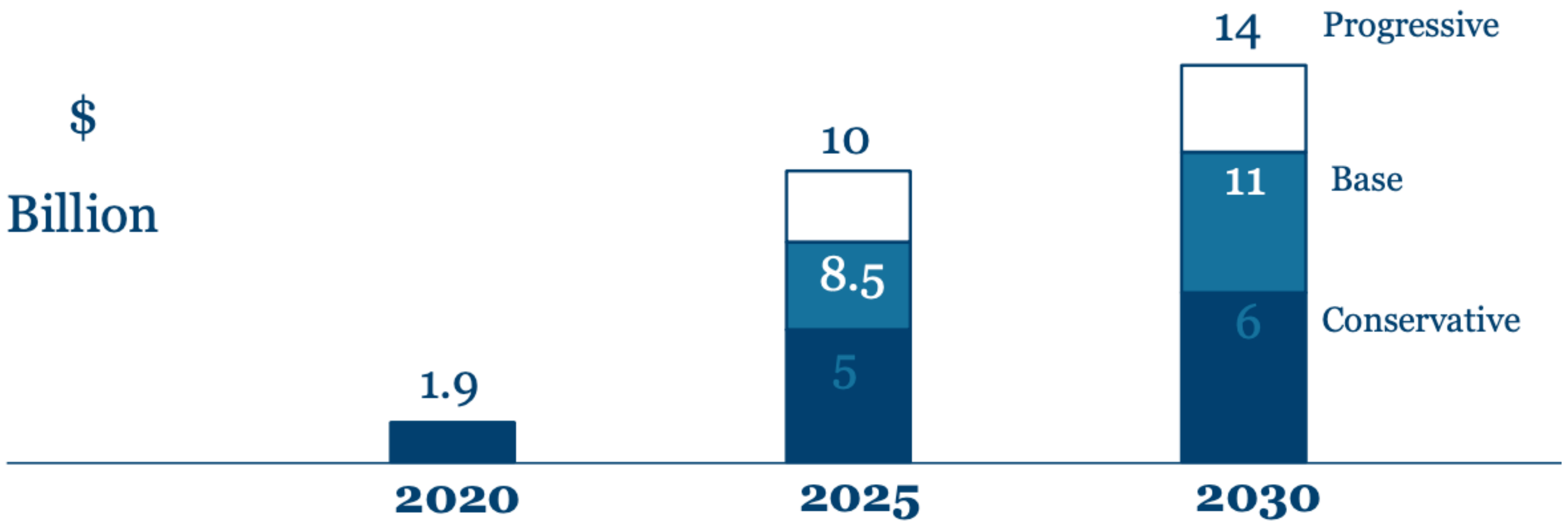
Drones for digitalisation

Built environment

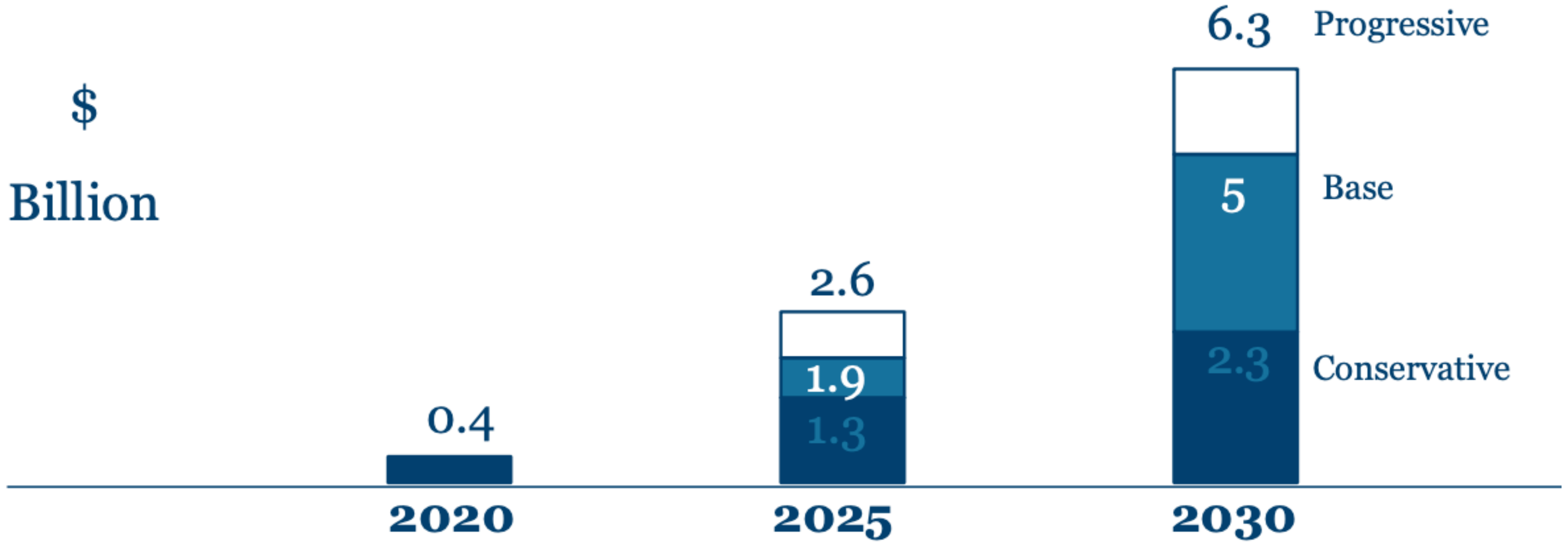


Construction

Market Size

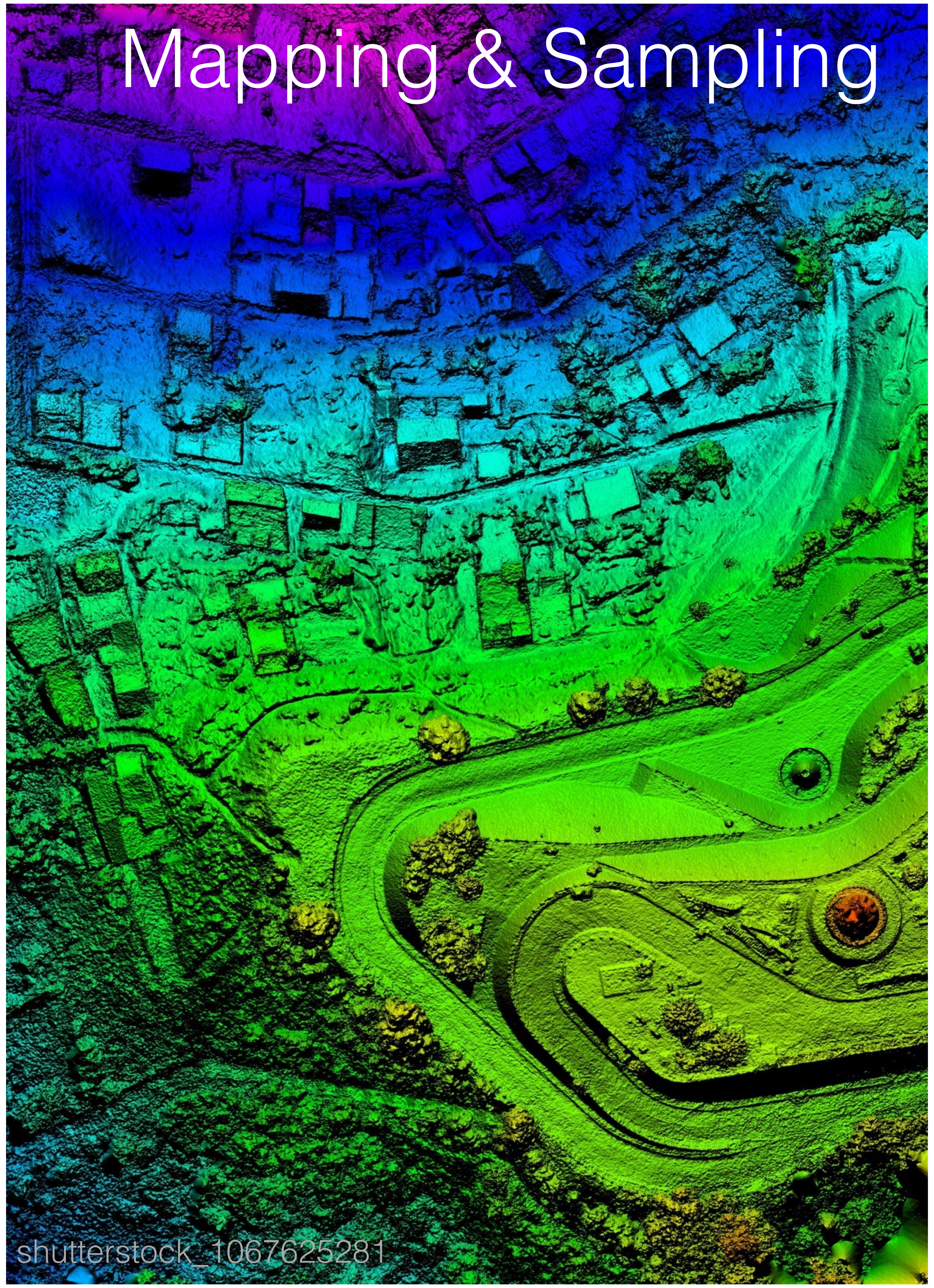


Market Size



Source: Levitate Capital White Paper Dec. 2020

Drone based value chain - today



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Mission statement

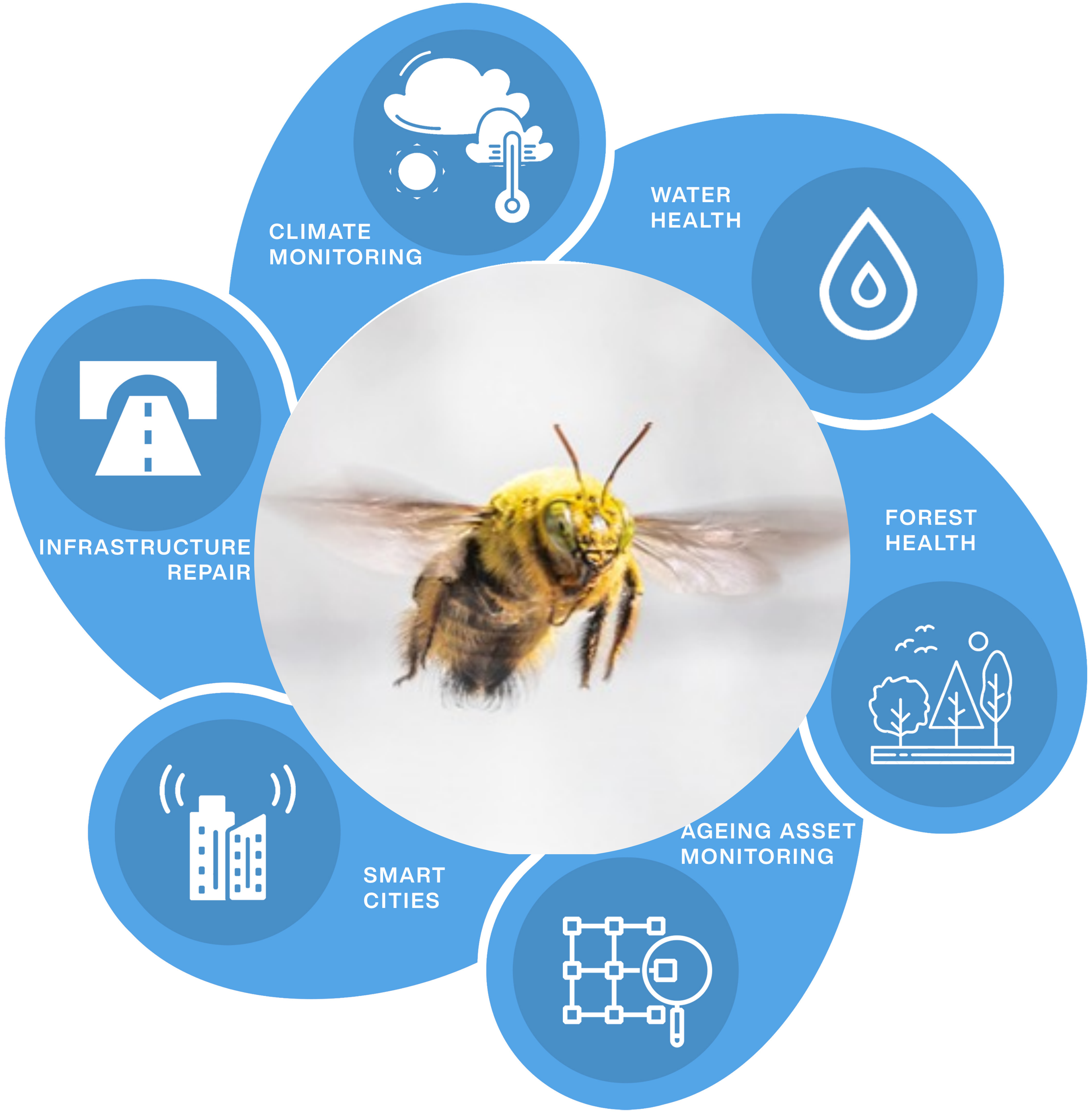
Novel Robotics and AI technologies to measure and modify environments to deliver sustainable outcomes

Mission statement

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

Hypothesis

Lifelike robots can provide data at lower cost, lower risk and higher sustainability compared to established methods of environmental sensing.



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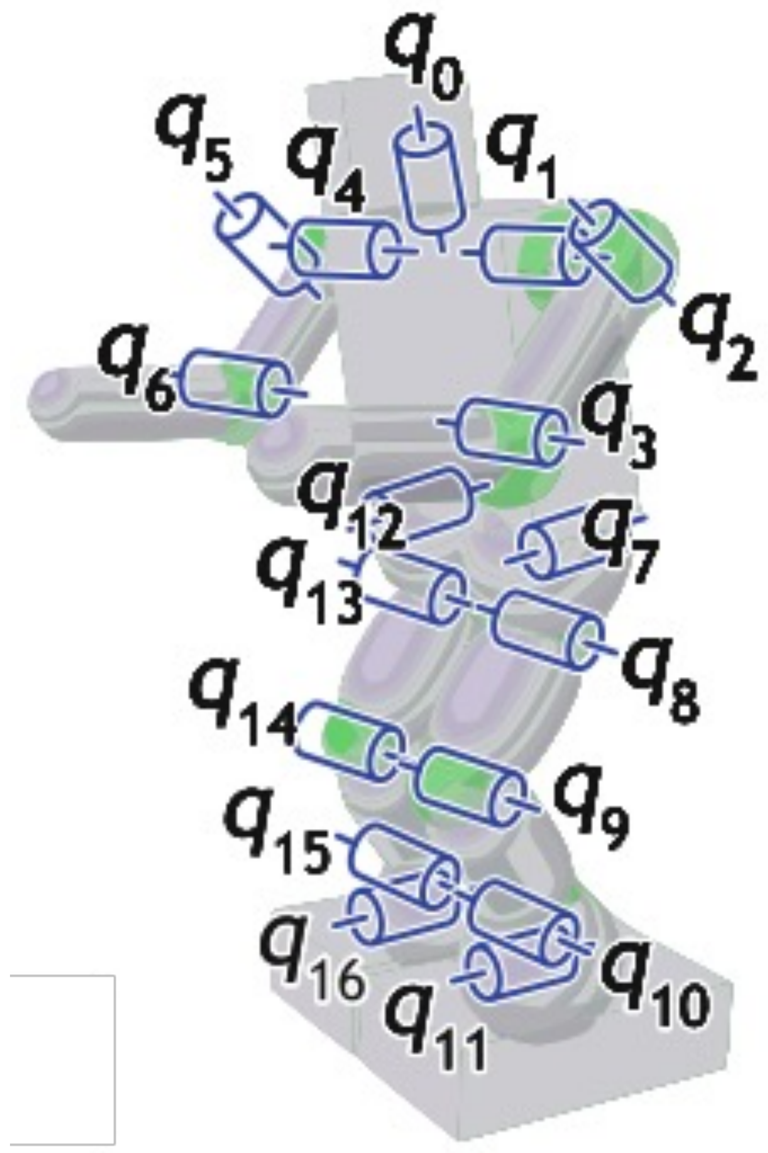
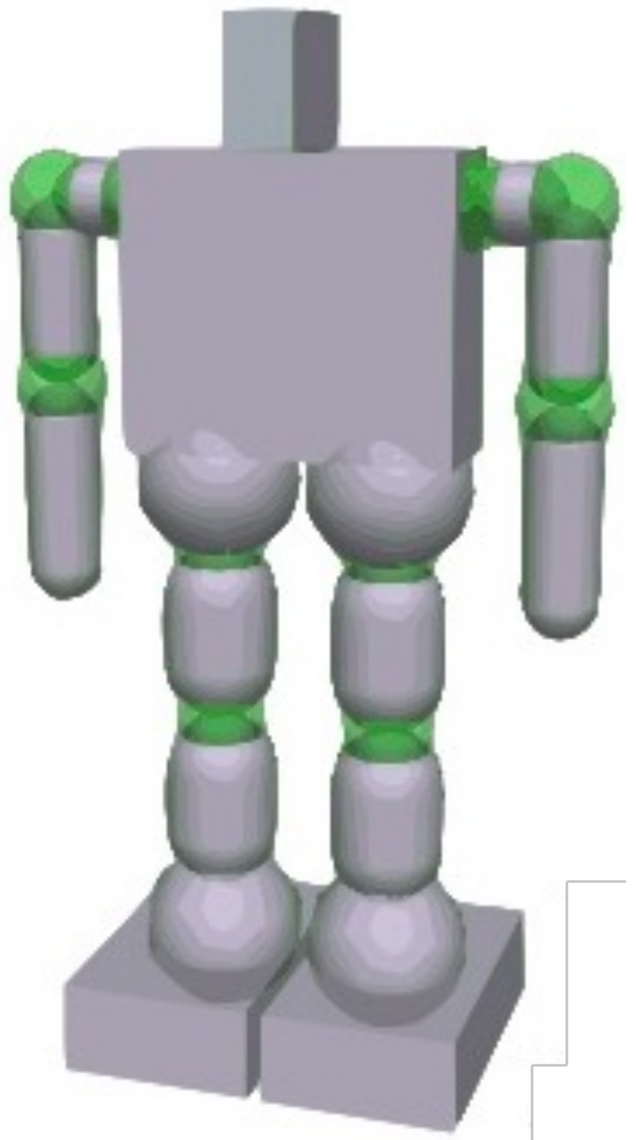
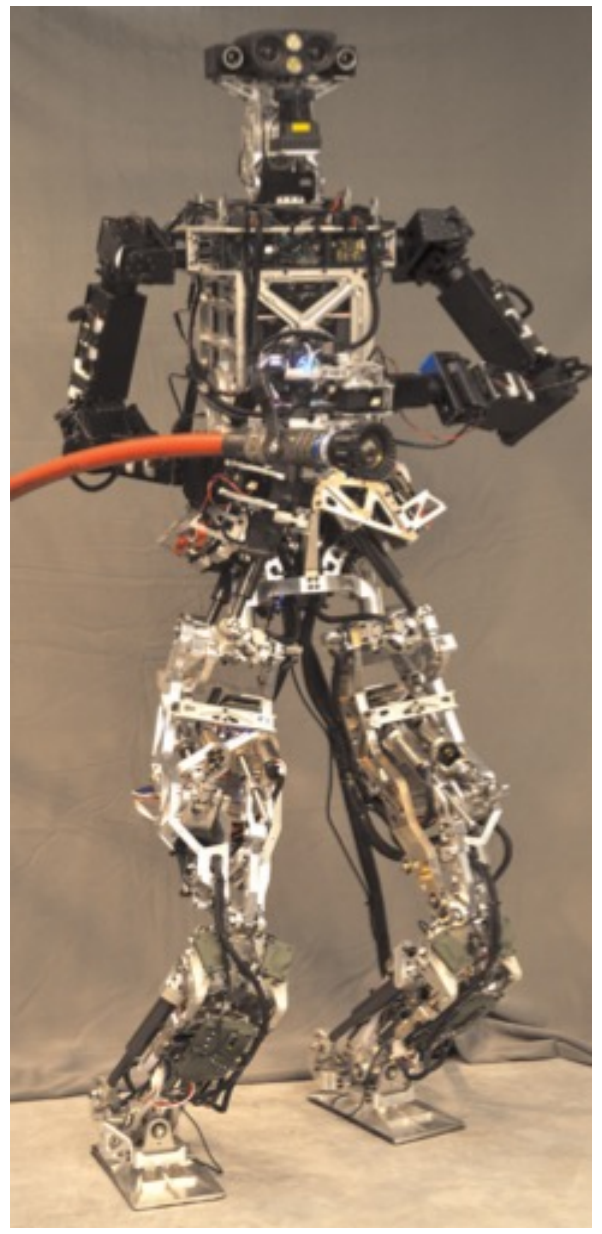
Robotics and AI (the classical paradigm)



Yamaguchi et al (2013) *AR*


Yamaguchi et al (2013) *AR*


Buschmann et al (2009) *JP*


Kim, J. et al (2015) *FSJ*

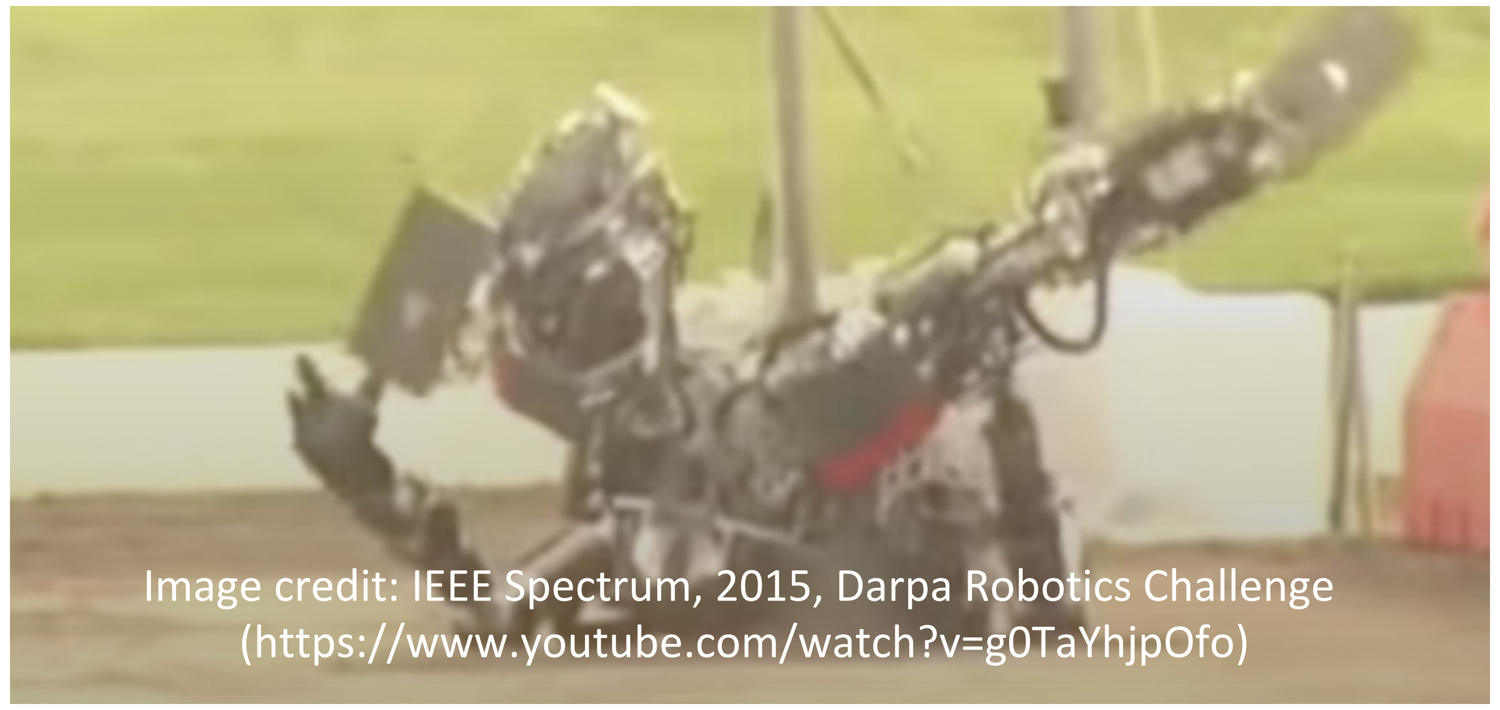


Image credit: IEEE Spectrum, 2015, Darpa Robotics Challenge (https://www.youtube.com/watch?v=g0TaYhjpOfo)

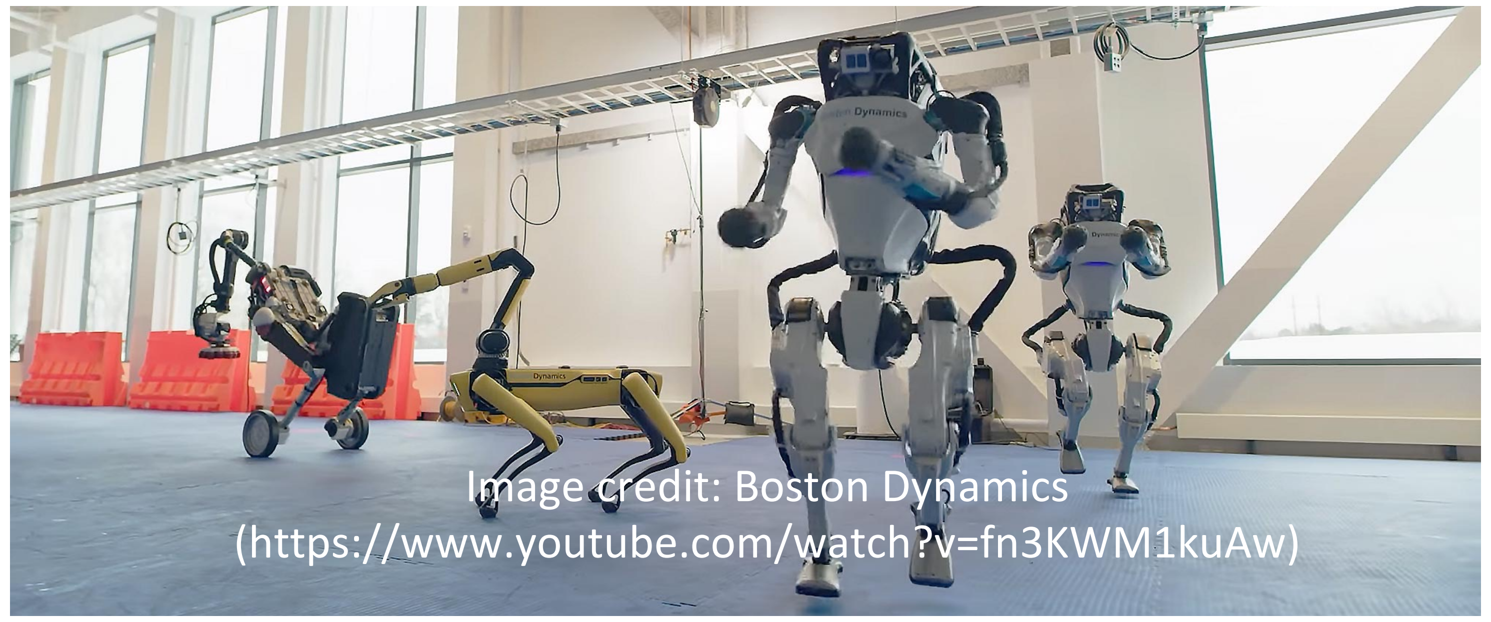
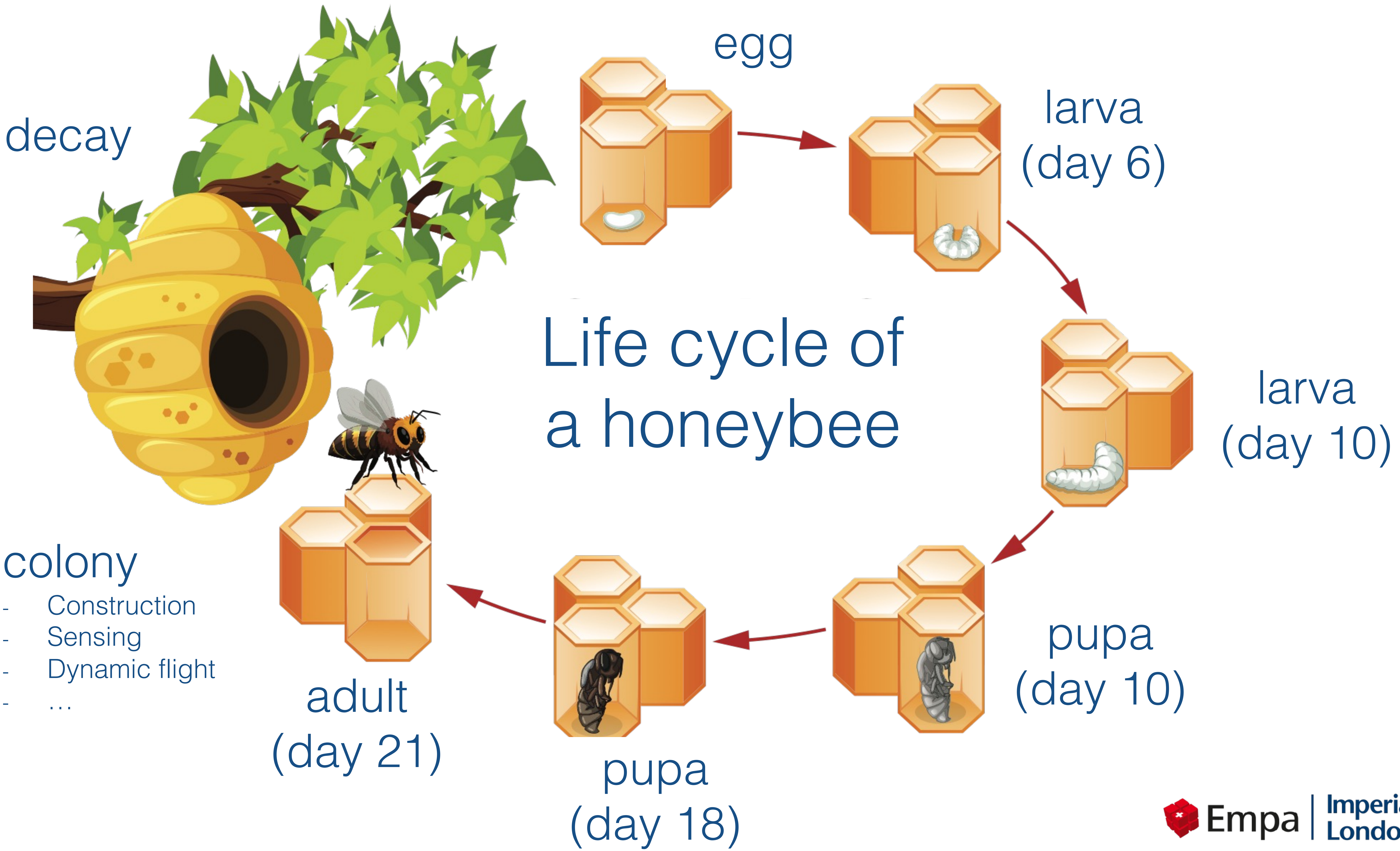


Image credit: Boston Dynamics (https://www.youtube.com/watch?v=fn3KWM1kuAw)

Life cycle of a honeybee

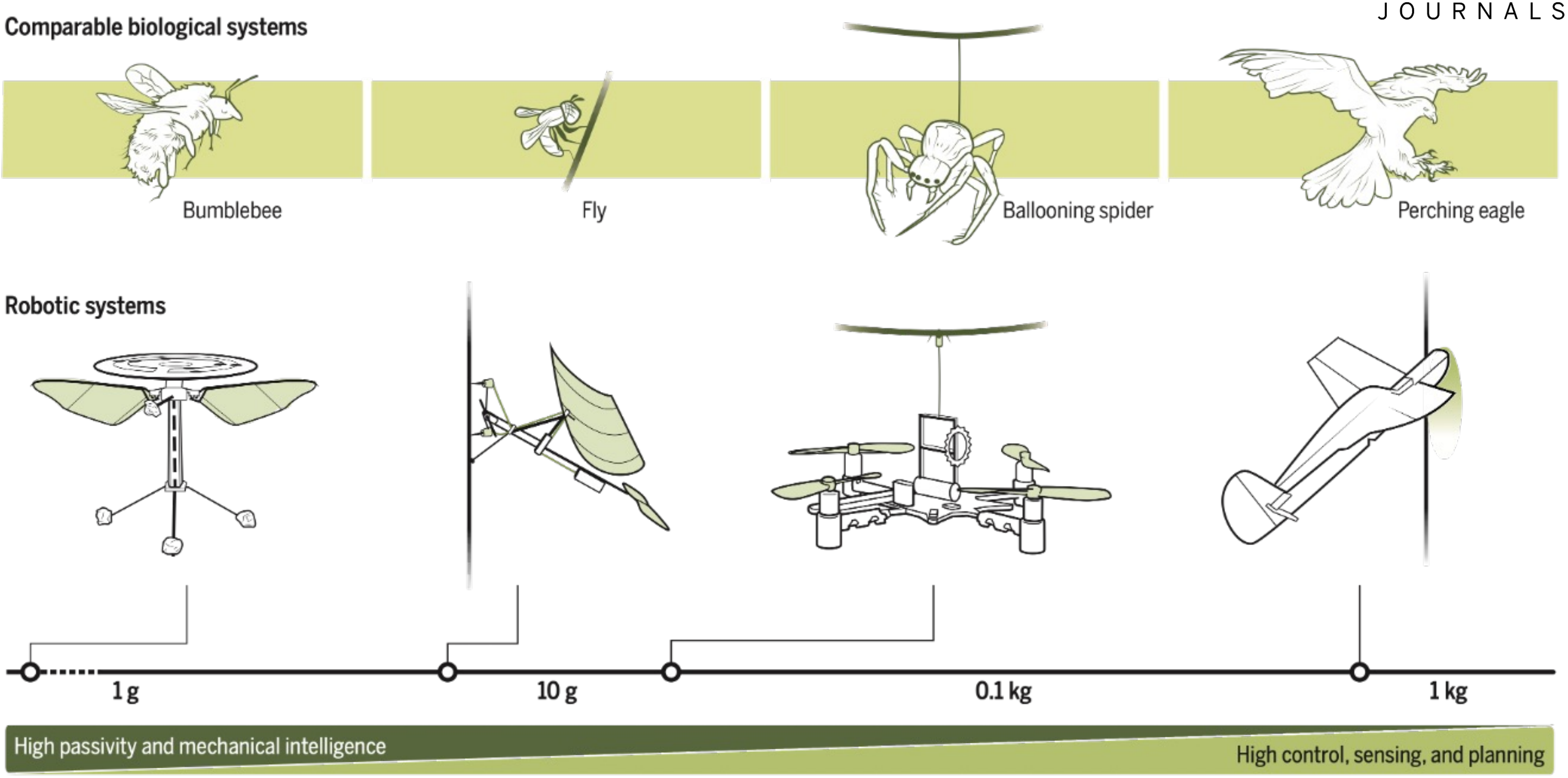


colony
- Construction
- Sensing
- Dynamic flight
- …

Physical Artificial Intelligence

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

Lifelike aerial capability



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


SUSTAINABLE DEVELOPMENT GOALS
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

Sustainability Robotics

Sustainability Robotics

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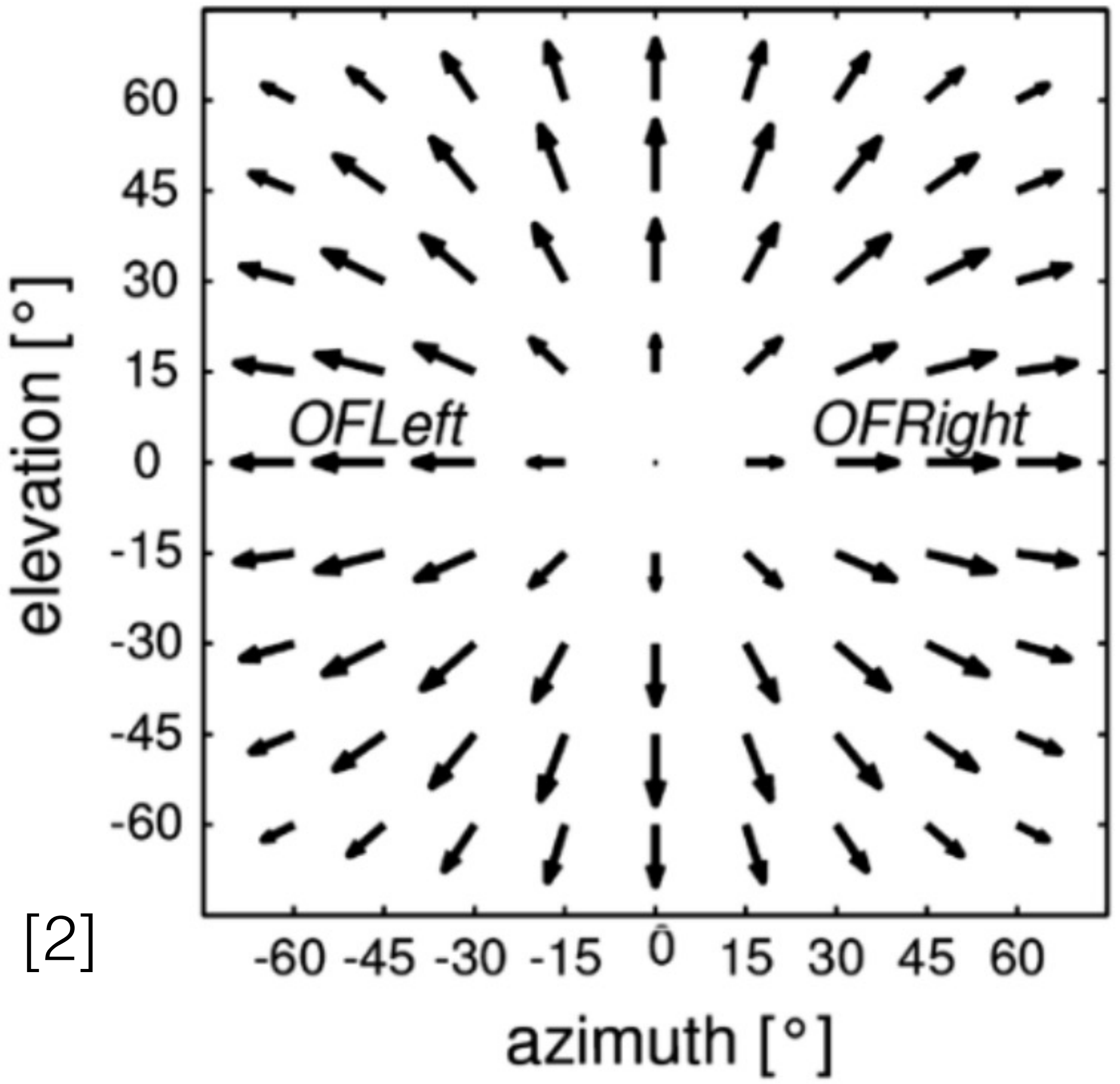
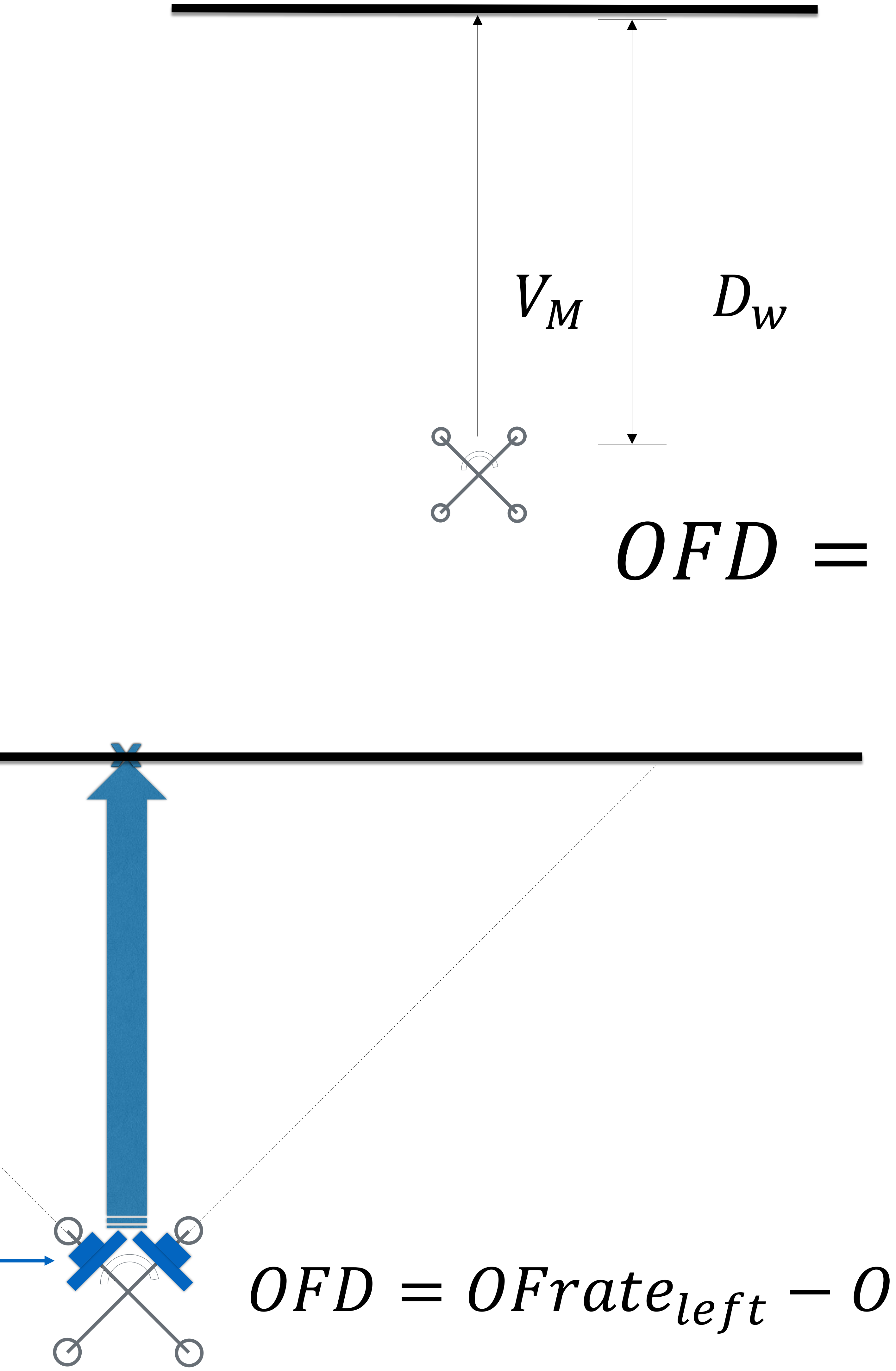
Illustration: Yusuf Kaya Furkan

Bio-inspired forrest flight autonomy



[2]



$$OFD = \frac{V_M}{D_w}$$

Divergent Optical Flow Pair (DOFP)

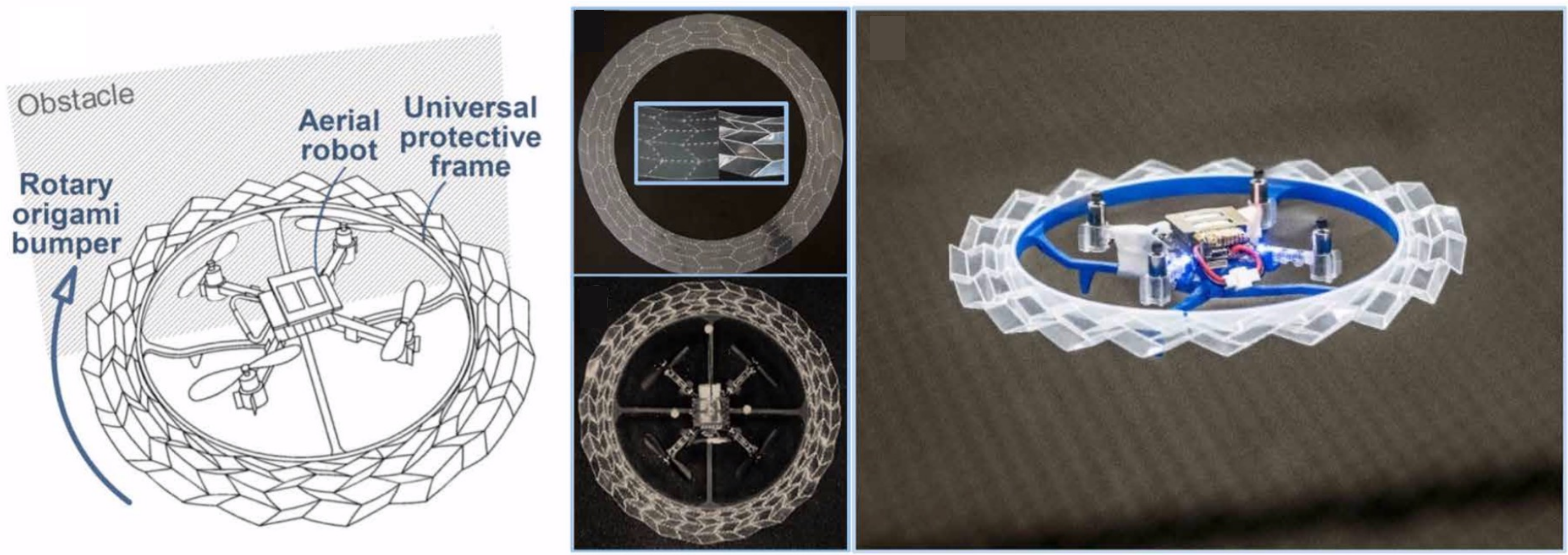
$$OFD = OFrate_{left} - OFrate_{right}$$

[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.

Xiao, F., Zheng, P., Tria, J., Kocer, B., Kovac, M., *IEEE ICRA / RAL 2021*

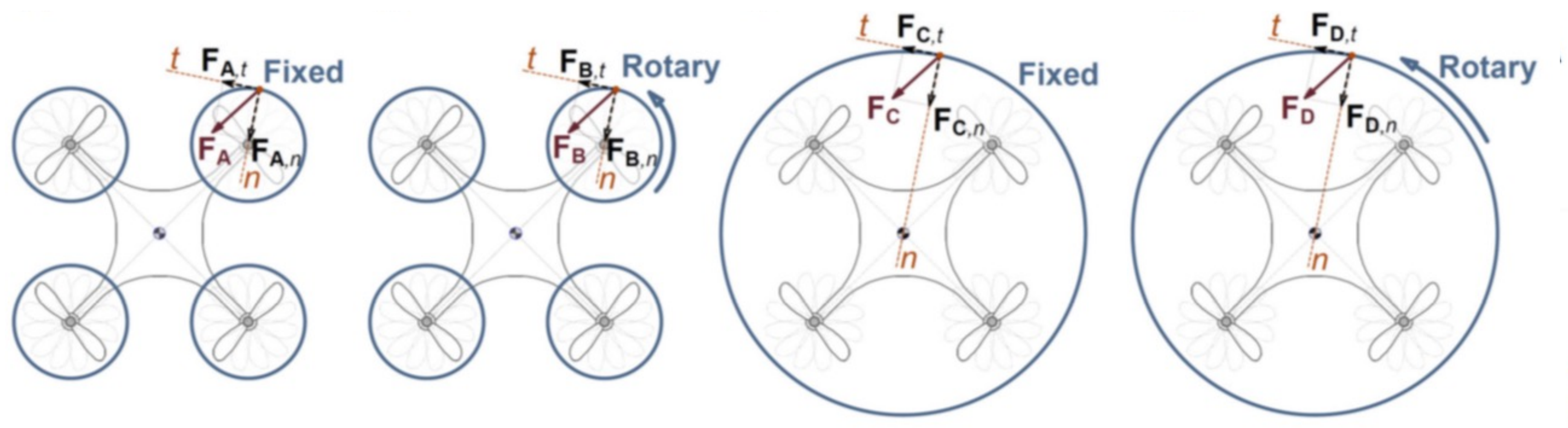

Xiao, F., Zheng, P., Tria, J., Kocer, B., Kovac, M., *IEEE ICRA / RAL 2021*

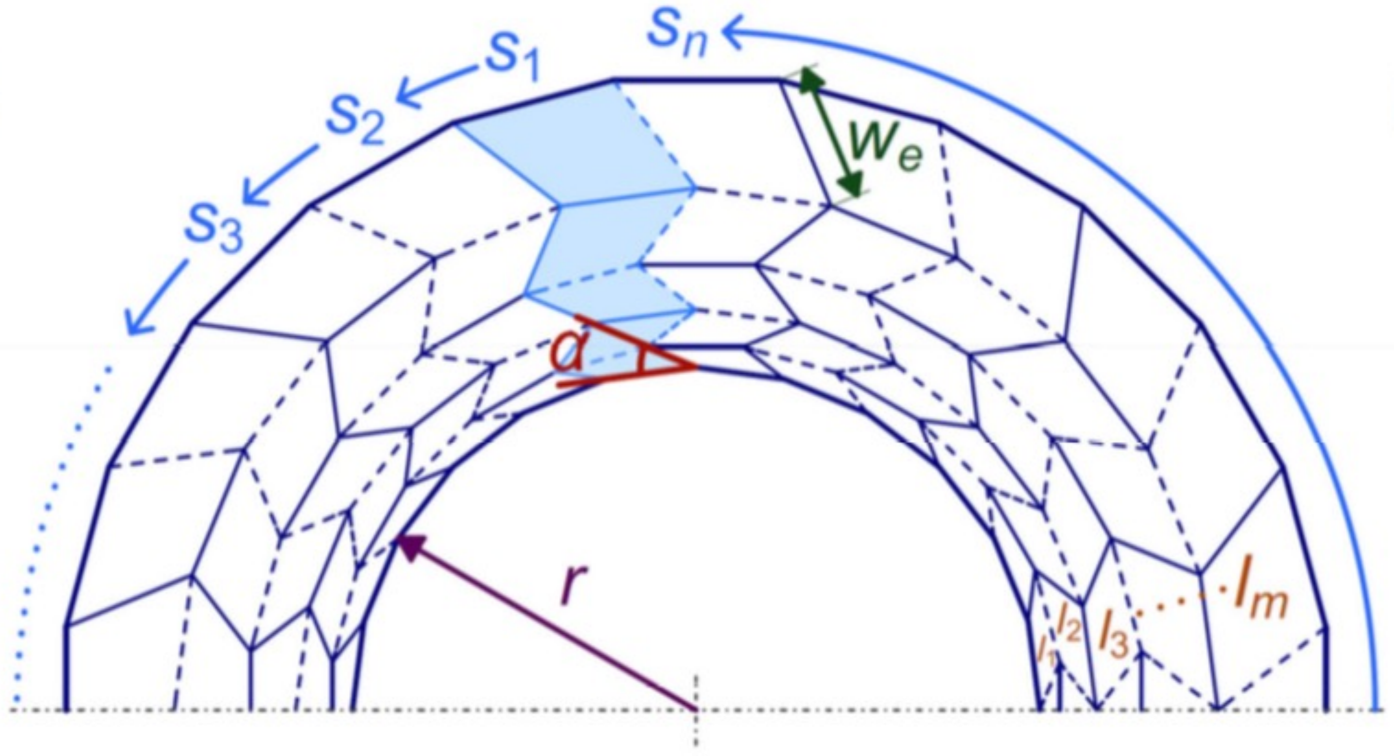
Rotorigami for impact protection

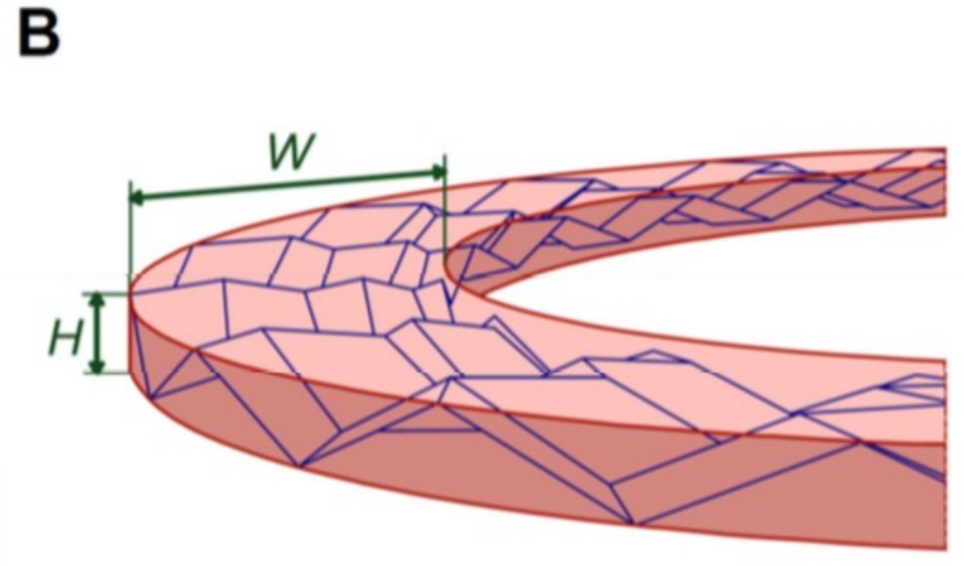


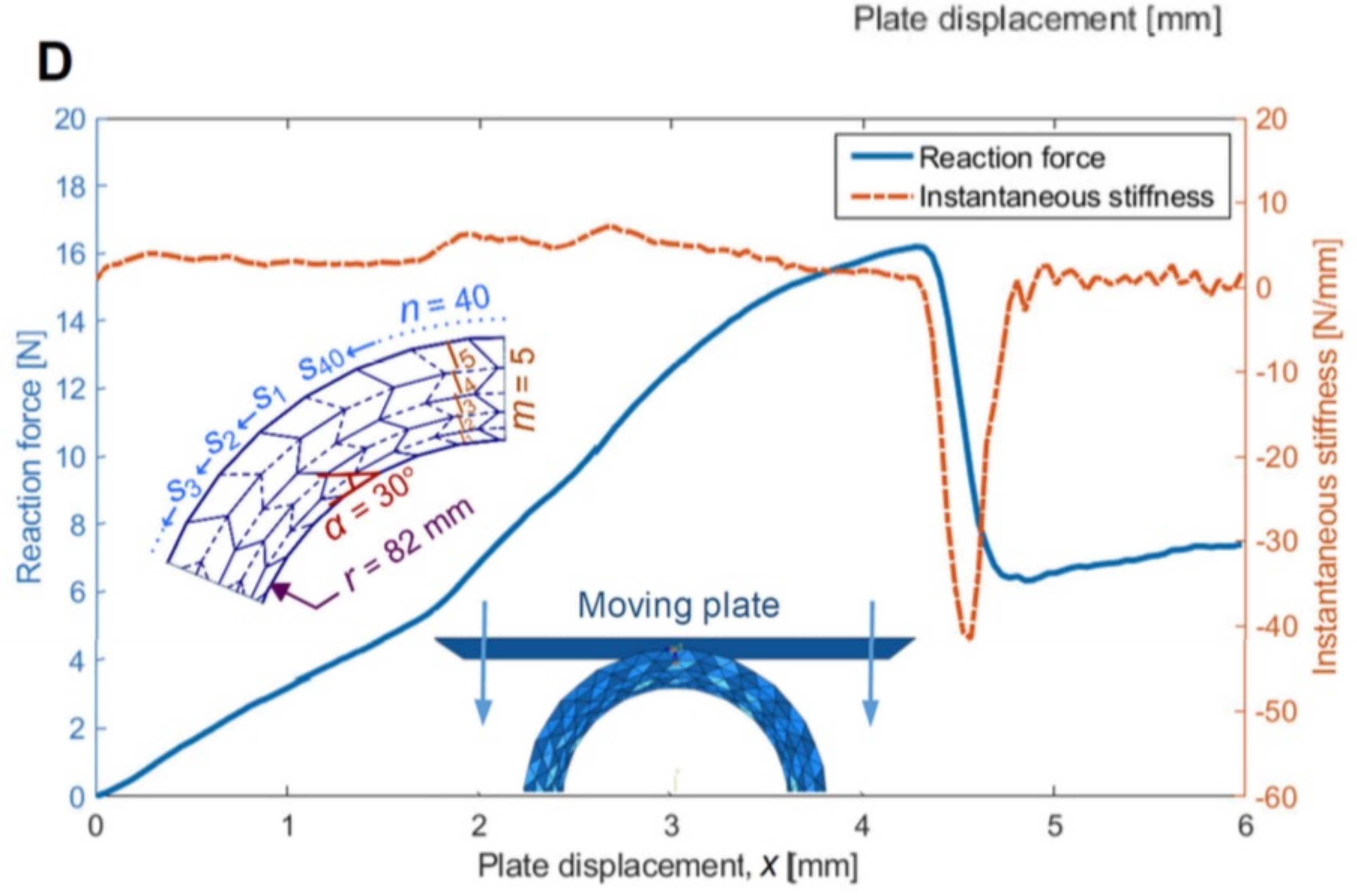
P. Sareh, P. Chermprayong, M. Emmanuelli, H. Nadeem, M. Kovac (2018)
Science Robotics (2018)

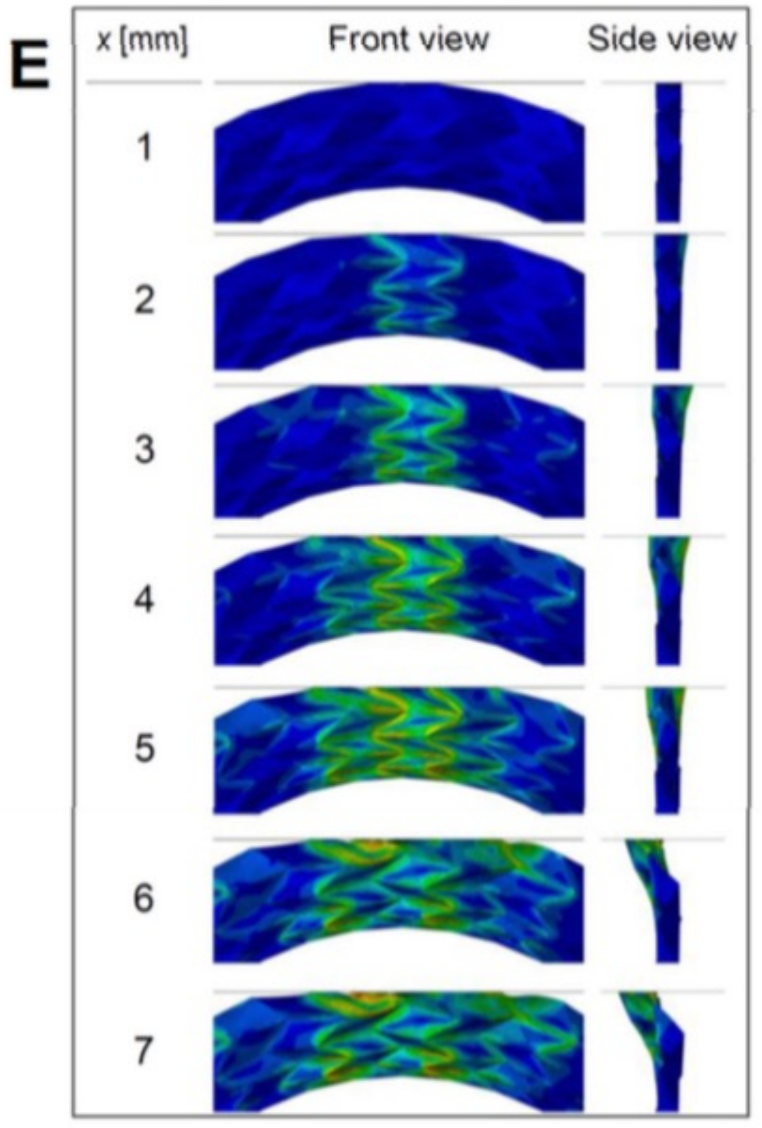
Rotorigami for impact protection

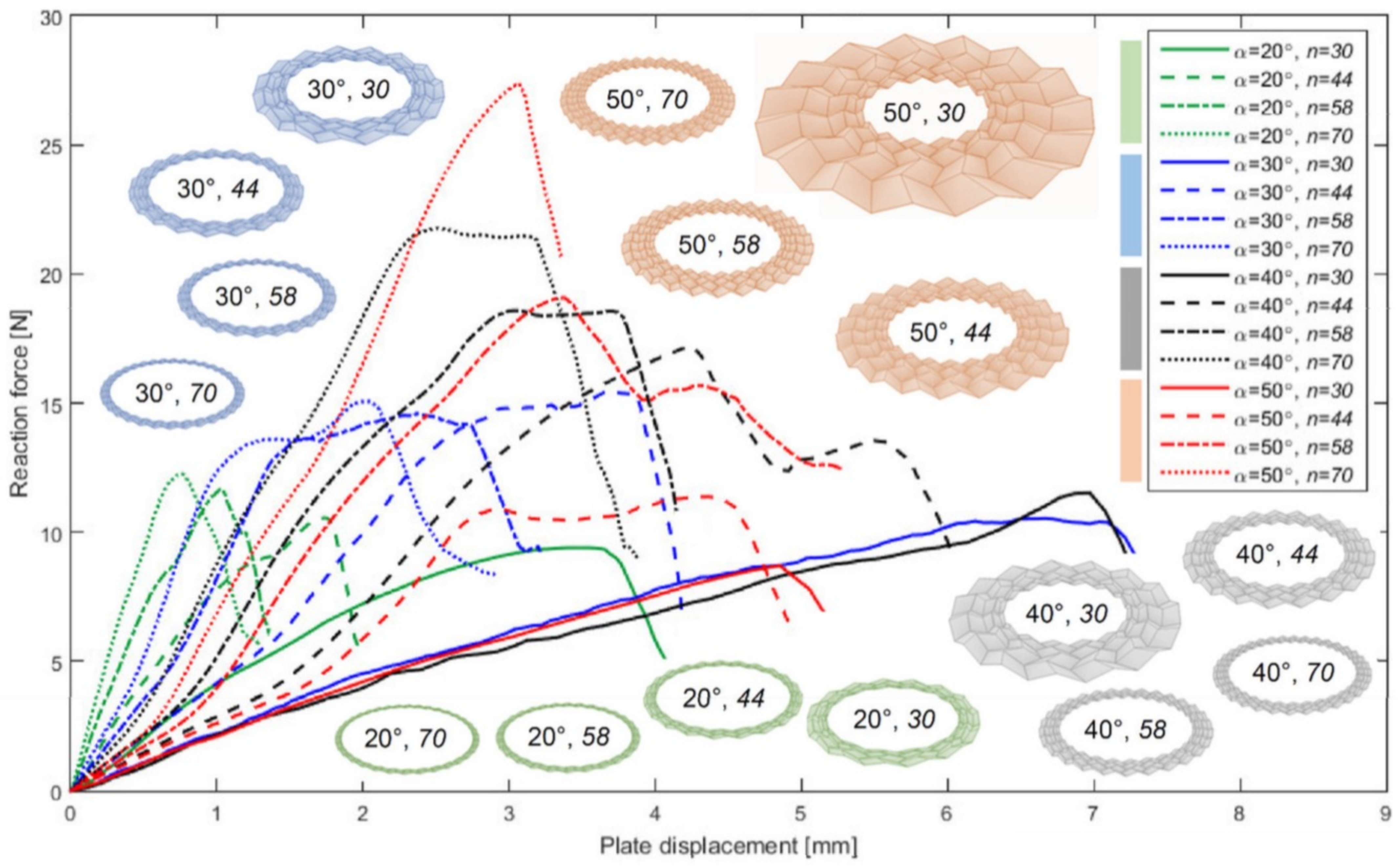












P. Sareh, P. Chermprayong, M. Emmanuelli, H. Nadeem, M. Kovac (2018)
Science Robotics (2018)

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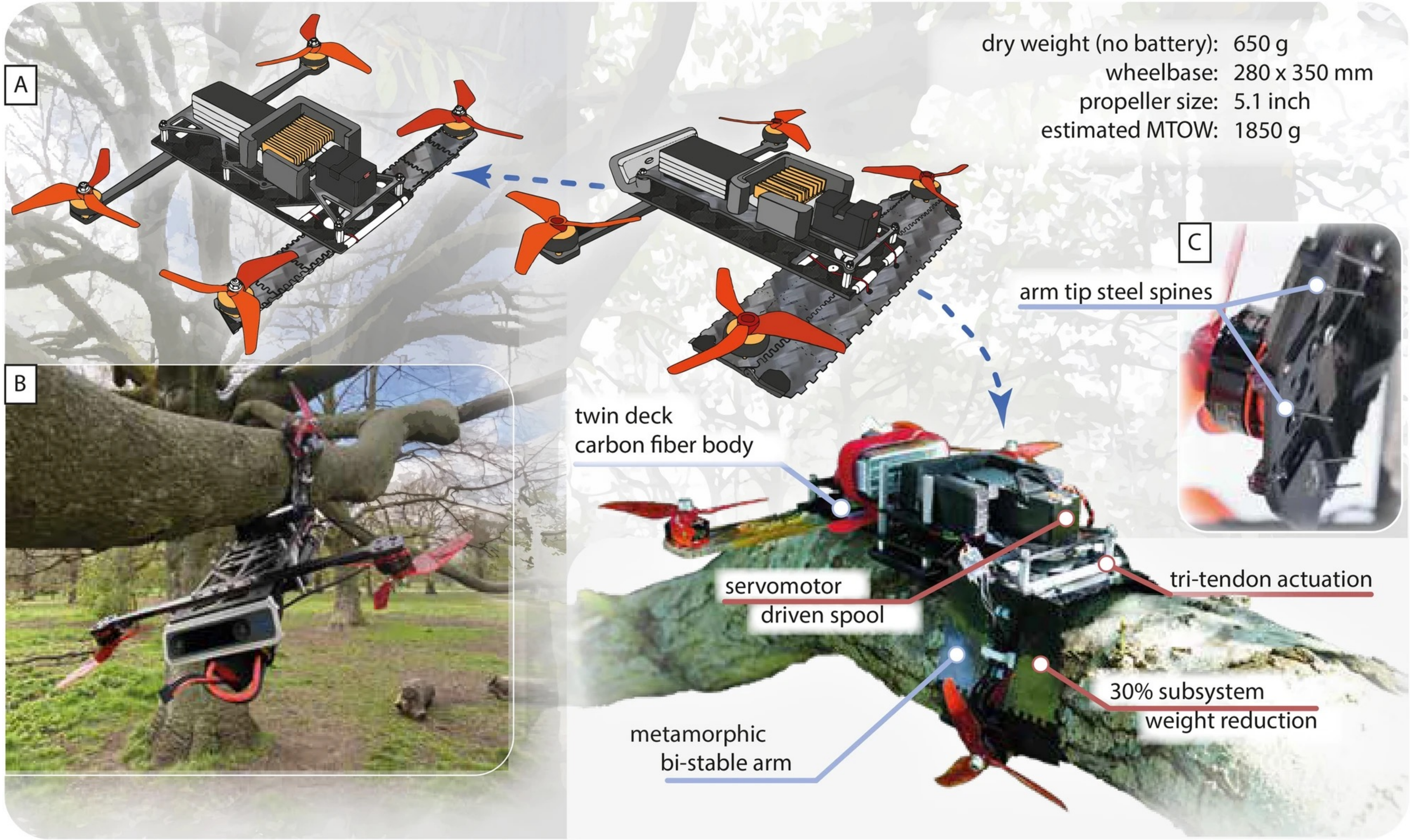
Rotorigami for impact protection

P. Sareh, P. Chermprayong, M. Emmanuelli, H. Nadeem, M. Kovac (2018)
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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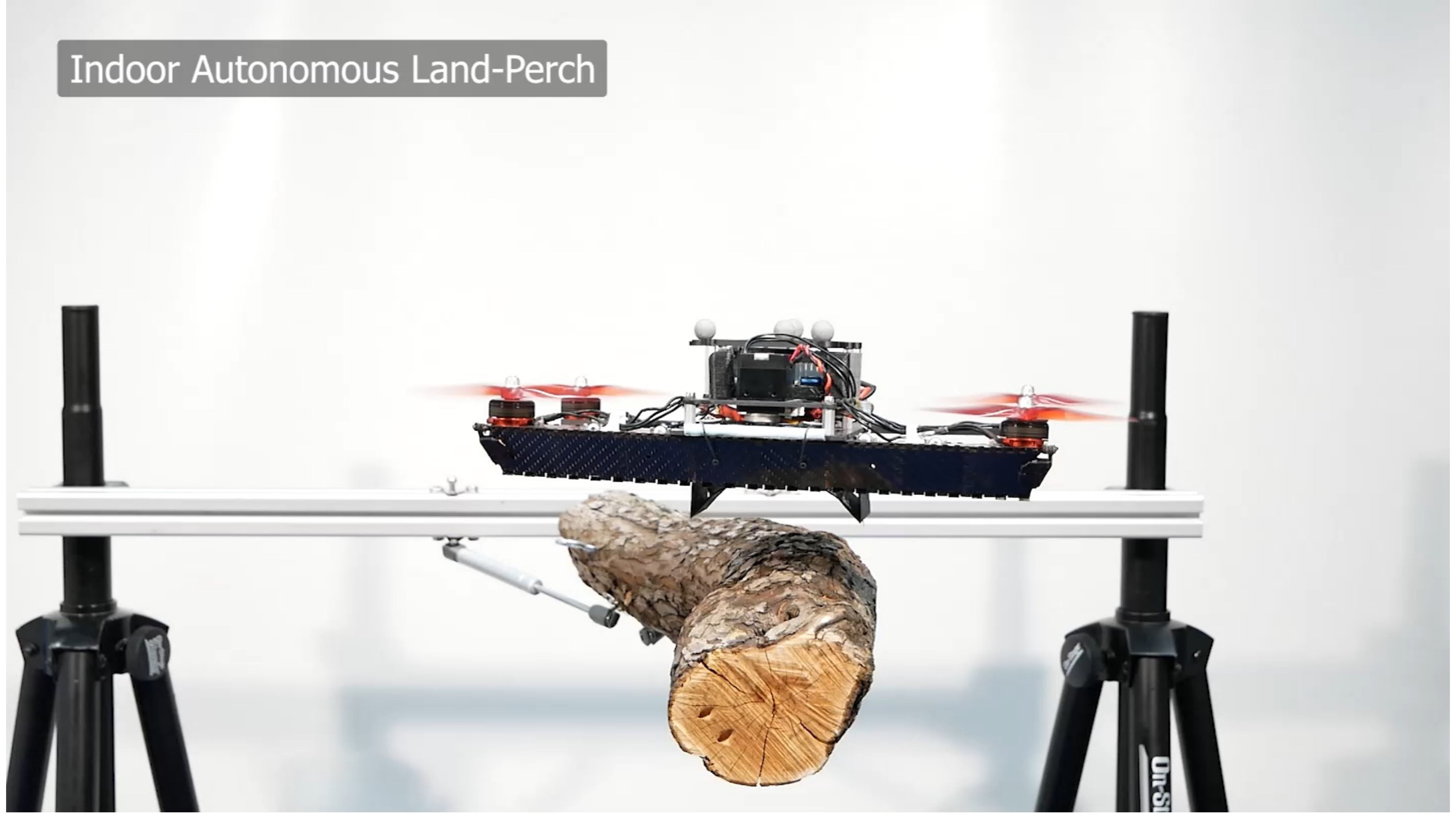
Meta-morphic full body perching



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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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

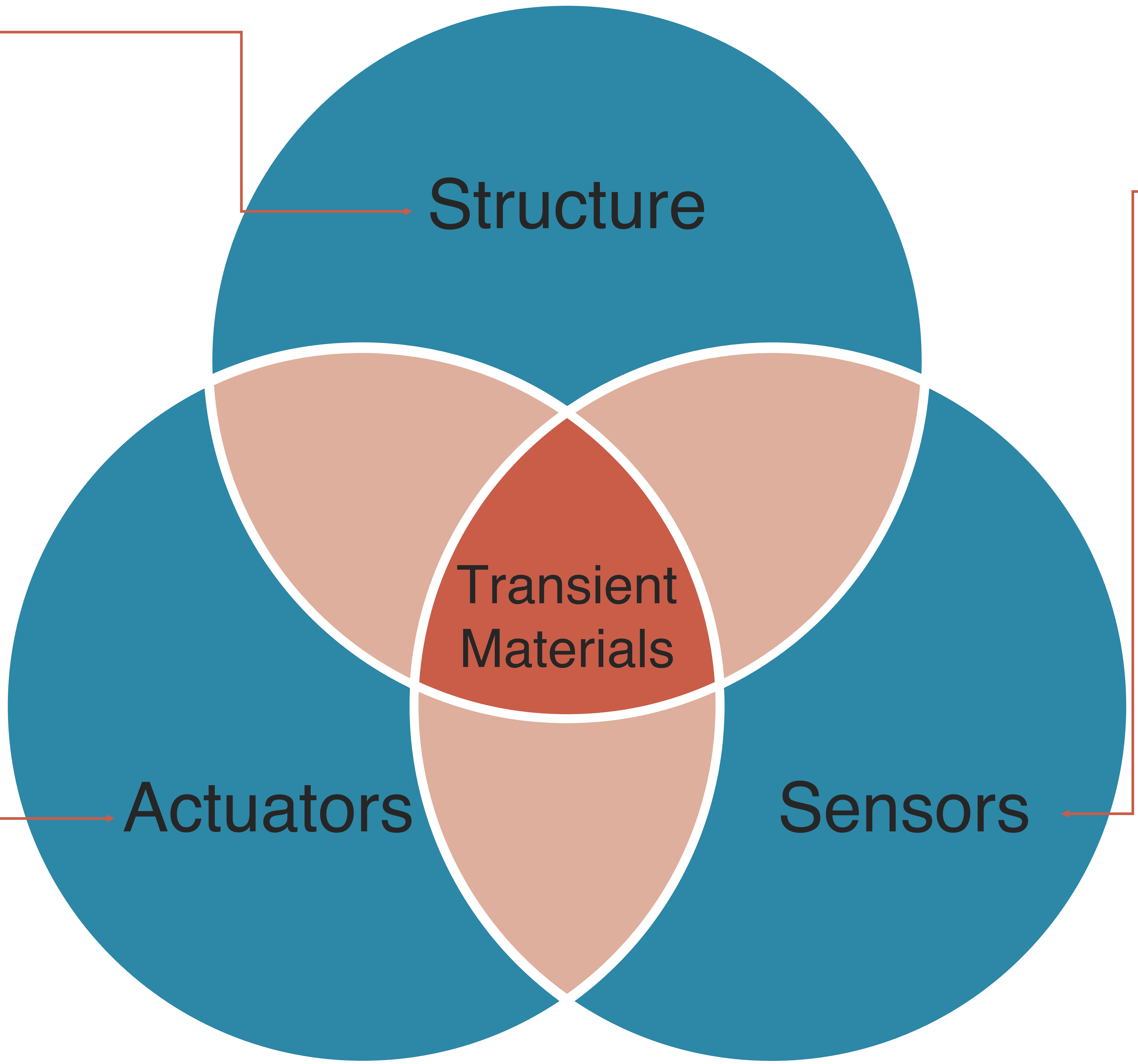
Transient materials for Sustainability Robotics

Structural materials

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

Actuating materials

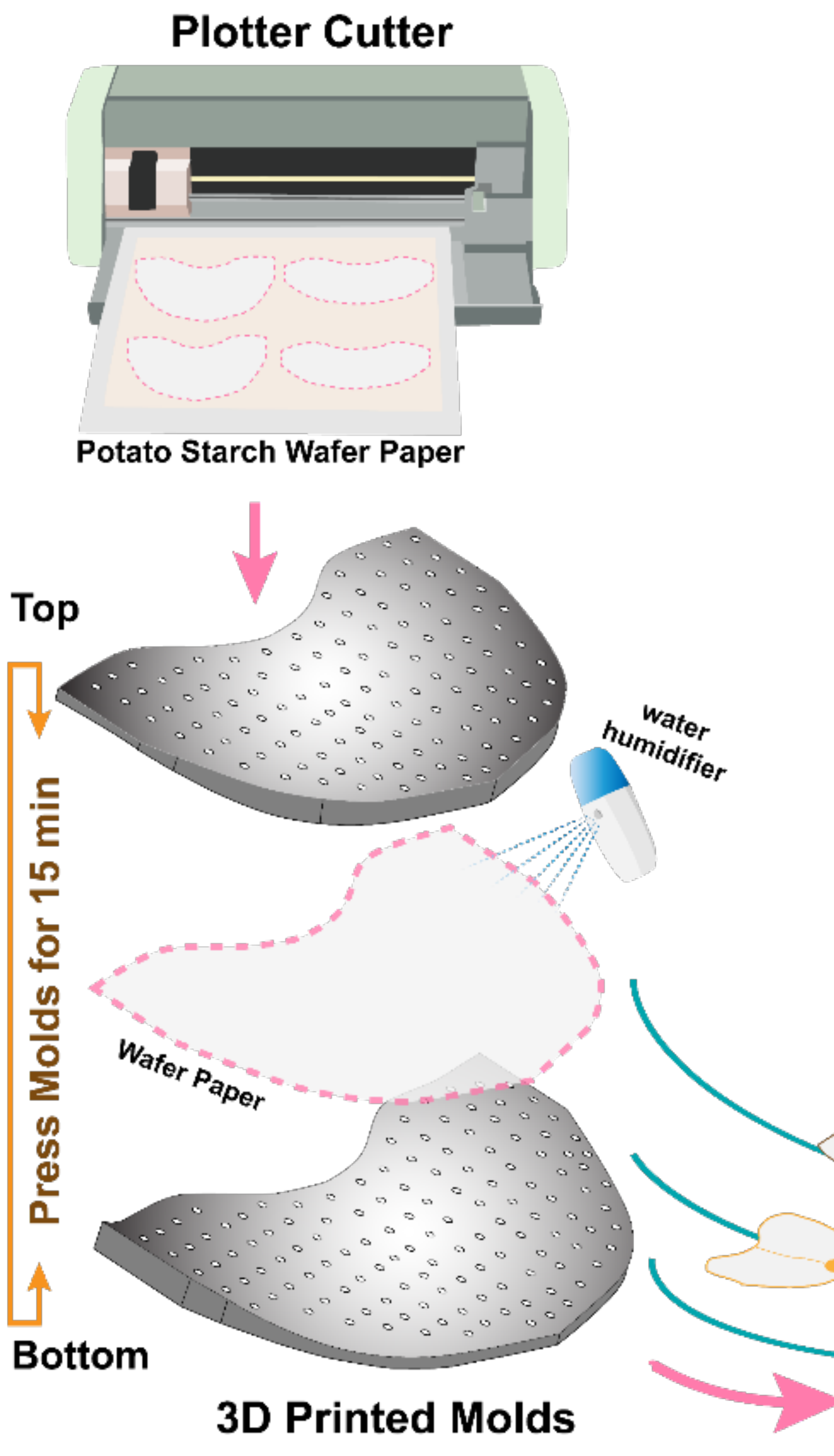
- Electro thermal actuators
- Humidity responsive actuators (swelling etc.)
- Micro-organisms induces shape changes (e.g. bacteria growth)
- Eco-friendly electro active polymers (e.g. polypyrrole)



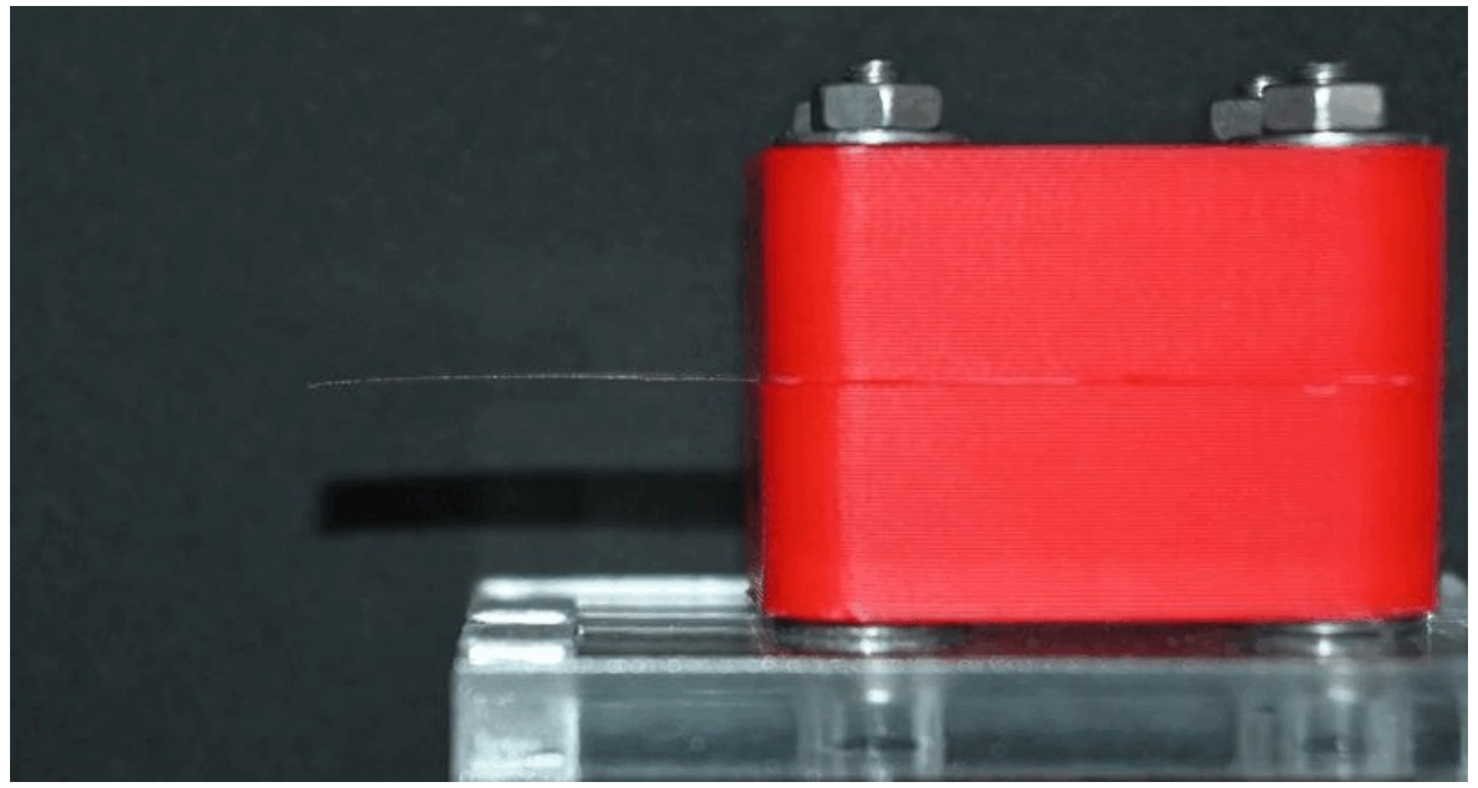
Sensing materials

- 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)

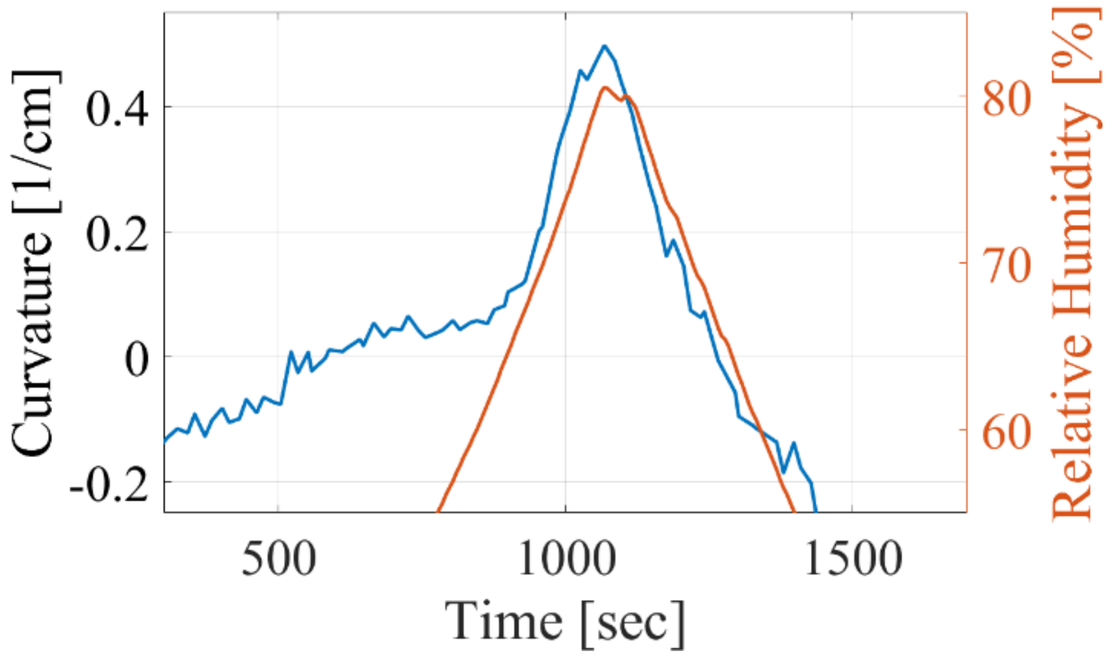
Actuation: Humidity responsive composites

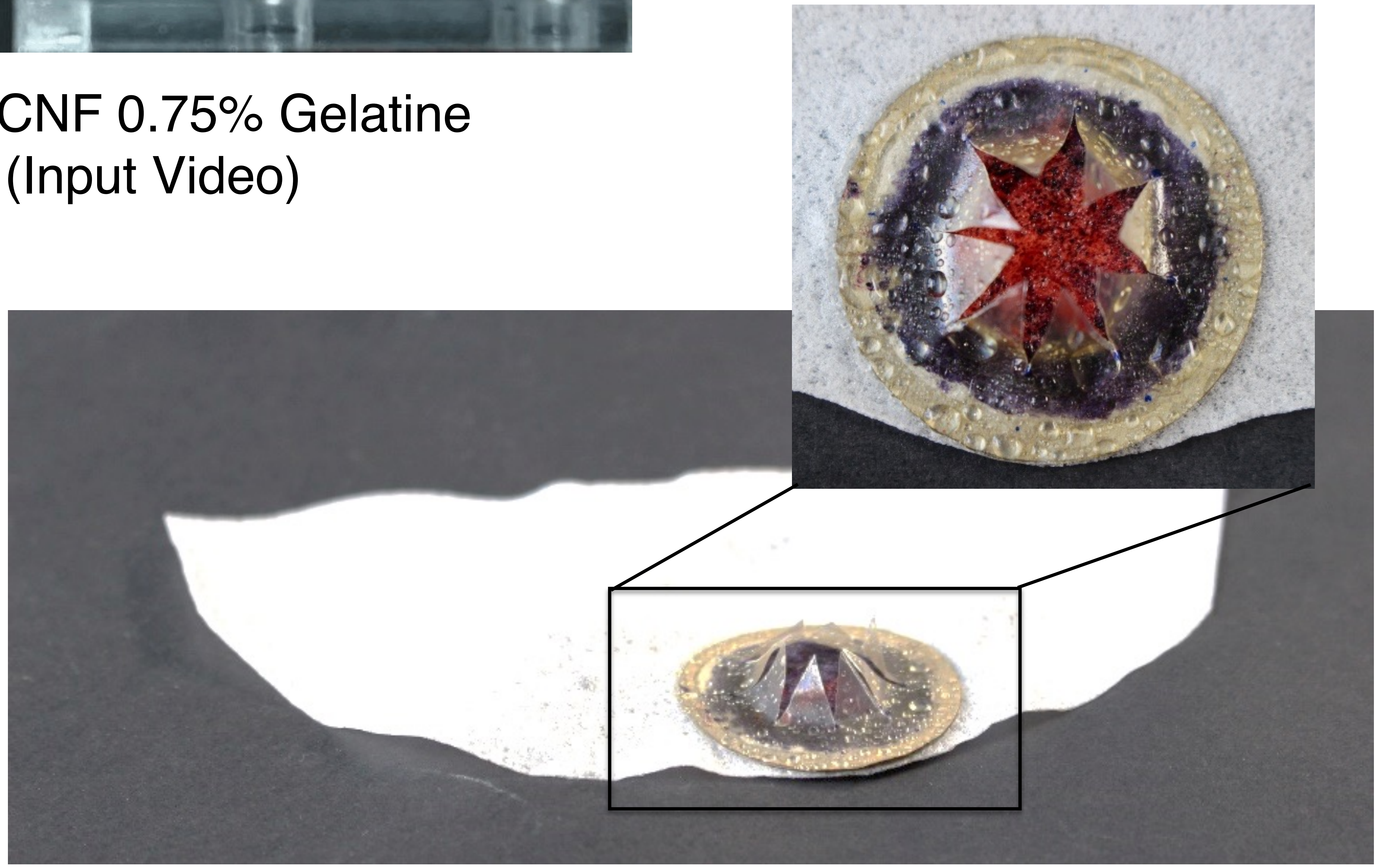


0.25% CNF 0.75% Gelatine



0.25% CNF 0.75% Gelatine
(Input Video)





F. Wiesemüller, G. Nyström, M. Kovac et al.,
IEEE Robotics and Automation Letters (2021), *IEEE Airpharo* (2021), *N.I.C.E.* (2022)

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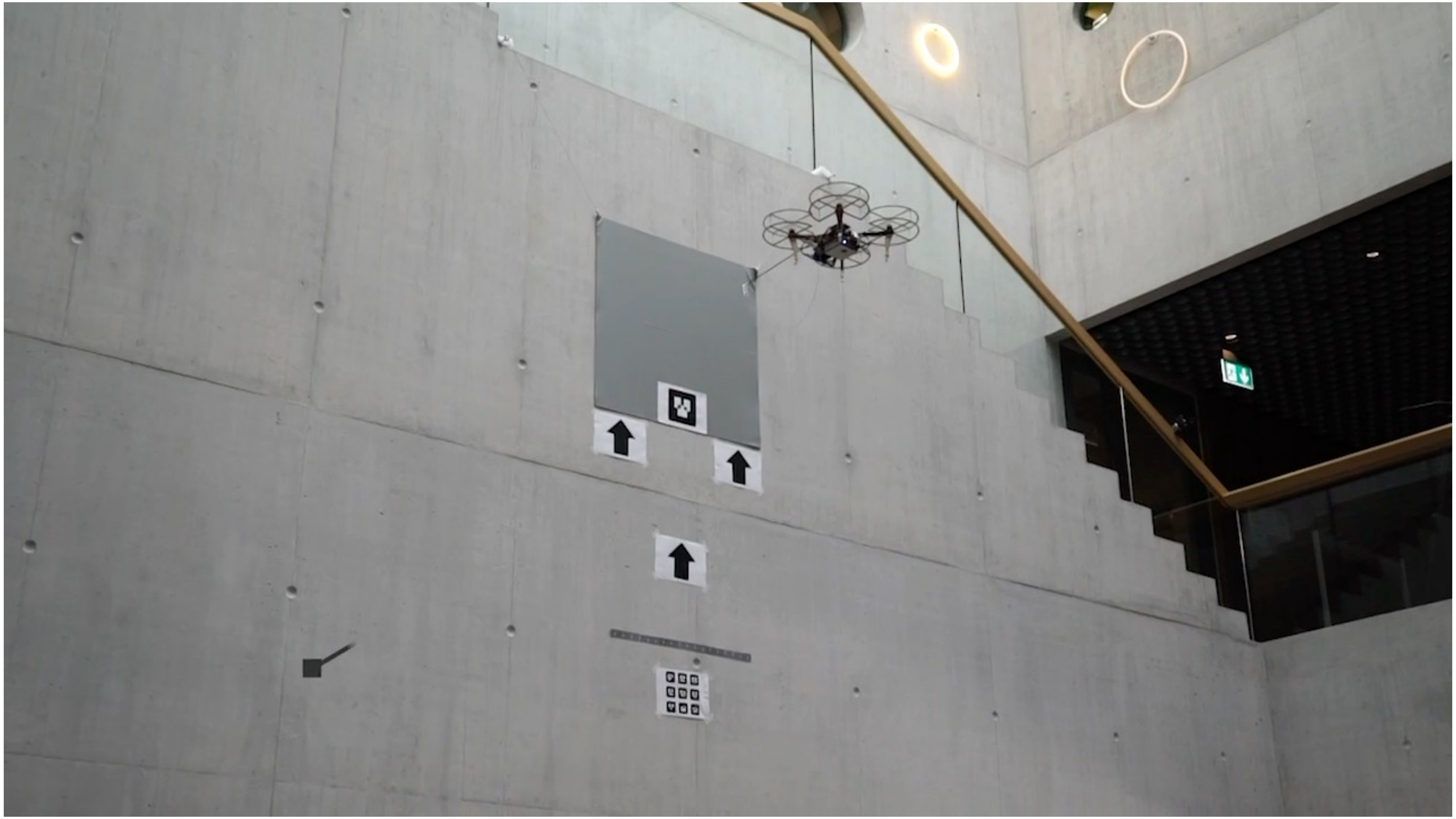
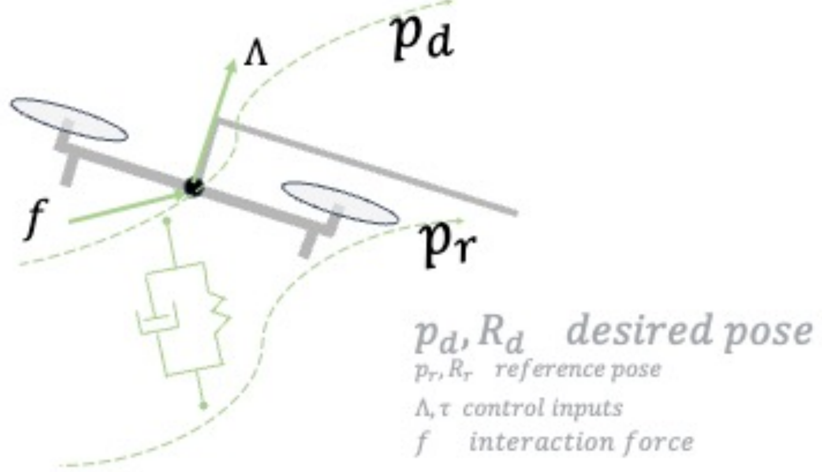
Sustainability Robotics

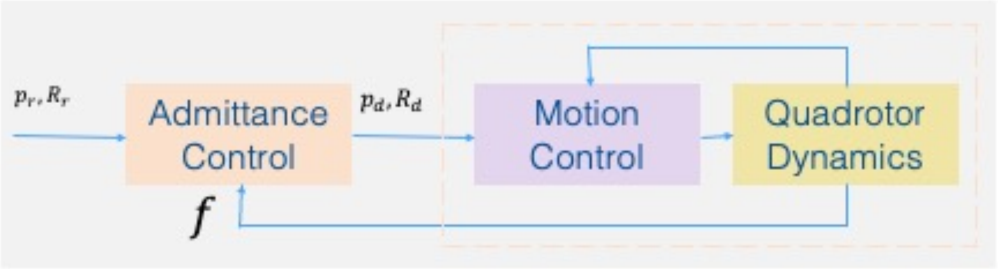
Tensile construction

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

Tensile construction







*N. Hogan, J. Dyn. Syst. Meas. Control, 1985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Scotland Scotland Politics Scotland Business Edinburgh, Fife & East Glasgow & West

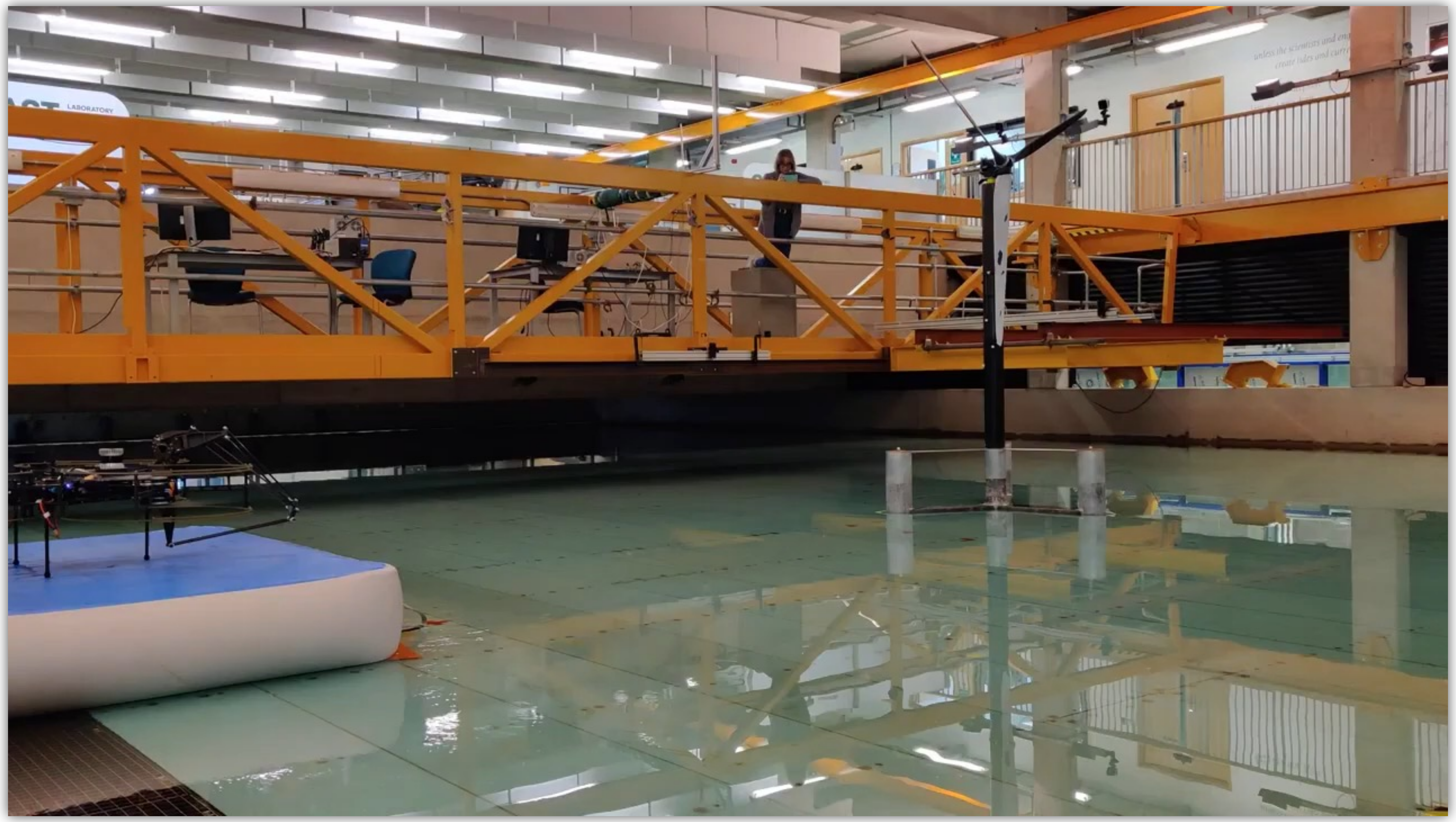
Robotic inspectors developed to fix wind farms

By Ken Macdonald
BBC Scotland Science Correspondent

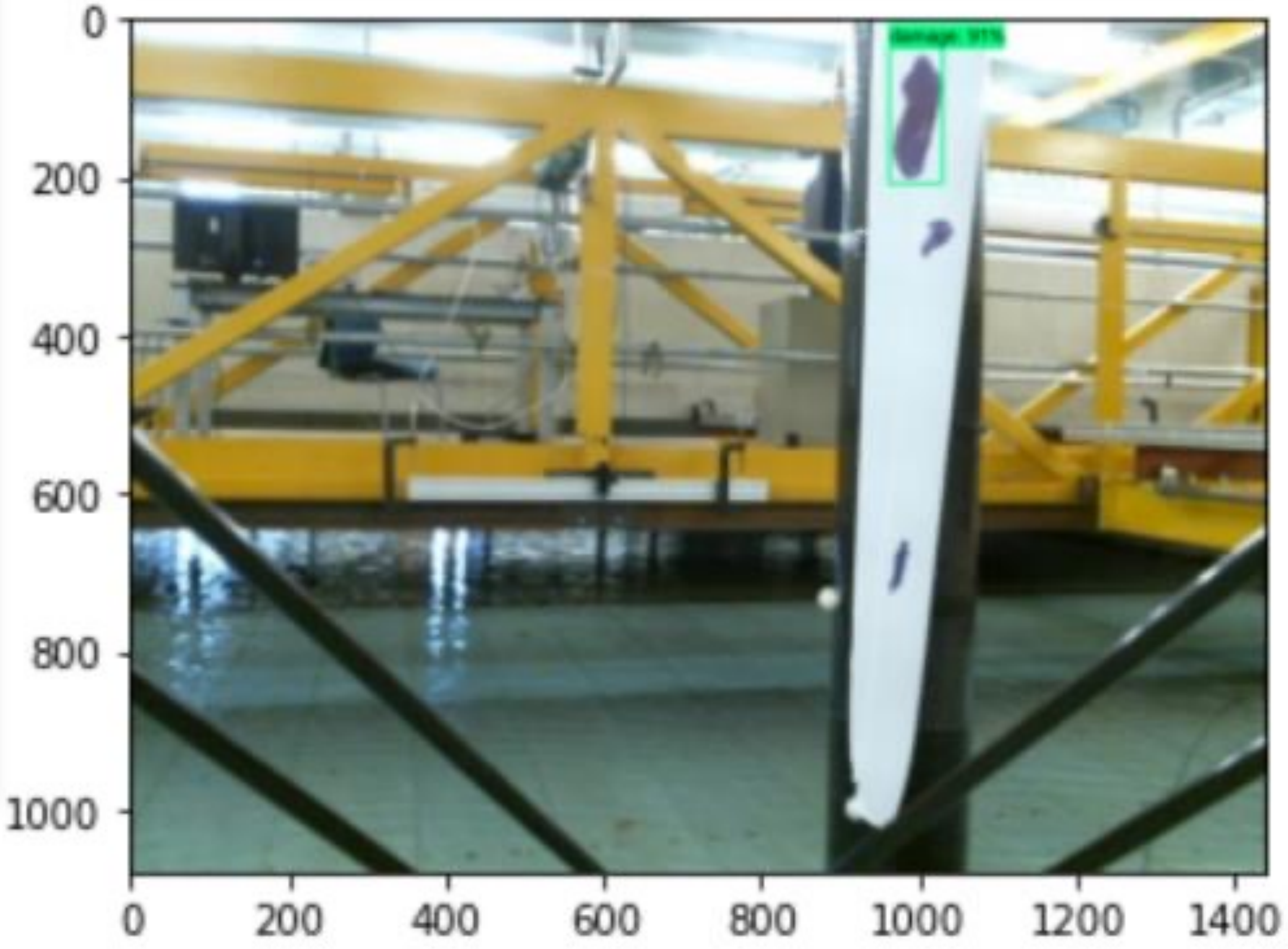
14 October 2019 Share

Nguyen, H-N, Stephens, B., Kovac, M., *IEEE ICRA* 2019 (video contribution)

Autonomous turbine 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)

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Illustration: Yusuf Kaya Furkan

Aerial-AM

AERIAL ADDITIVE MANUFACTURING

3D Printing with Autonomous Aerial Robots

Imperial College London | University College London | University of Bath

Bio-inspired construction principles

Science
JOURNALS AAAS

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

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Scan-drone
Build-drone
1.2
1
0.8
0.6
0.4
0.2
0
z [m]
0.2
0
-0.2
x [m]
-0.2
0
0.2
y [m]
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
z [m]
0.2
0
-0.2
x [m]
-0.2
0
0.2
y [m]
2
1.5
1
0.5
0
z (height) [m]

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

Aerial Additive Manufacturing

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 article)

Sustainability Robotics

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Aquatic Jump gliding with water reactive fuel

Science JOURNALS AAAS

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

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

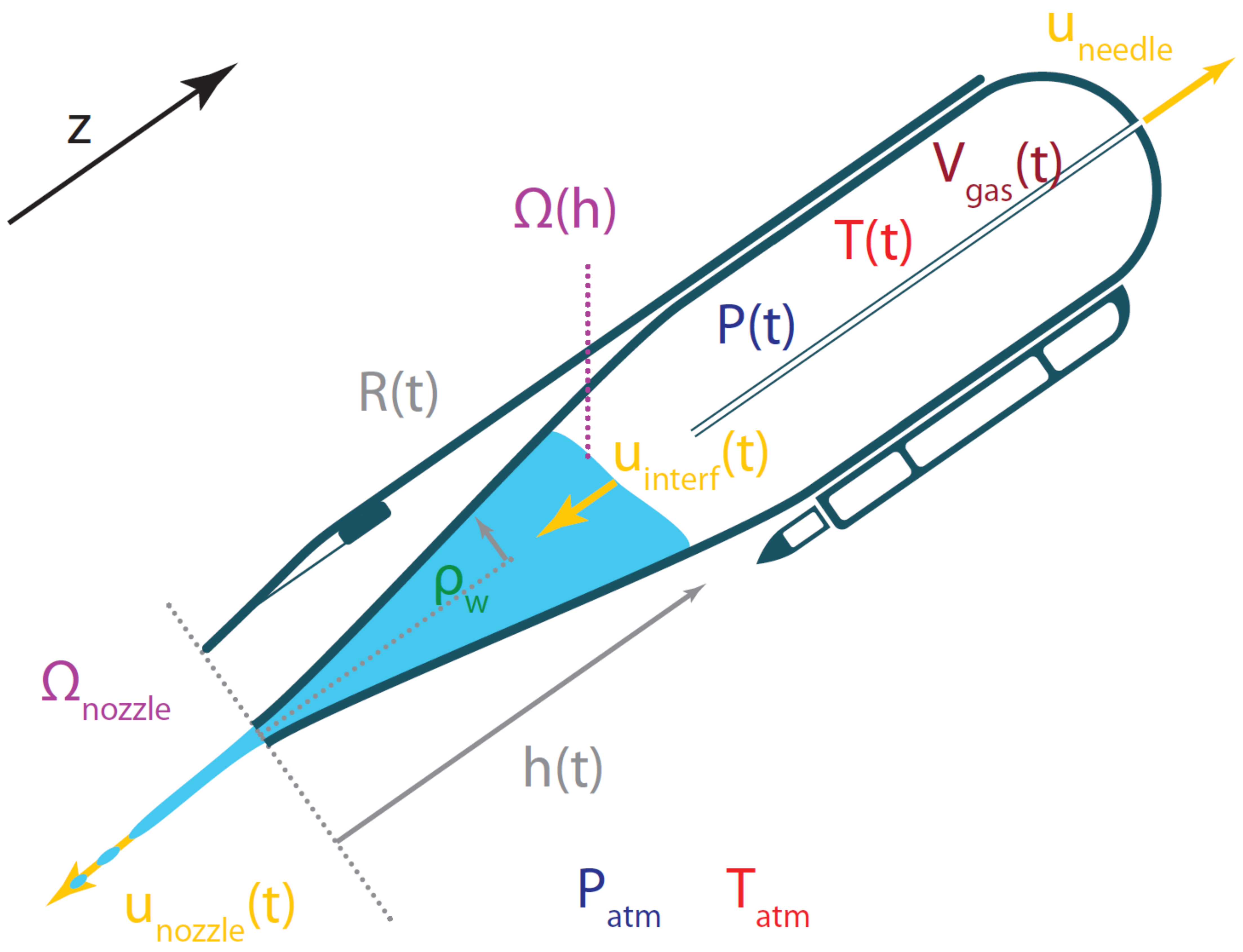
Aquatic Jump gliding with water reactive fuel

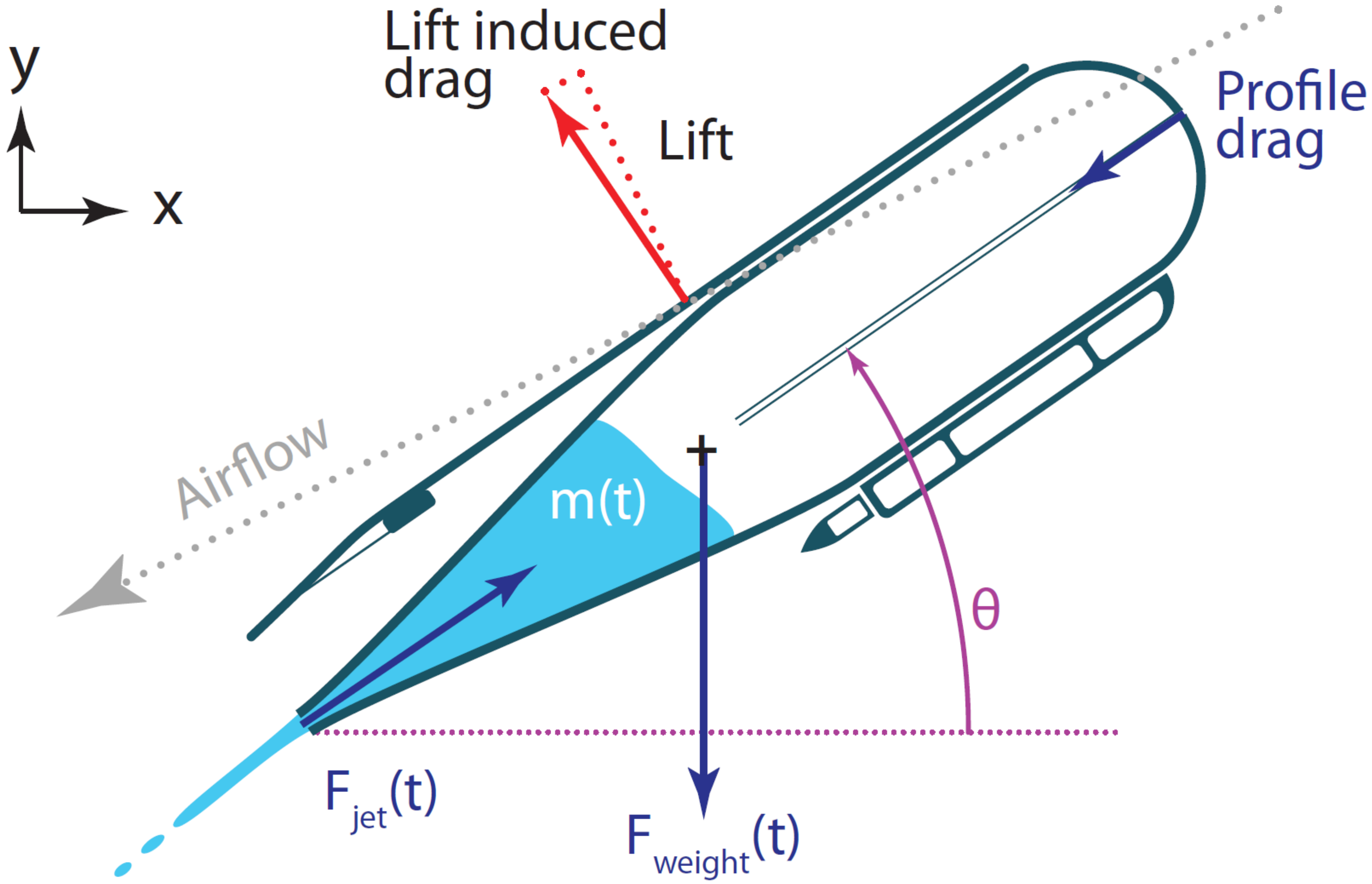
Science JOURNALS AAAS

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

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

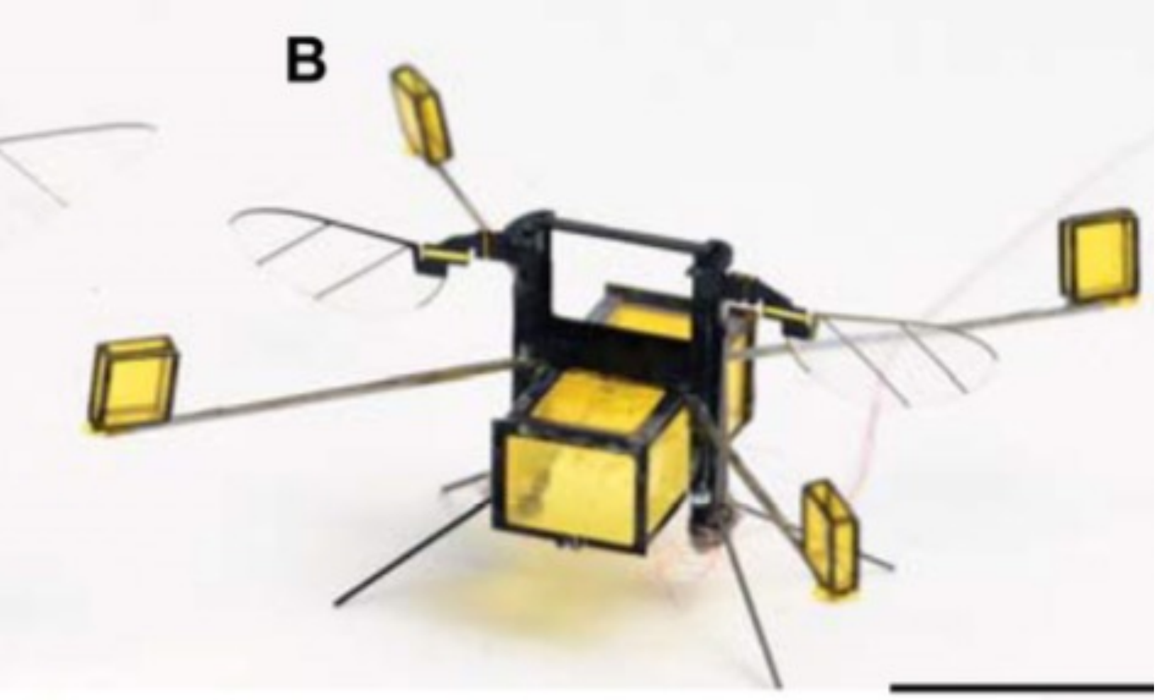
Physics-based development

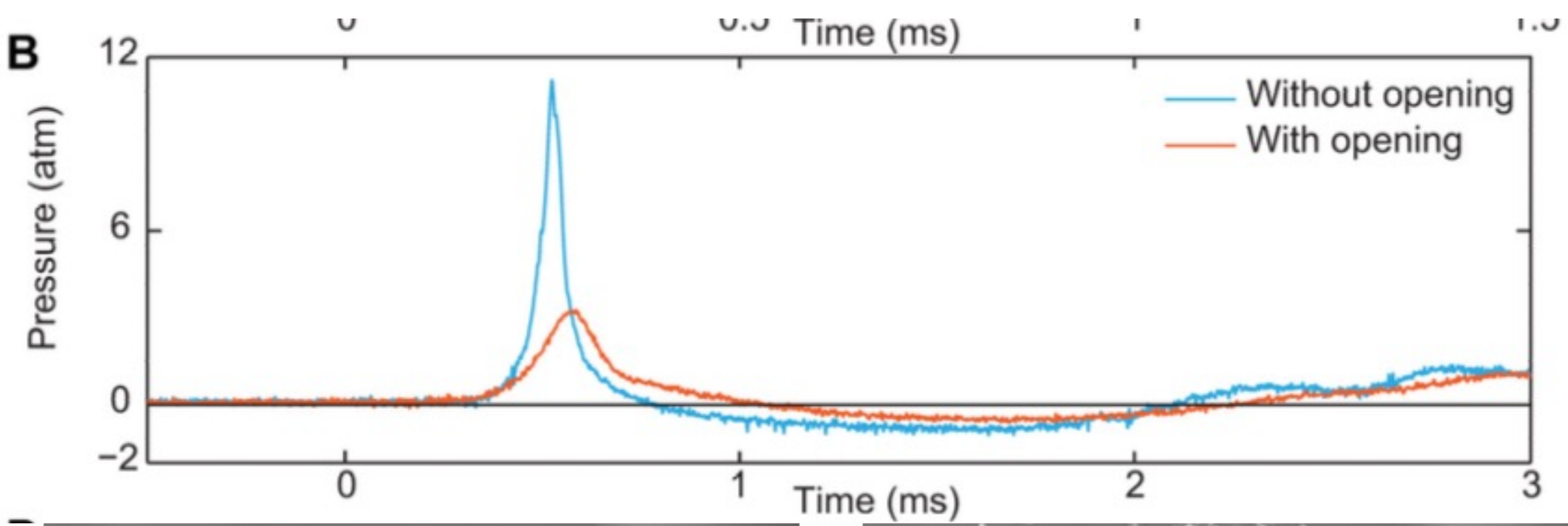


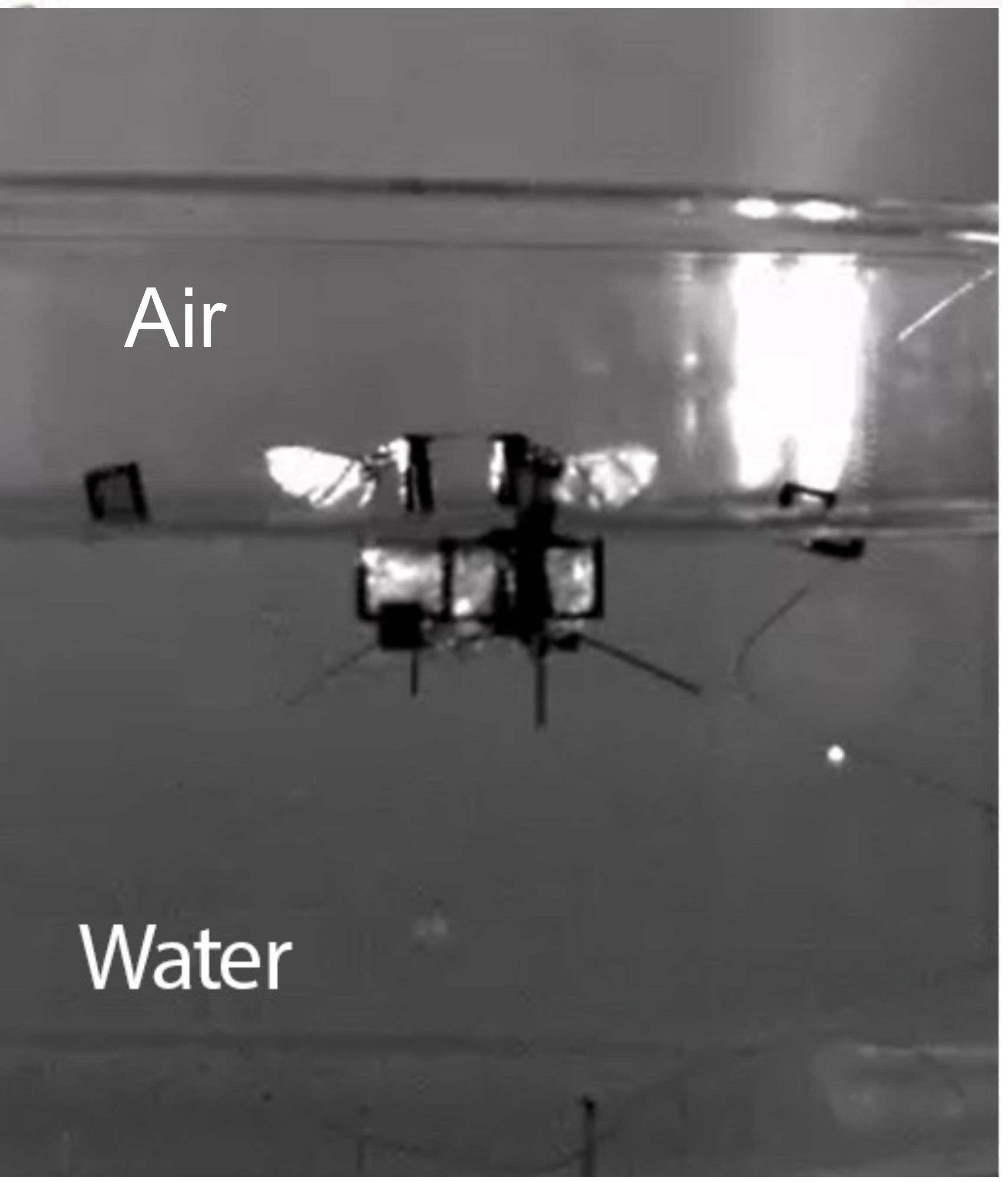


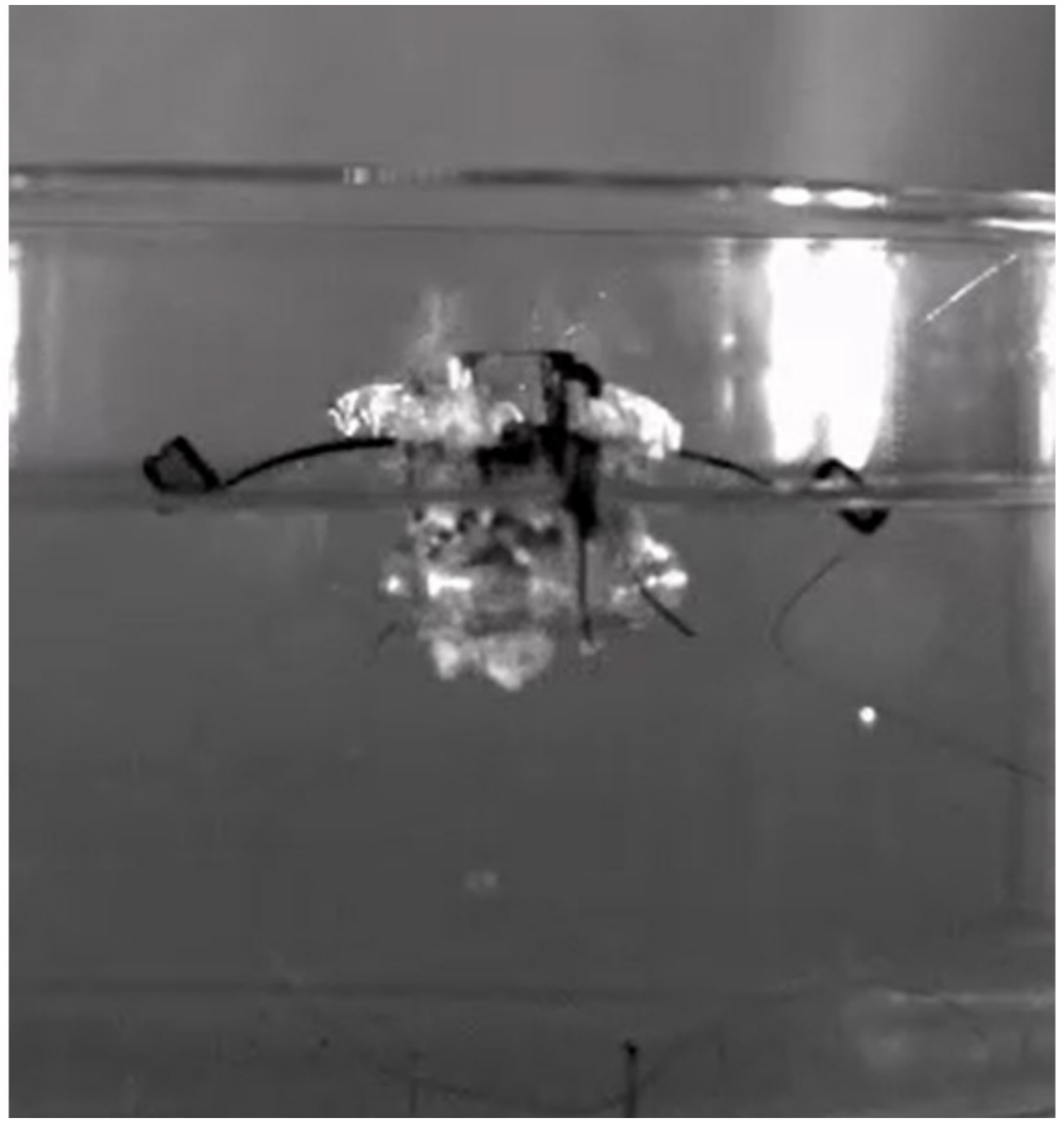
Zufferey, Ortega Ancel, A., Farinha, A., Siddall, R., Armanini, S.F., Nasr M., Brahmal, R. V., Kennedy, G., Kovac, M., *Science Robotics* (2019)

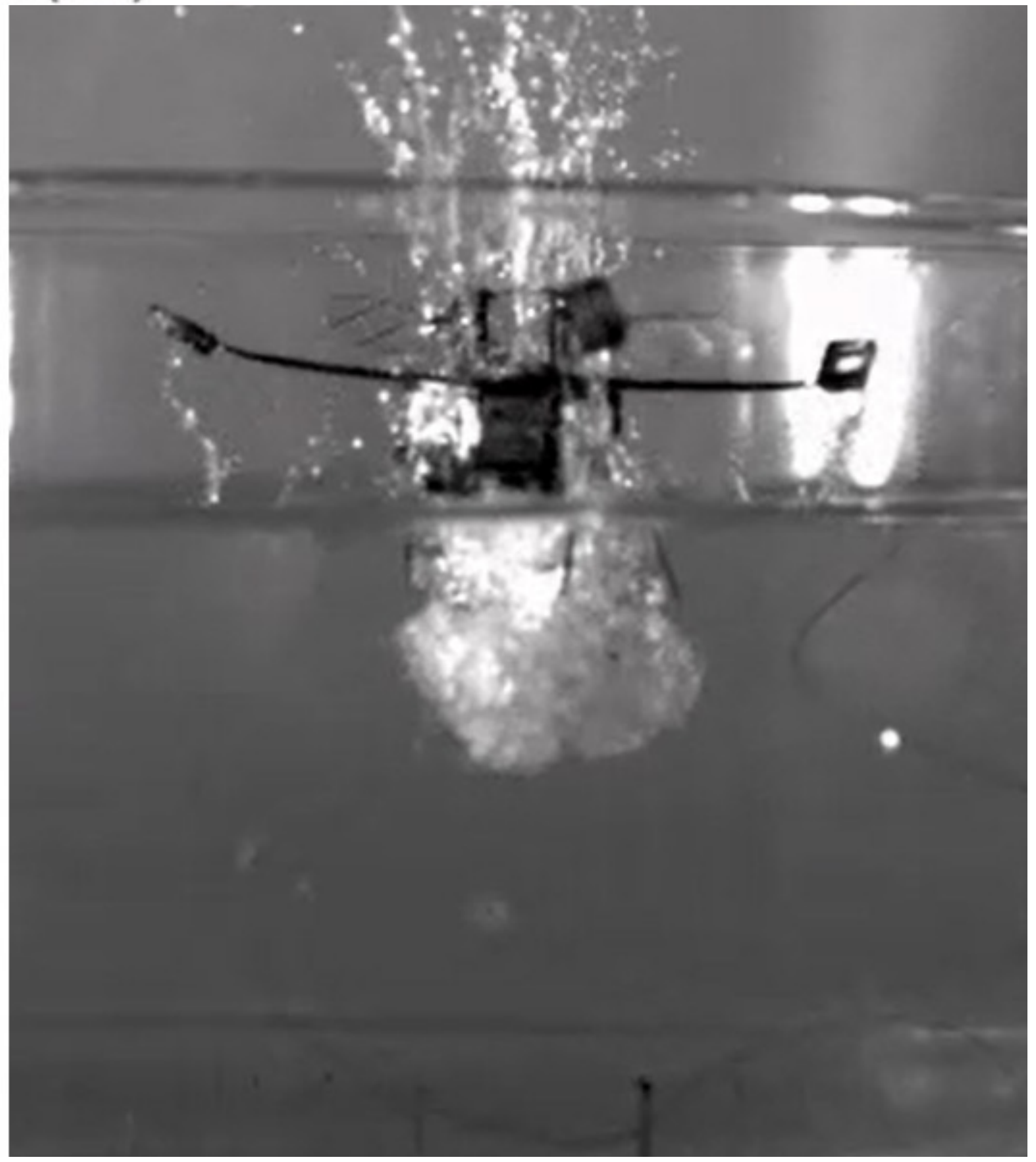
Science
JOURNALS AAAS

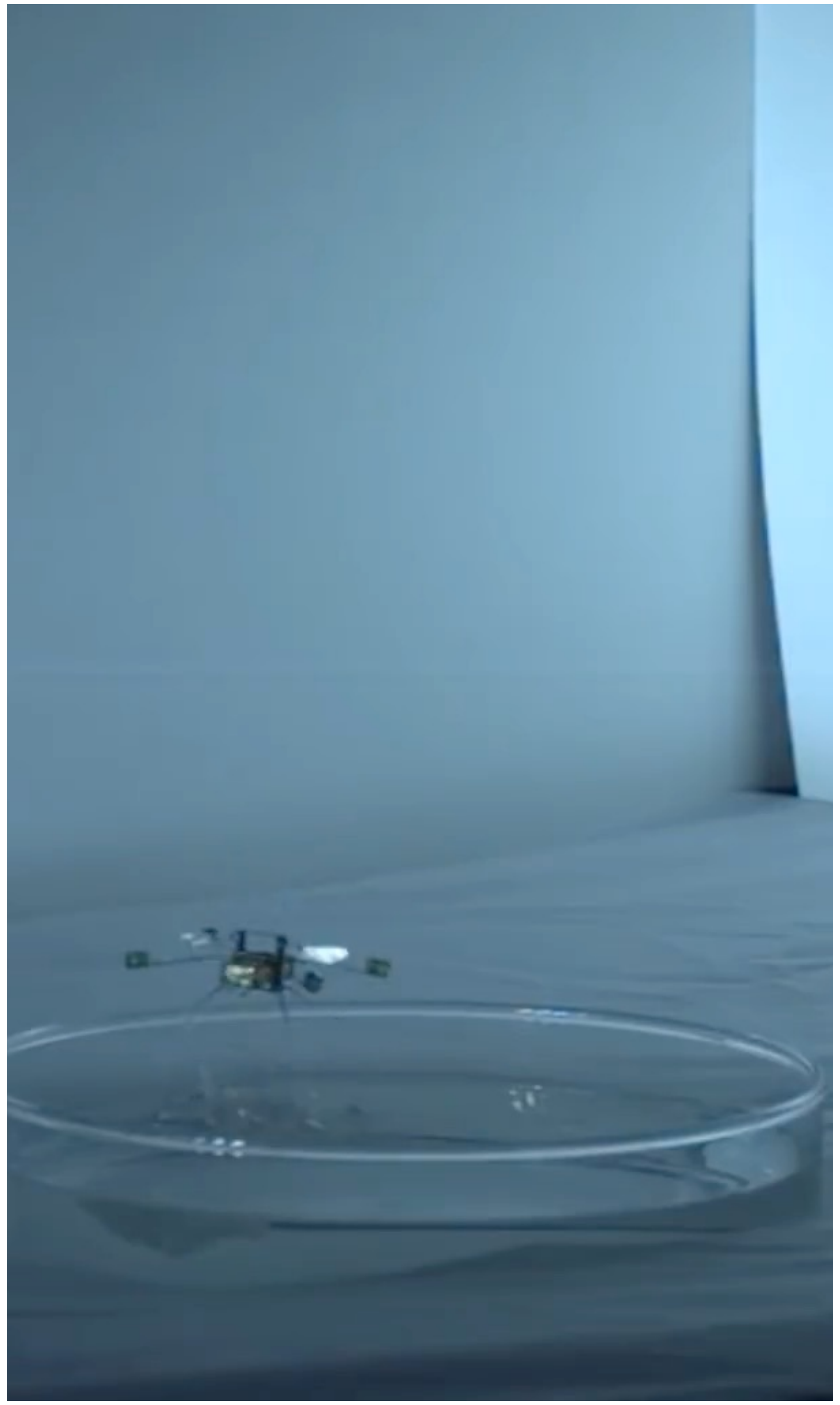












Chen, K., Zufferey, R., Kovac, M., Wood, R. et al.
Science Robotics (2017)

Empa | Imperial College London

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

Nature (Remora Fish) | Robot

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

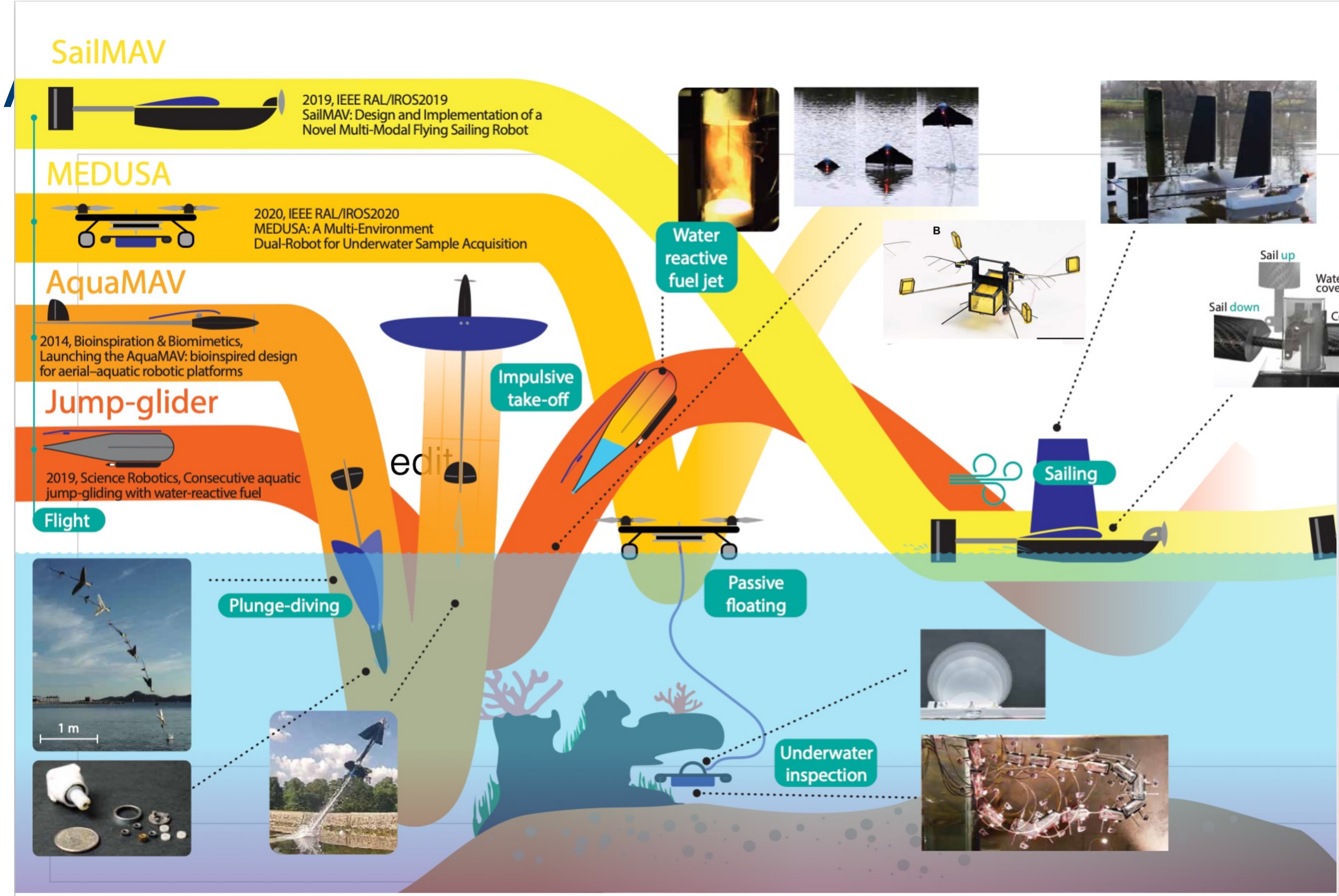
Raphael Zufferey, Alejandro Ortega, Célia Raposo, Sophie F. Armanini, Andre Farinha, Robert Siddall, Ion Berasaluce, Haijun Zhu and Mirko Kovac

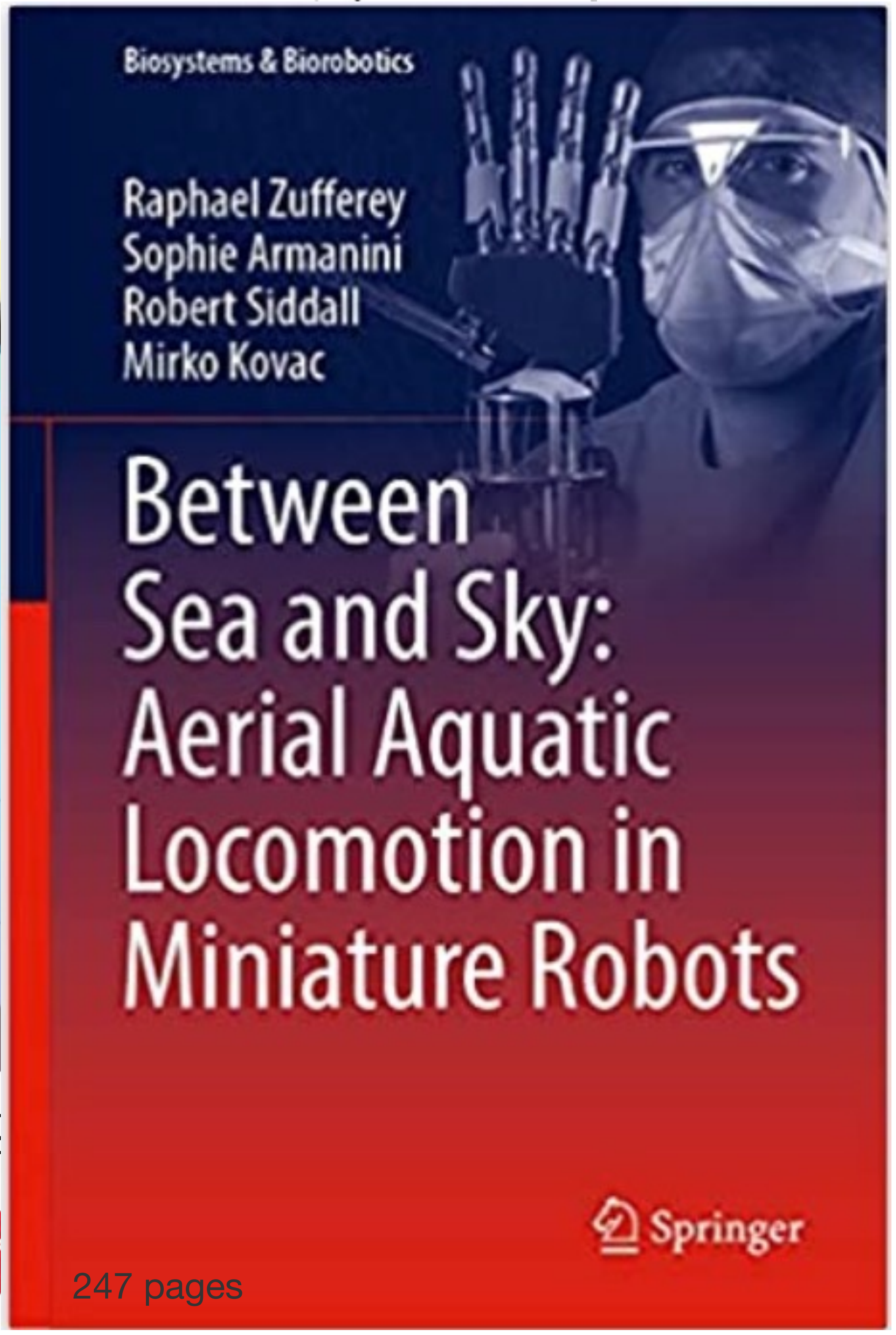
Aerial Robotics Laboratory, Imperial College London

Submitted 24.02.2019 to RA-L

Aerial - Aquatic Vehicles

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





Kovac et al. *Science Robotics* 2016, 2019, 2022, *Royal Society Interface Focus* 2x 2017, *ICRA/RA-L* 2016, 2017, 2
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

Meta-morphosis for tri-modal mobility

European Research Council

Consolidator grant 2021

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 Brahmal 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

theguardian

DroneHub

Building-drone interface for integrated living

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

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Imperial College London

D r o n e H u b

Building-drone interface for integrated living

Infrastructure Robotics Facade

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

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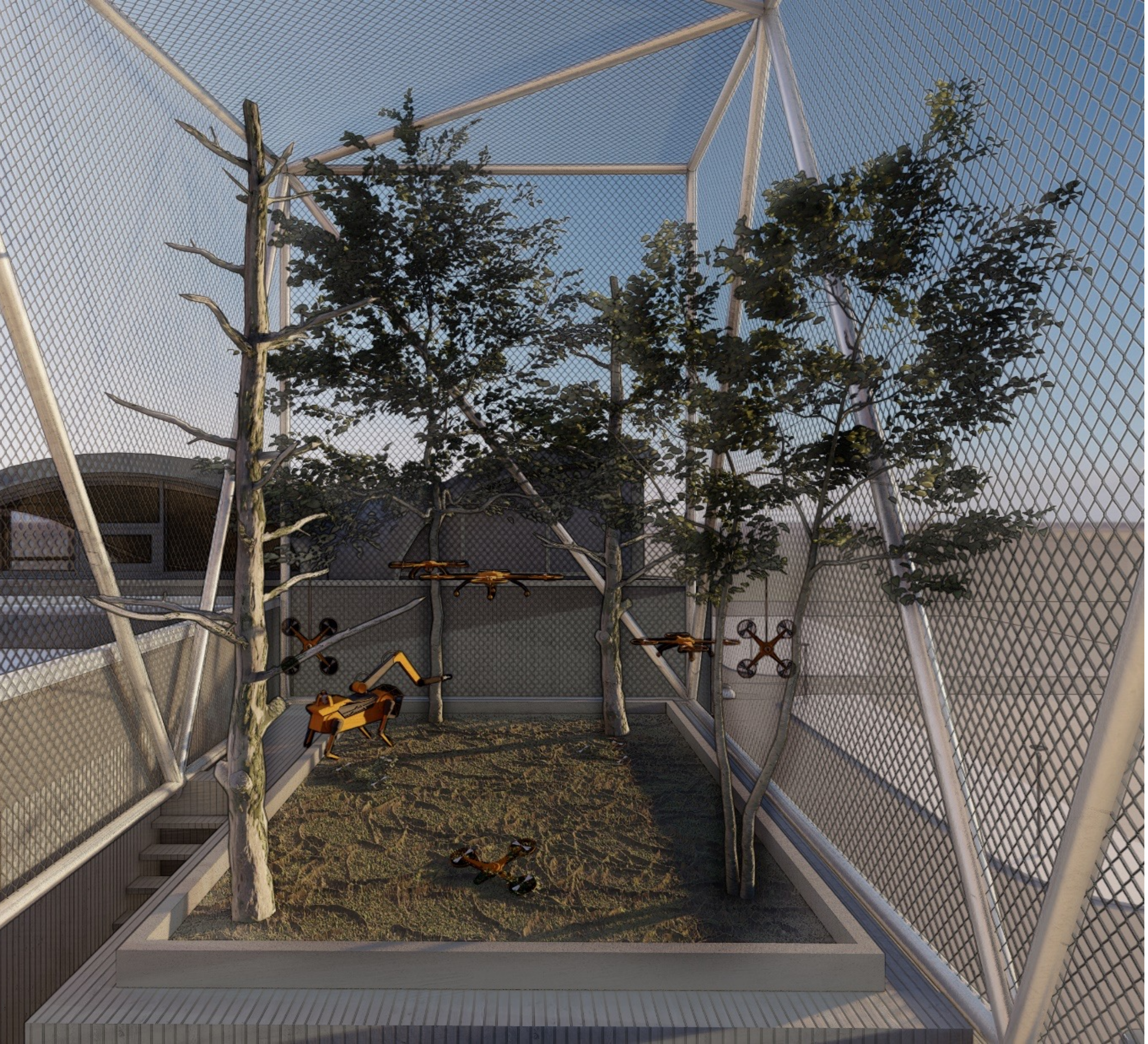
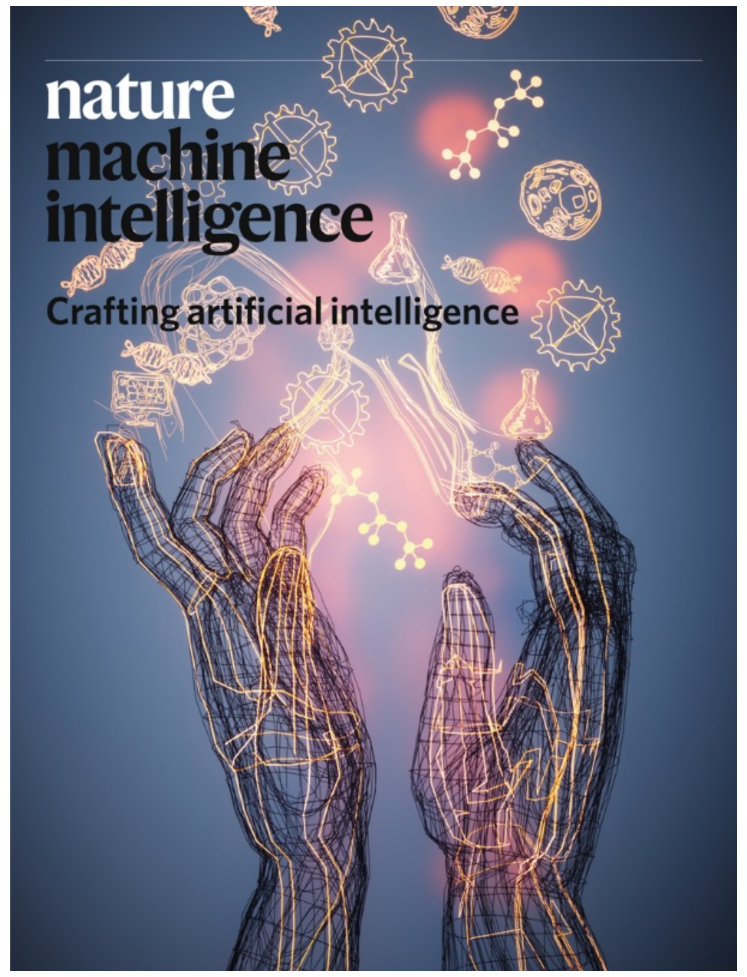


Biosphere for environmental sensing

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



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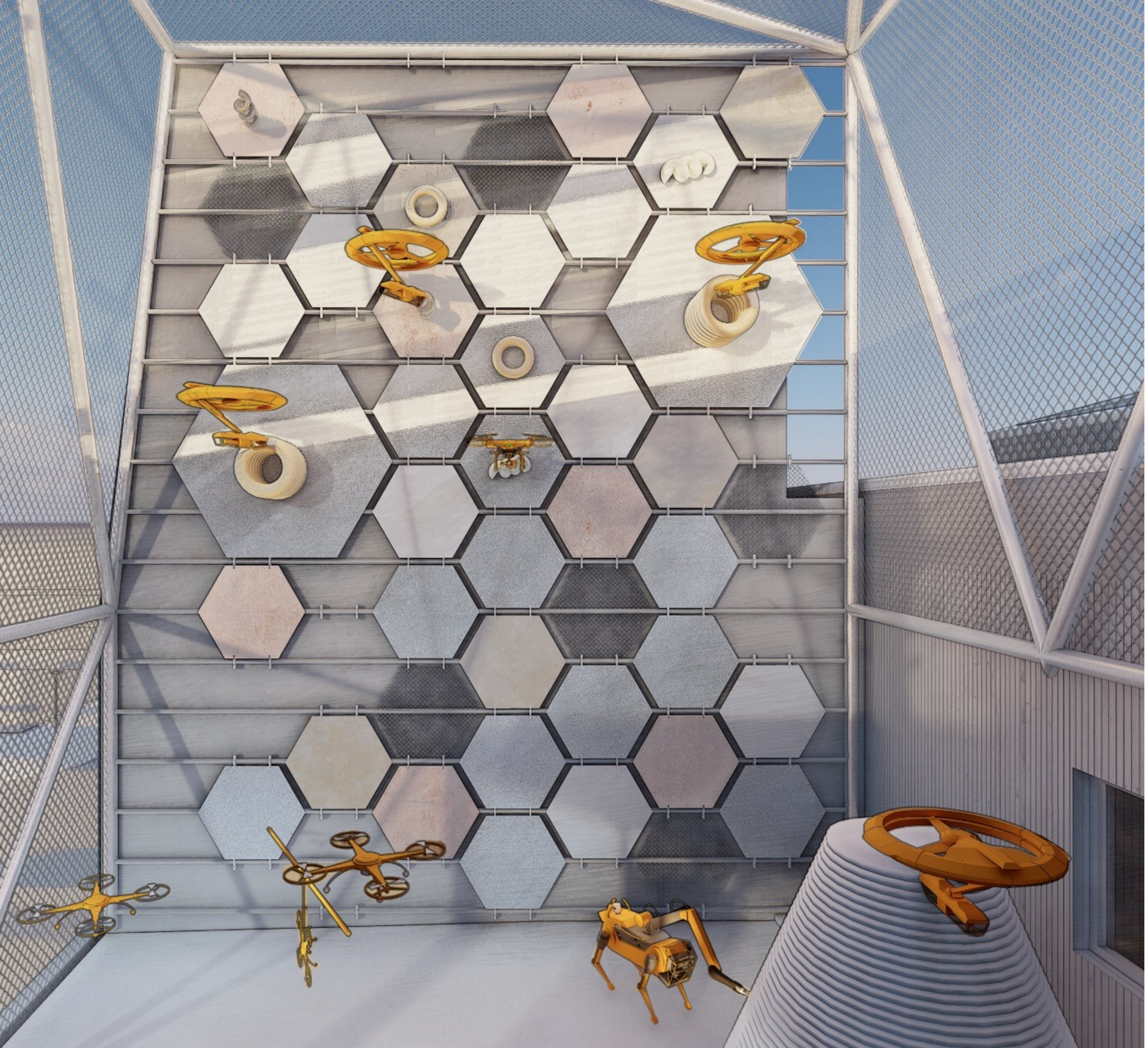

Aerial Additive Manufacturing

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

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Sustainability Robotics Testbed @ Empa

The 1000m^3 flight arena universal drone testbeds

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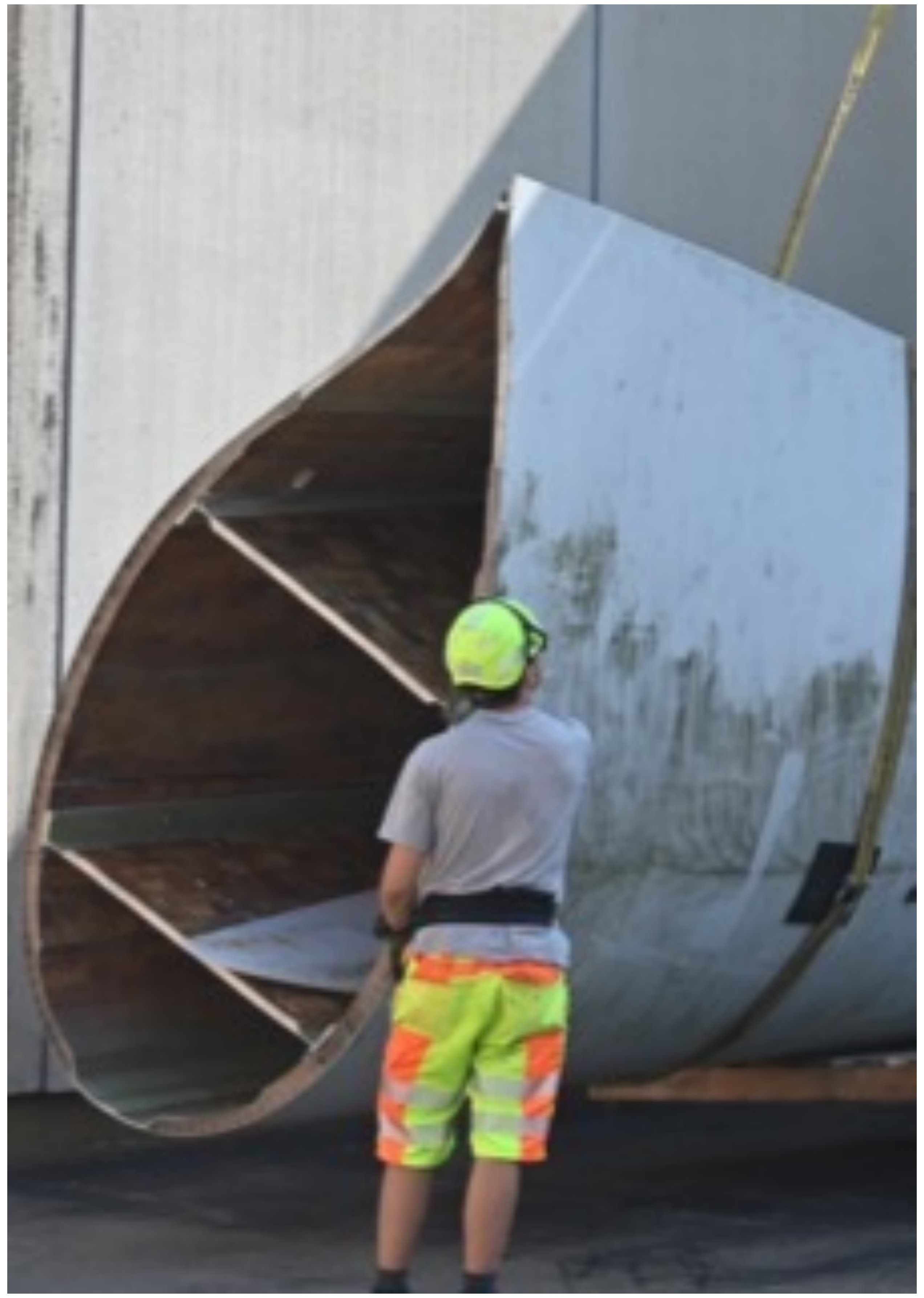
Sustainability Robotics Testbed @ Empa

Wind blade tip (7m)

Wind blade base (6m)



Bridge element (8m)

Water tunnels

Ecosystems of Autonomy at Empa

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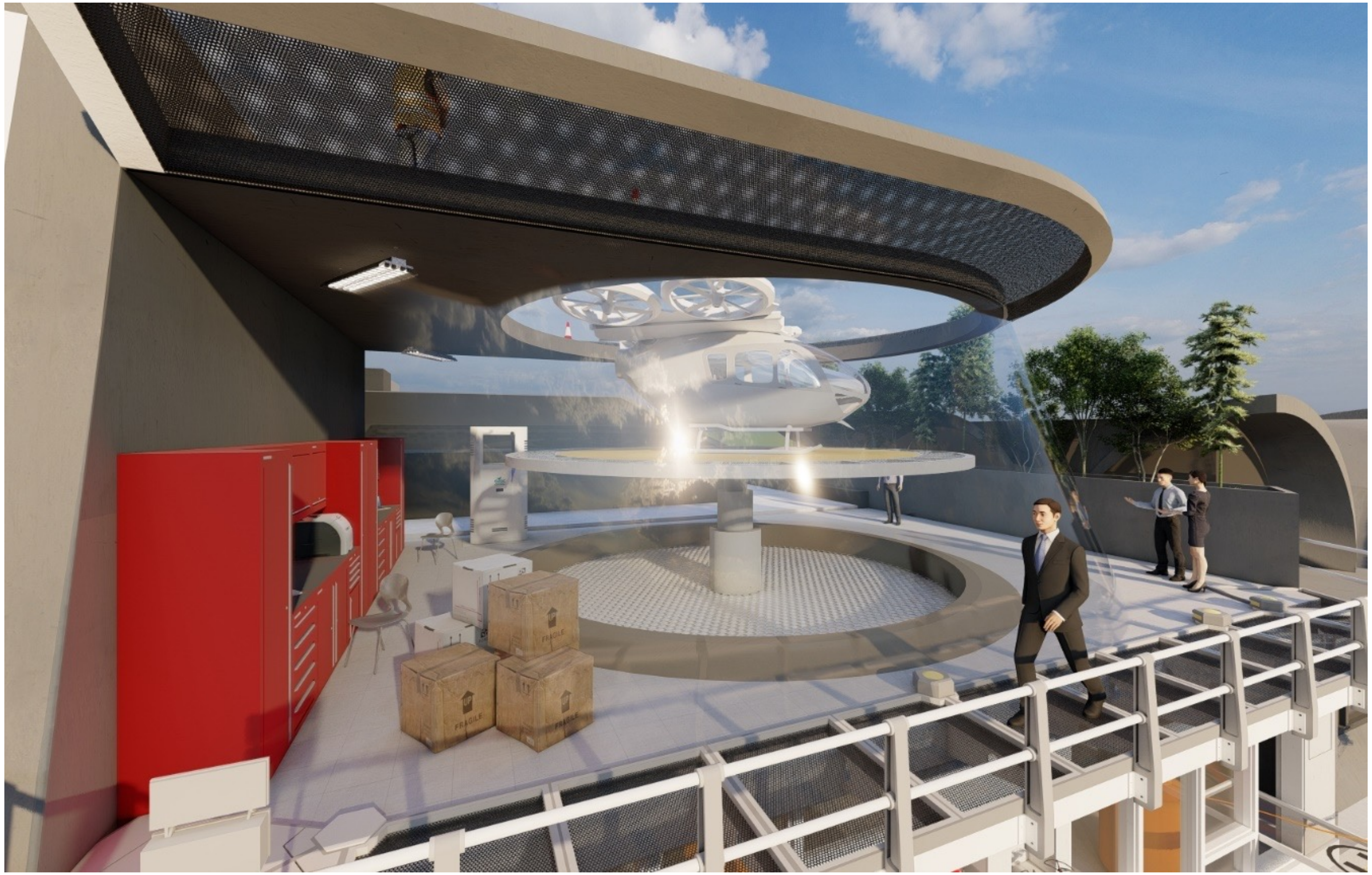
Autonomous Air Taxi interfaces



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Air-corridor in Dübendorf

Thank you!

HORIZON 2020

AeRoTwin

Imperial College London

[dstl]

ADIA

Abu Dhabi Investment Authority

RoboCom++

Rethinking Robotics for the Robot Companion of the future

Office of Naval Research Global Science & Technology

THE ROYAL SOCIETY

Royal Society Wolfson Fellowship

Imperial Fund for EU Partnership

Empa Materials Science and Technology

Imperial College London

Grantham Institute for Climate Change

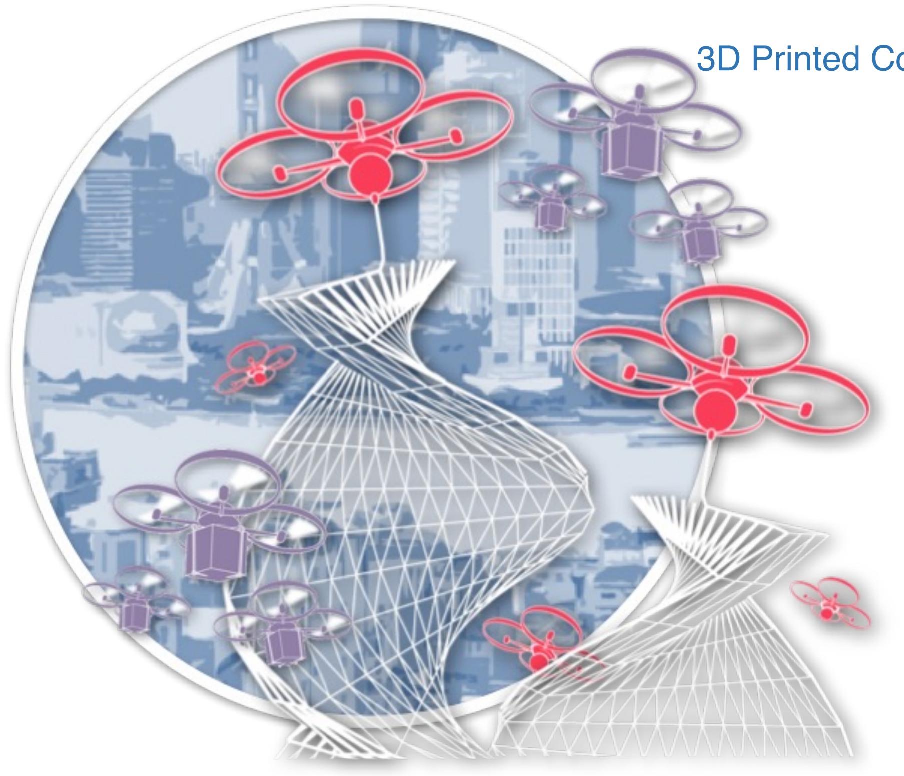
An institute of Imperial College London

NERC SCIENCE OF THE ENVIRONMENT

EPSRC Engineering and Physical Sciences Research Council

Aerial Additive Building Manufacturing (ABM) Research Grant
01/05/2016 - 30/04/2020, £3.4m
5 UK academic partners + 5 industrial project partners

3D Printed Construction using a Swarm of autonomous Aerial Robots



Aerial Robotics Laboratory | Imperial College London

UNIVERSITY OF BATH

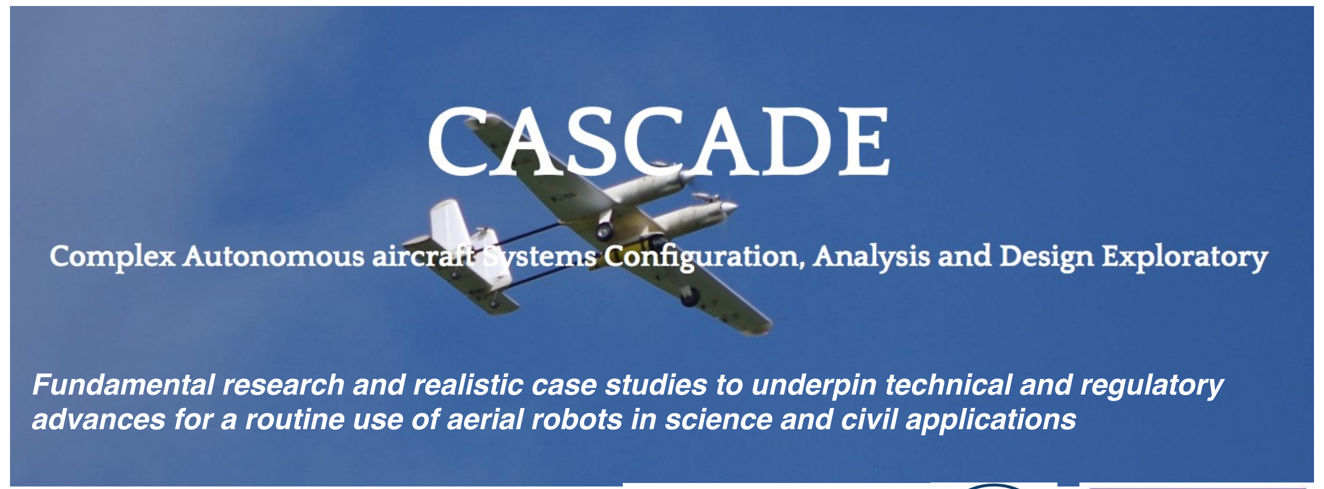
Smart Robotics Lab

Architectural Association School of Architecture

UCL

EPSRC Engineering and Physical Sciences Research Council

CASCADE Program Grant
01/02/2018 - 31/01/2021, £4.45m
5 UK academic partners + 26 project partners



University of Southampton, University of Bristol, Imperial College London, Cranfield University, The University of Manchester

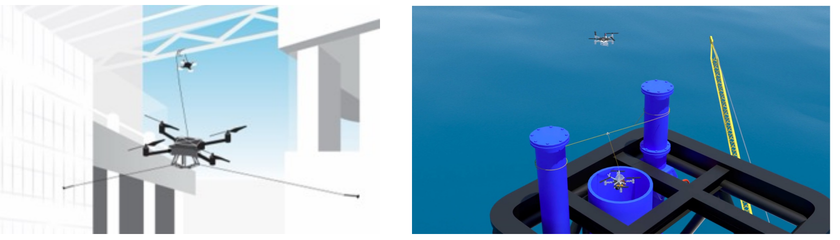
Research challenge on platform "capability" enabling radical new flying behaviour

EPSRC Engineering and Physical Sciences Research Council

ORCA HUB in the ISCF - Industrial Strategy Research Fund
02/10/2017 - 01/04/2021, £14.6m
5 UK academic partners + 31 industrial project partners

Edinburgh Centre for Robotics, Heriot Watt University, The University of Edinburgh, Imperial College London, University of Oxford, University of Liverpool

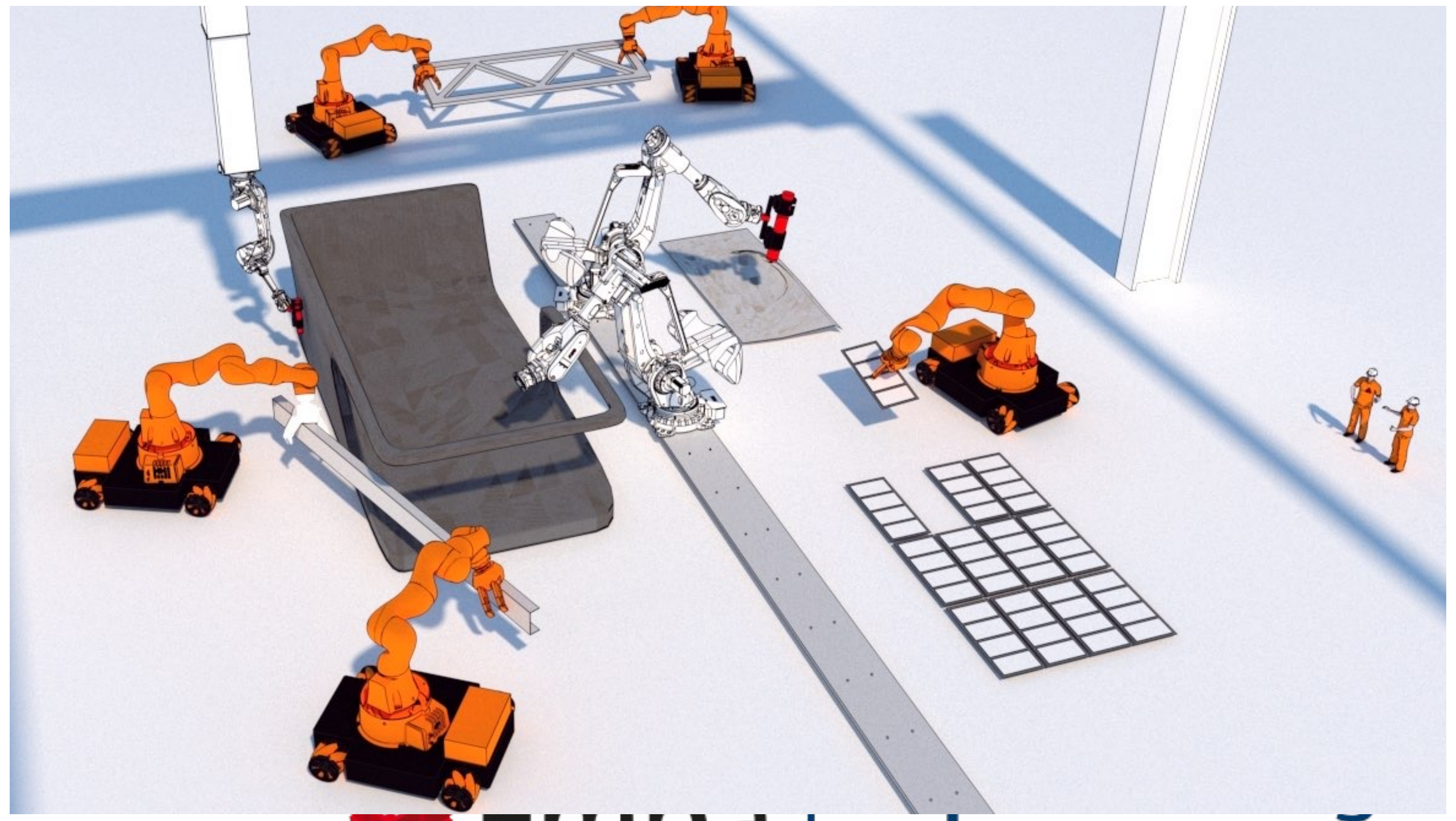
Aerial robots for infrastructure inspection and sensor placement



EPSRC Engineering and Physical Sciences Research Council

Applied off-site and on-site collective multi-robot, autonomous building manufacturing
01/01/2019 - 31/12/2021, £1.2m
2 UK academic partners + 6 industrial project partners

UCL | Imperial College London



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EPSRC Engineering and Physical Sciences Research Council

Aquatic Micro Aerial Vehicles (AquaMAV) Research Grant
01/06/2016 - 31/12/2016, £123,194

Illustration/visualisation credit: Yusuf Fukan Kaya, Robert Stuart-Smith, Jose Pereia, Aerial Robotics Lab

THANK YOU

For further inquiries
Mirko.Kovac@empa.ch

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

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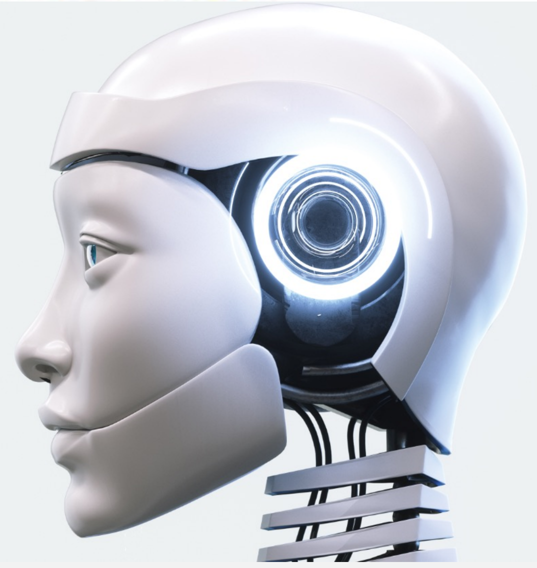
Call for Papers



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