InnoRenew CoE

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Engineered living materials
– the future of sustainable and resilient architecture

21st InnovaWood General Assembly

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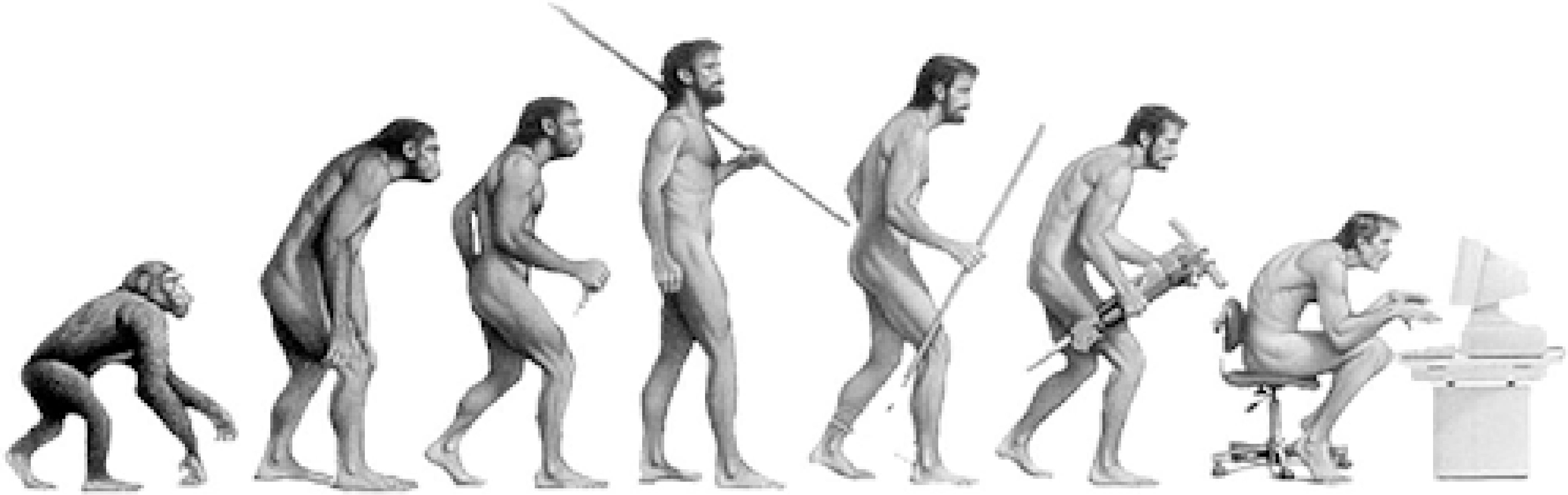
my research interests…



NIR spectroscopy – wood provenance – NMR & genetics – wood degradation – wood appearance & aesthetics – measurement of beauty – physiological responses – service life performance – wood modification & functionalization – biomimetic and bioinspiration – materiomics - engineered living materials

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ARCHI-SKIN

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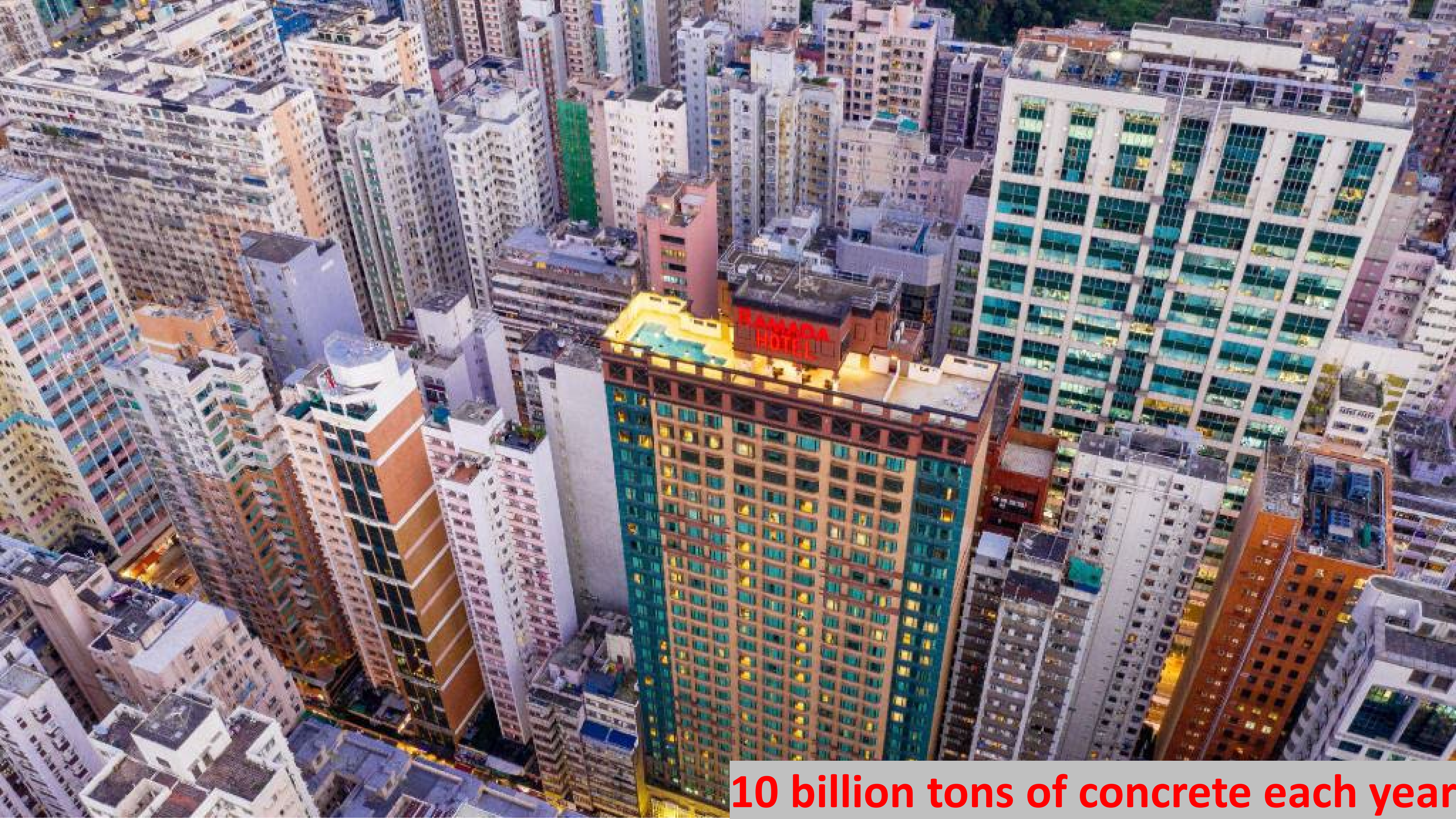
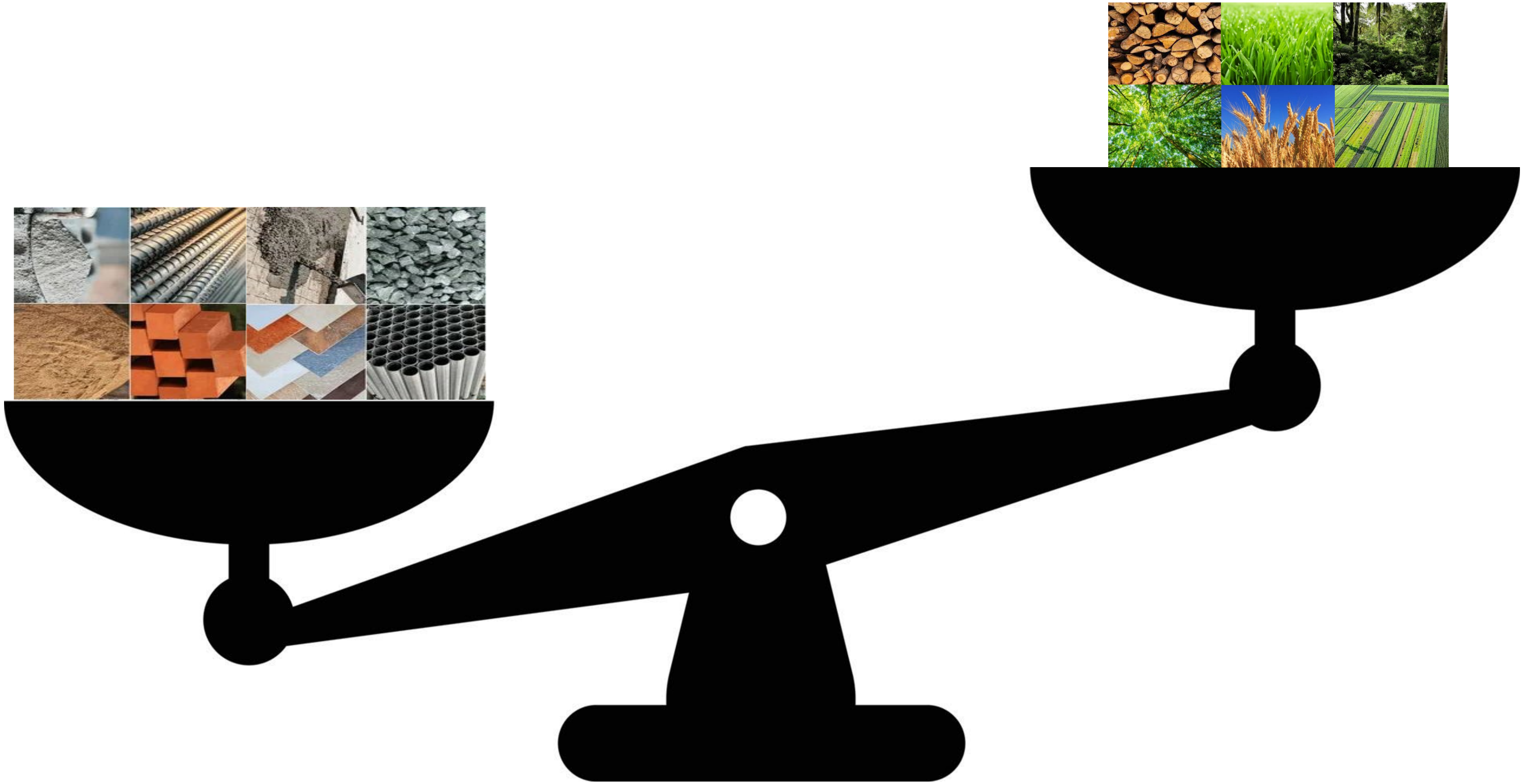
300,000 years





RAMADA
HOTEL
10 billion tons of concrete each year


300 million tons of plastic each year

14 million tons of plastic end up in oceans each year



Human-made materials, including concrete, metal, plastic, bricks and asphalt, exceed the overall living biomass on Earth

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Am Tunnel




Are all biobased building products fully sustainable and environmentally friendly?

- Engineered wood products
- Fiber boards
- Hybrid materials
- Resins
- Impregnates
- Biocides
- Adhesives
- External contaminations (e.g., metals)

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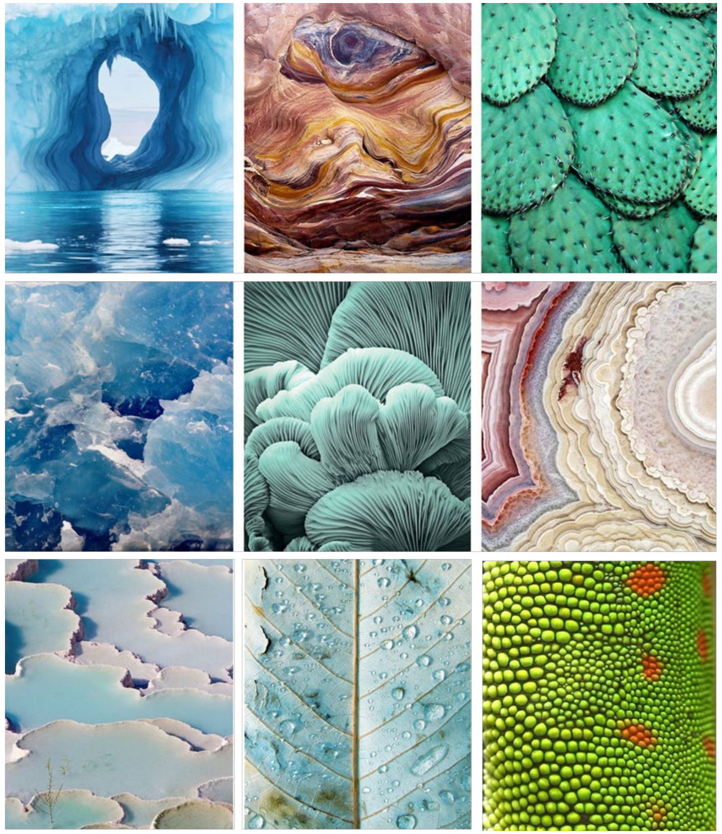
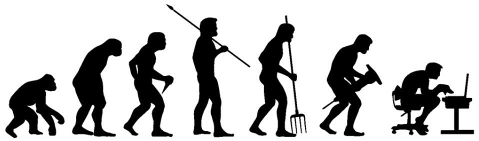
Do we need a new perspective on sustainability?

*"Living things have done everything we want to do, without guzzling fossil fuel, polluting the planet, or mortgaging their future.
What better models could there be?"*

Benyus: Biomimicry: Innovation Inspired by Nature



3.6 billion years of development



300,000 years

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Nature approach

- 96% of natural material is made from four elements: carbon, oxygen, hydrogen, and nitrogen
- Use of resources in closed-loop cycles
- The waste from one becomes a nutrient for another organism
- Long-term release of toxic emissions is very rare
- Processes at ambient temperature and atmospheric conditions
- Hierarchical structure with varying properties at different levels
- Simple, functional, and reliable solutions

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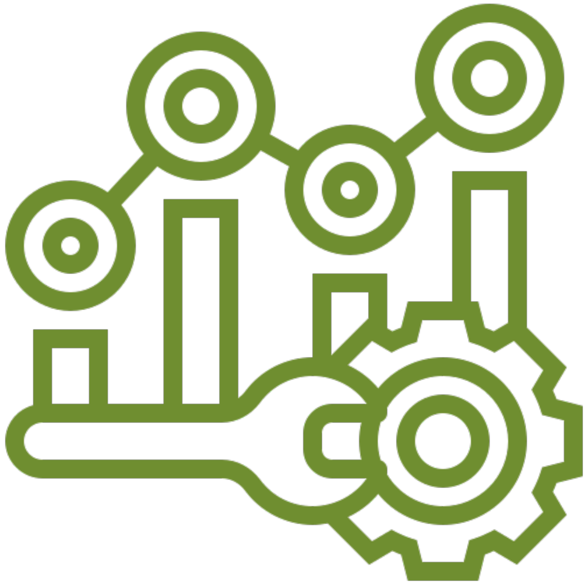
Biological systems

multifunctional



optimized

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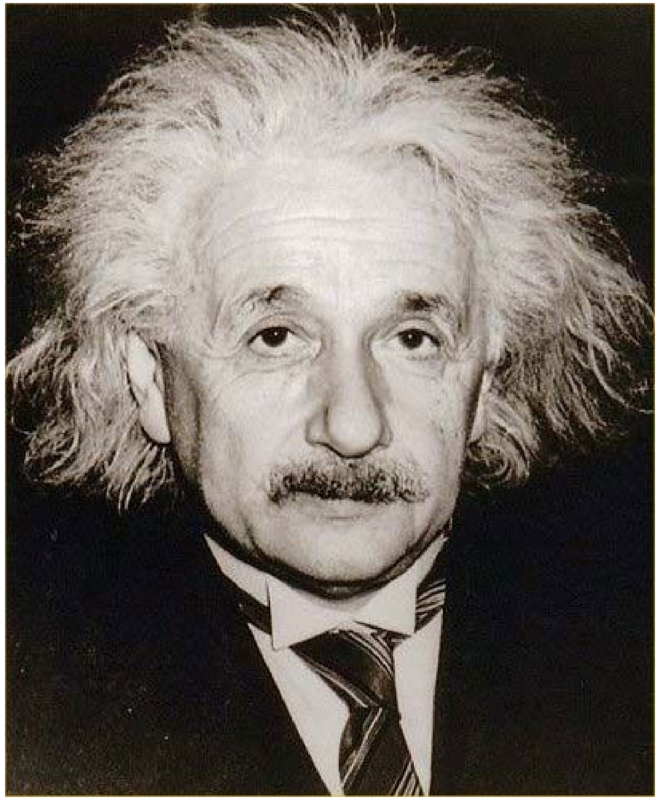
Inspiration or imitation?
Bioinspiration or biomimicry?



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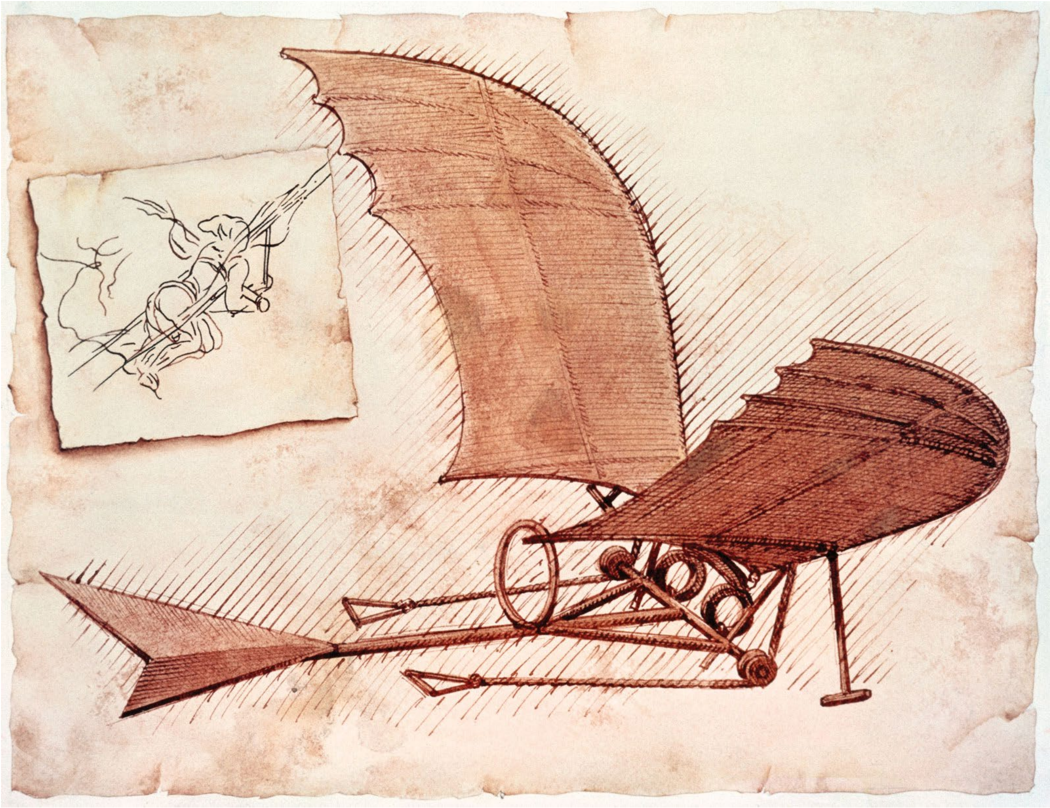
Systems created in nature might inspire development of new concepts, materials and solutions in various fields



Bioinspired innovations

- things that are created in nature can inform the development of new materials;
- the natural organization can inform potential shapes for man-made materials;
- the way organisms perceive can inspire a new generation of sensors;
- the way animals and plants move in their environment can inform advances in mechanics and kinetics;
- the way living organisms interact can inspire new ways of communication,
- the way living organisms perform can inspire man-made processes.

Shinkansen

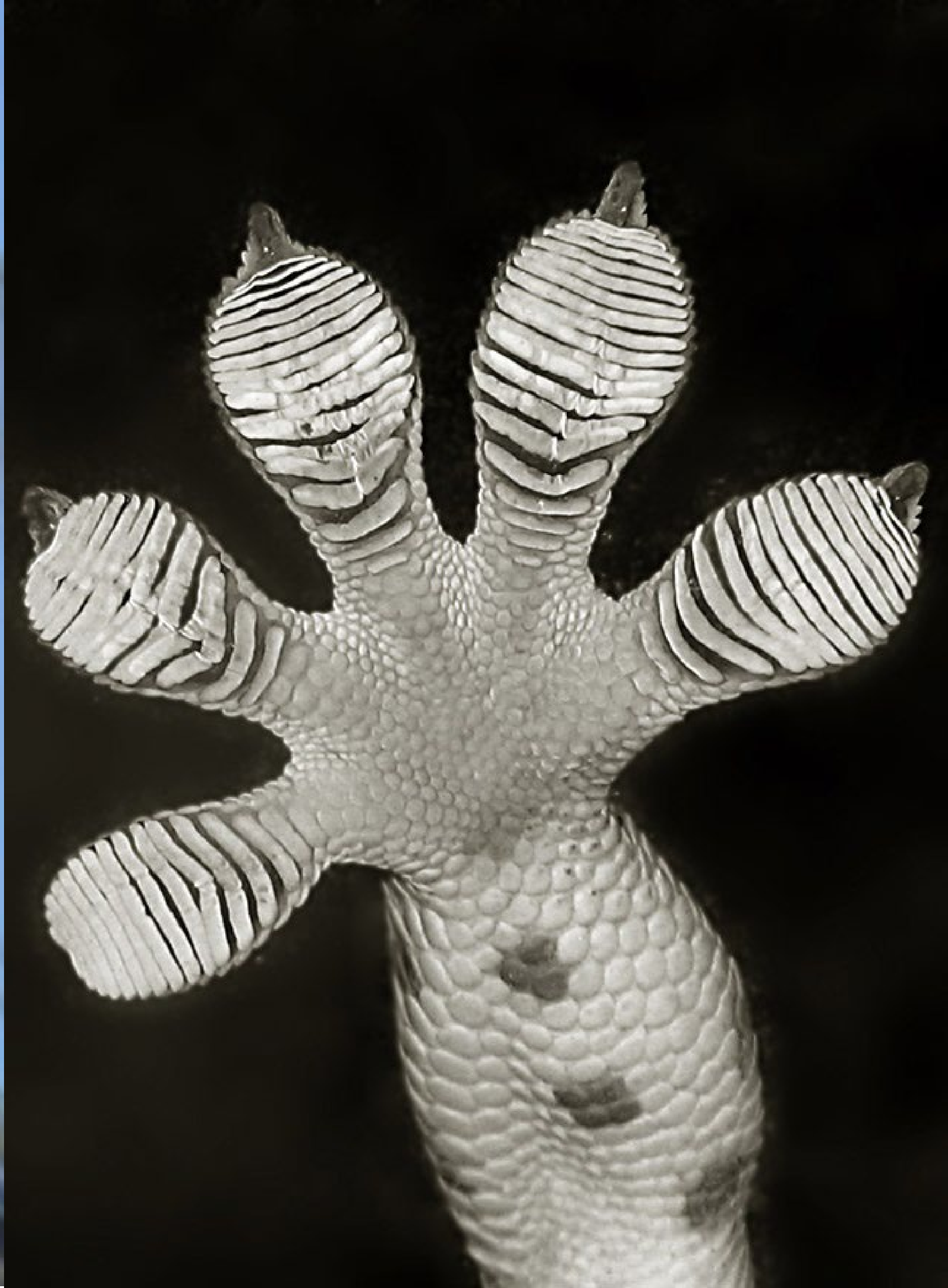
https://earthsky.org/earth/sunni-robertson-on-how-a-kingfisher-inspired-a-bullet-train

Shark inspired swimming suit

https://www.sciencehistory.org/distillations/winning-skin

Gecko inspired climbing adhesives

https://www.sciencemag.org/news/2014/11/gecko-inspired-adhesives-allow-people-climb-walls



Biomimicry for materials development

- smart materials reacting in response to external stimuli
- novel materials shape and structural arrangement
- surface modifications

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Can we go beyond that?

Materials in nature

Valuable properties of materials in nature include programmability, multifunctionality, or the **'self'-properties** such as self-growth, self-adaptivity, self-assembly, or self-healing

What if materials with these characteristics could be made?

Which kind of new applications will be possible?

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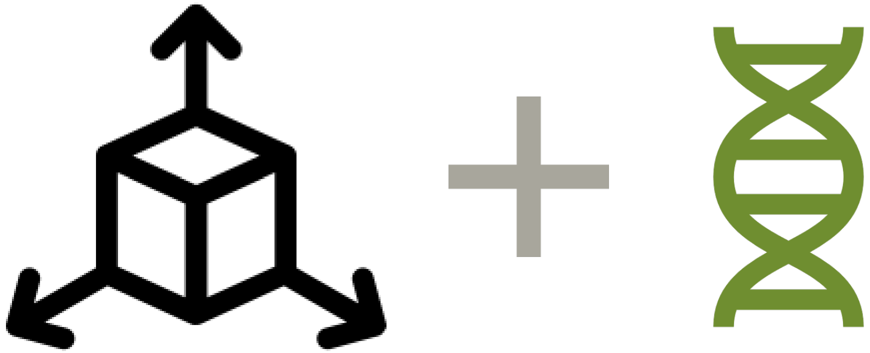
Engineered Living Materials (ELM)

engineered materials are composed of living cells
that form or assemble the material itself
or modulate the functional performance of the material



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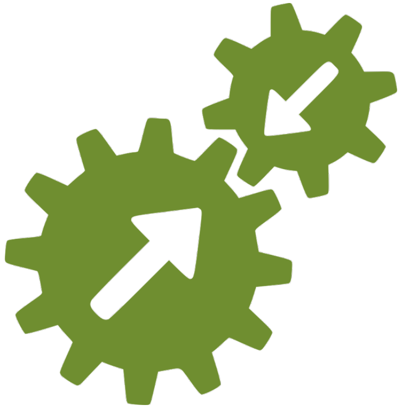
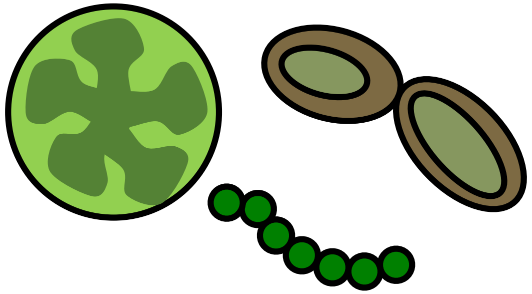
Desired properties





- remodelling
- self-regulation
- self-replication
- resilient
- sensing
- signalling
- UV protection
- anti-corrosion
- evolvability
- self-healing
- antioxidant
- selective antimicrobial
- oxygen generation
- CO_2 sequestration
- bioremediation

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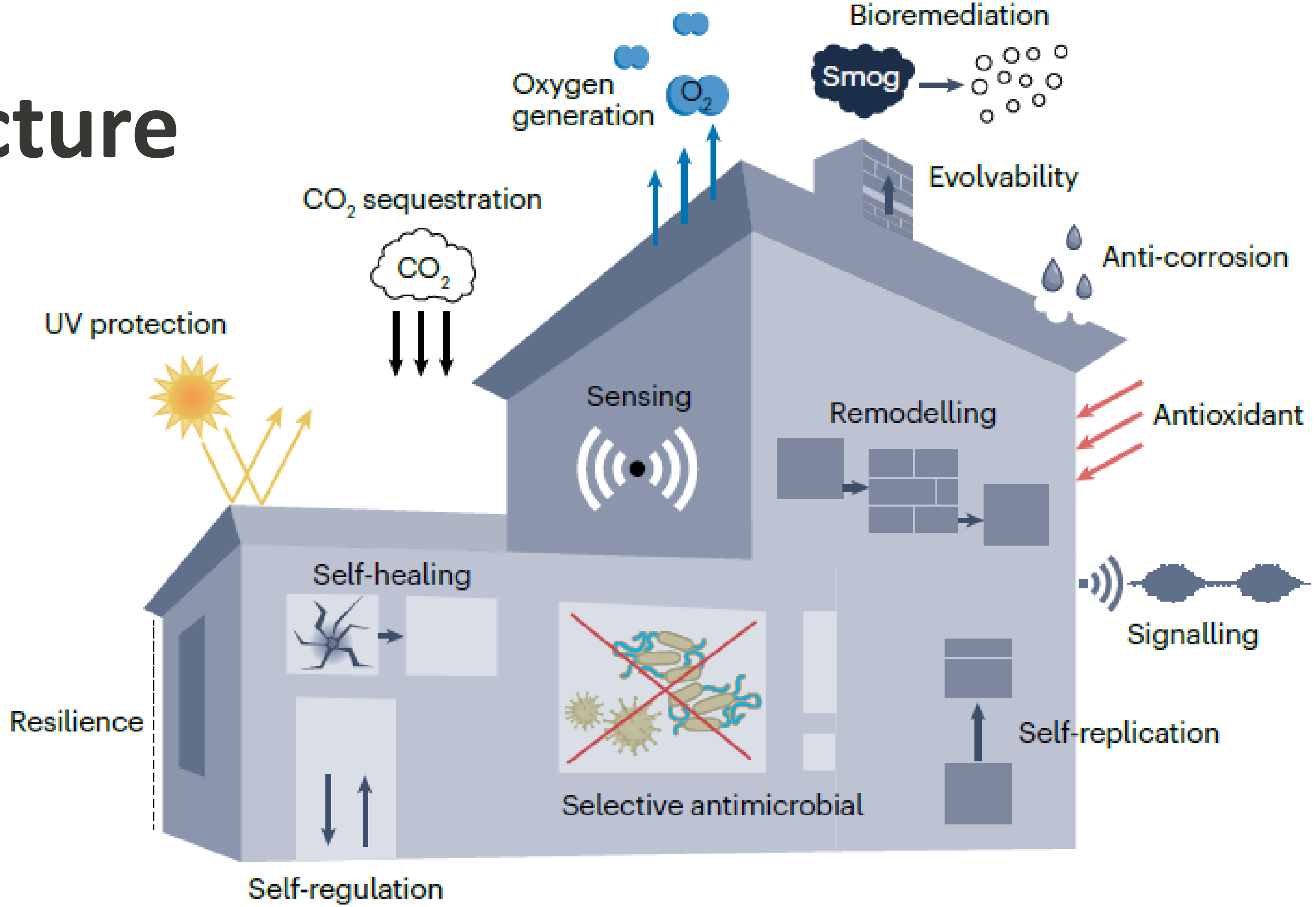
ELMs in architecture



Anna Sandak (2023) Engineered living materials for sustainable and resilient architecture
Nature Reviews Materials DOI:10.1038/s41578-023-00554-0

Coatings in architecture

- Architectural surfaces account for most of the demand for coatings, paints, and varnishes.
- The global exterior architectural coatings market size was valued at $44.4 billion in 2021 and is projected to reach $57 billion by 2027.
- 50 billion of liters produced in 2020

16000 Olympic swimming pools or amount of beer consumed yearly in Europe!

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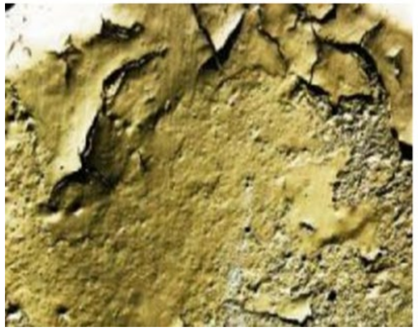
Weathering process





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Human approach

The conventional methods to improve coatings performance, based on adding biocides, mineral oil or synthetic chemicals make the formulation toxic and environmentally unfriendly.

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ARCHI-SKIN approach

The ARCHI-SKIN project will revolutionize conventional material protection by developing a new generation of active architectonic coatings

Smart living surfaces & engineered living materials

Bioremediation & self-healing

Coatings on different substrates in diverse climates

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https://realmomsdentalpocketguide.com/cavities-sweat-small-stuff-pt2/dental-plaque-sem

Using biofilm for materials protection?

- Functional application of biofilms for the protection of materials is rare.
- Research on biofilms focuses on the prevention of biofilm formation.

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Fungi

120,000 fungal species identified (with 1.5 million estimated)

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Fungal biofilm

Fungi are particularly adapted to grow on surfaces. It is evidenced by:

- their absorptive nutrition mode,
- secretion of extracellular enzymes to digest complex molecules,
- apical hyphal growth.

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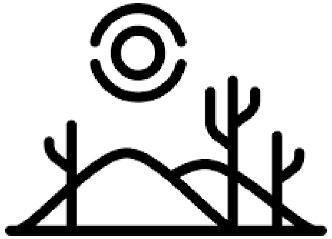
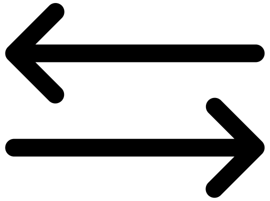
Aureobasidium pullulans

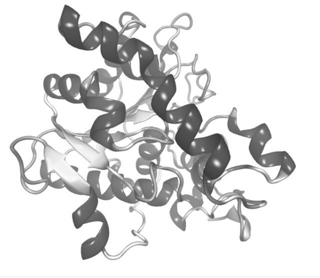
ubiquitous



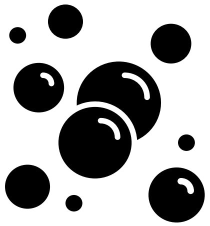
polyextremotolerant



phenotypic plasticity



enzymatic profile



pigmentations

not toxic

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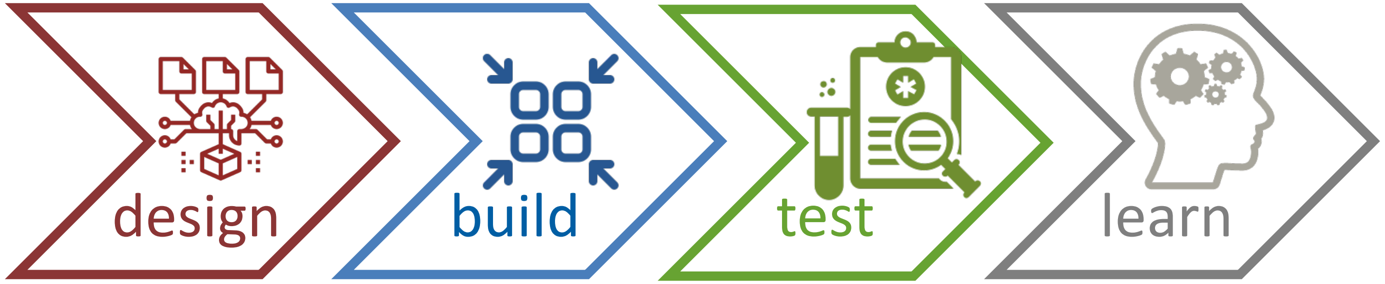
Methodology



EXPLORATION PHASE
UNDERSTANDING OF BIOFILM STRUCTURE

materiomics
live cell imaging

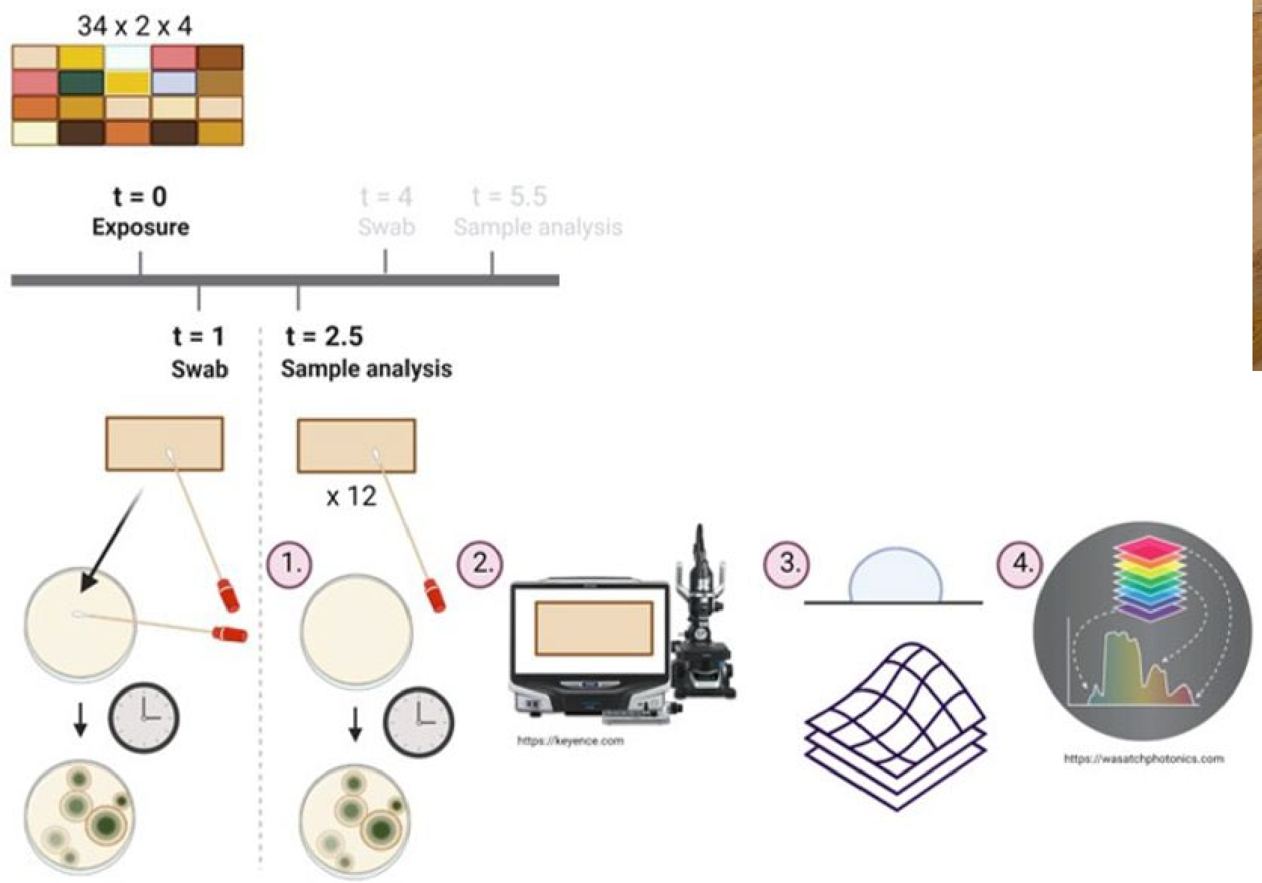
RESEARCH PHASE
DESIGN OF COATING SYSTEMS

in-silico methods
tailored formulations

VALIDATION PHASE
PERFORMANCE DEMONSTRATION

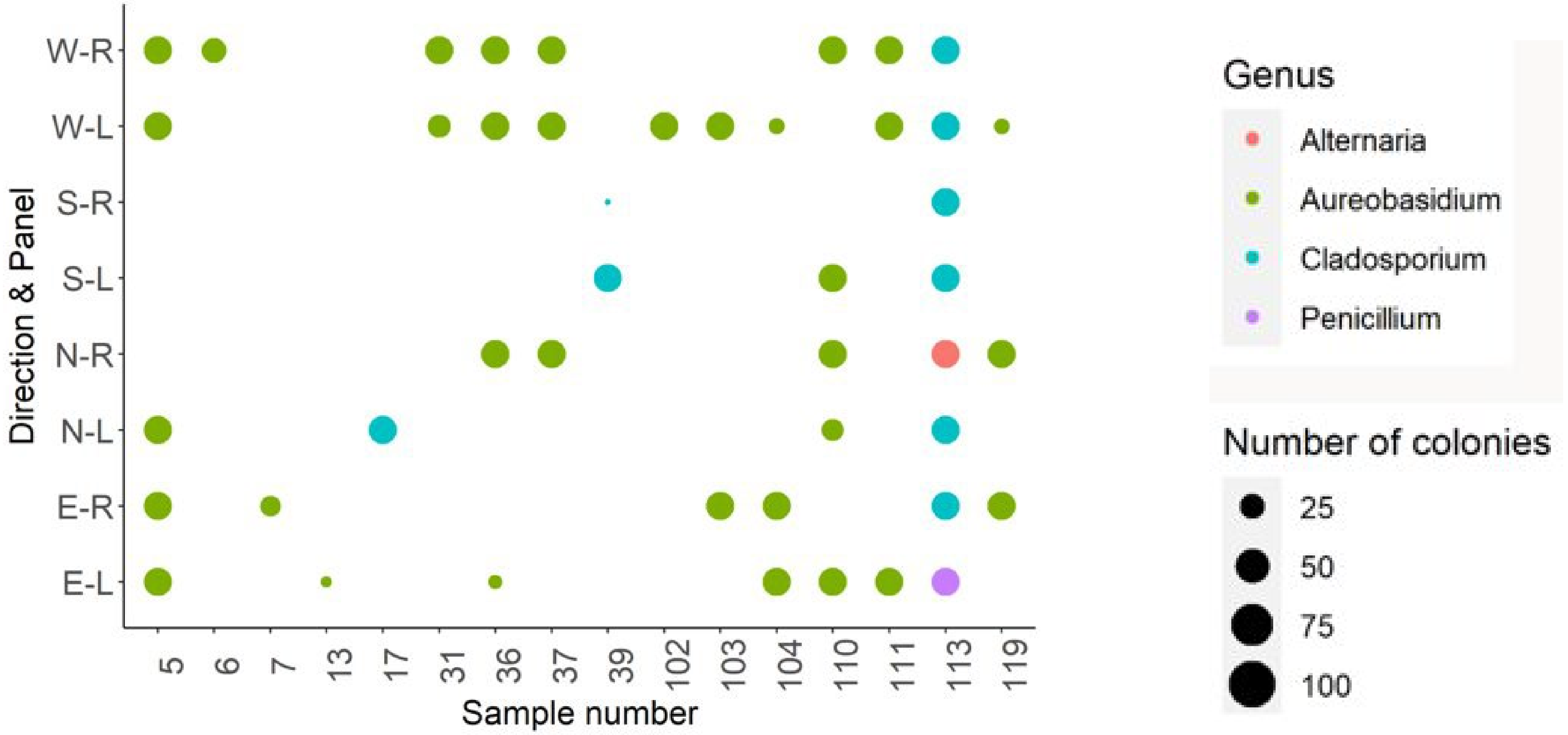
multi-functionality
biofilm stability

Bioreceptivity



multi-mode microplate reader
monitoring of the cell-growth cycle and cell-signaling events

Dominant species after 1-month exposure



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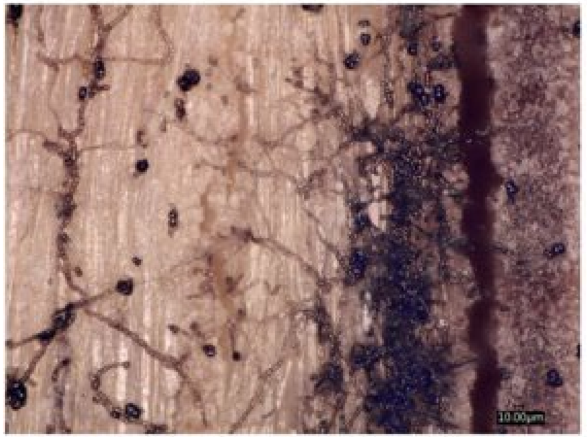
Surface investigation

Sample: 043
Tree: Beech
Group: Natural

Sample: 050
Tree: Beech
Group: Chemically modified, acetylated



digital optical microscope

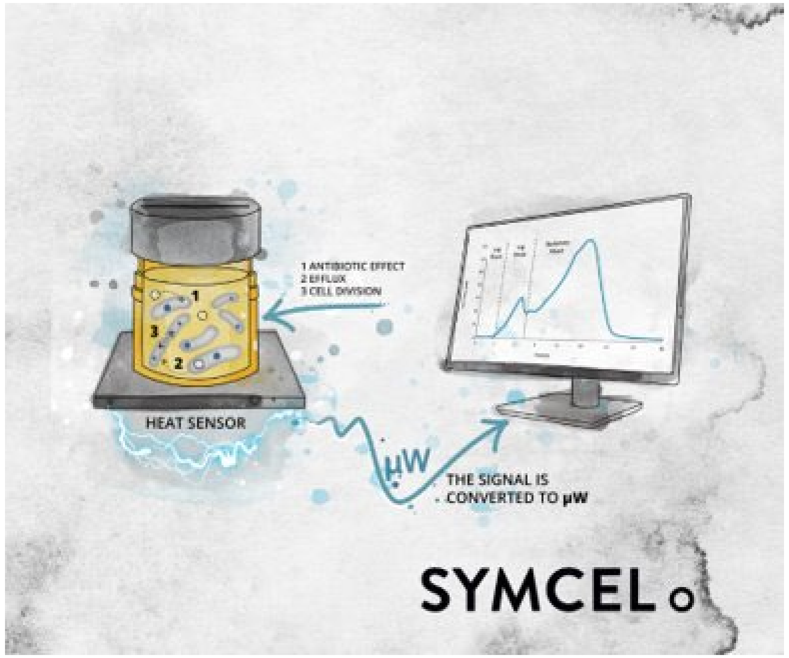
conventional colony counting

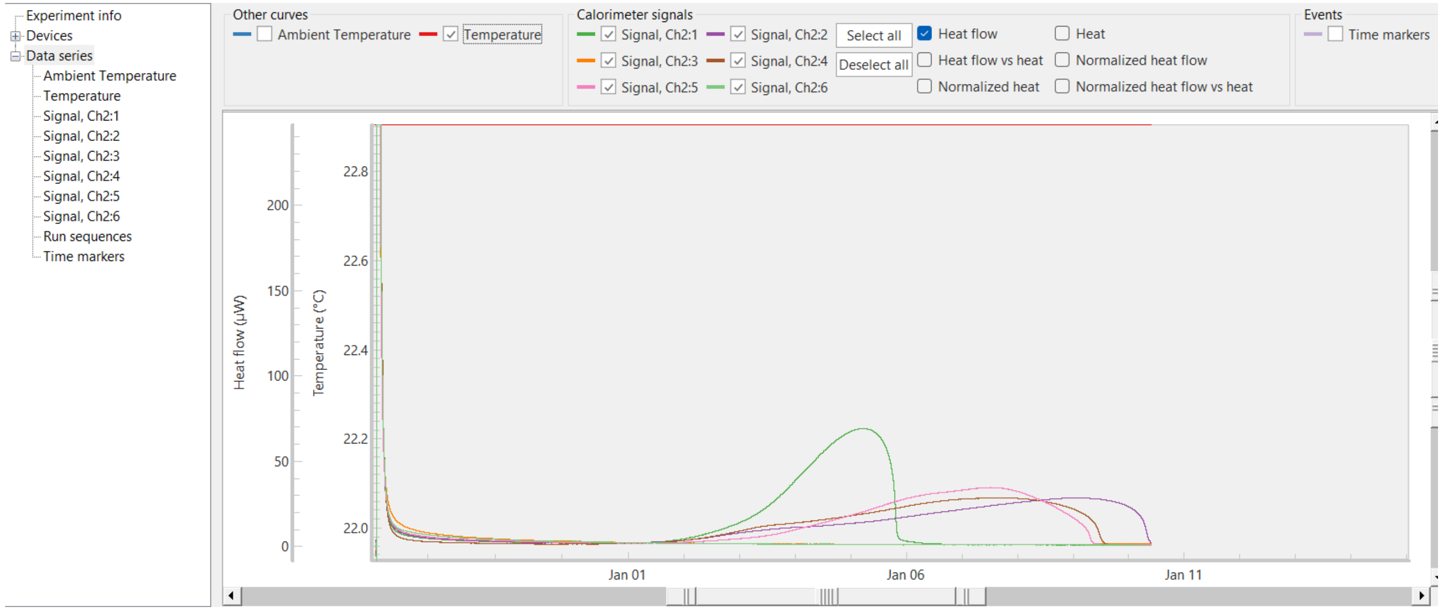
supported with high throughput methodology – hyperspectral and multispectral imaging

Microcalorimetry

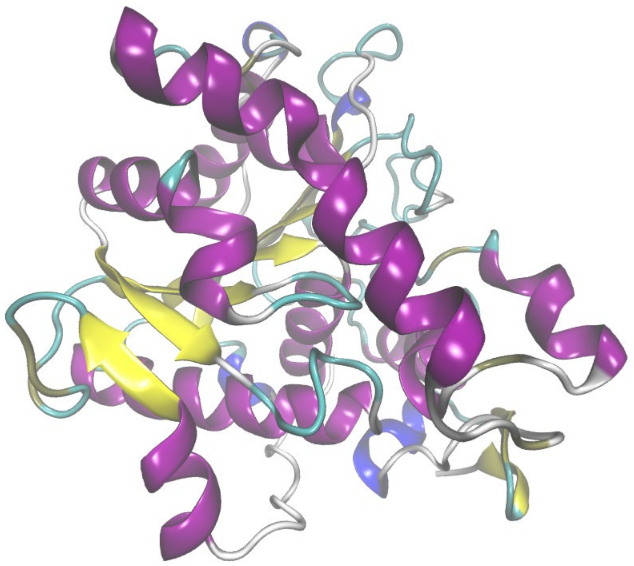
metabolism → heat

Sample ID	Sample Treatment	Innoculation
Chanel: 1	SN medium + olive oil	*A. pullulans*
Chanel: 2	SN medium + olive oil	*A. pullulans*
Chanel: 3	SN medium + olive oil	control/water
Chanel: 4	Olive oil	*A. pullulans*
Chanel: 5	Olive oil	*A. pullulans*
Chanel: 6	Olive oil	control/water

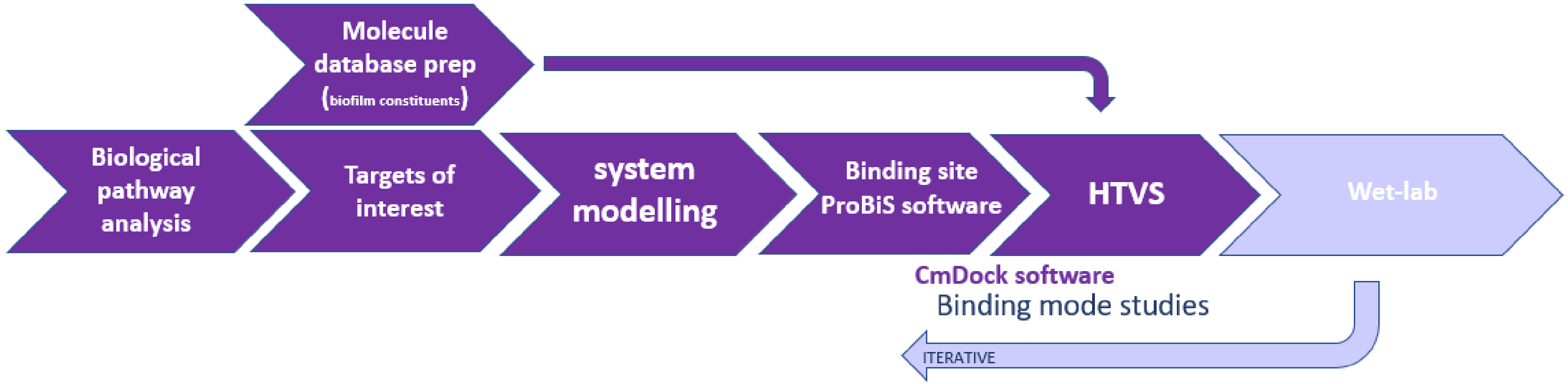




Molecular docking



A. pullulans are reported to produce amylases, cellulases, lipases, xylanases, proteases, laccase, mannanases, nucleases, urease, and phosphatase, which indicate the broad range of substances that might serve as nutrients.



modelling and optimisation of the best nutrient source for selected fungal strains

In collaboration with dr. Jure Pražnikar and dr. Marko Jukić - Department of Applied Natural Sciences, FAMNIT, UP

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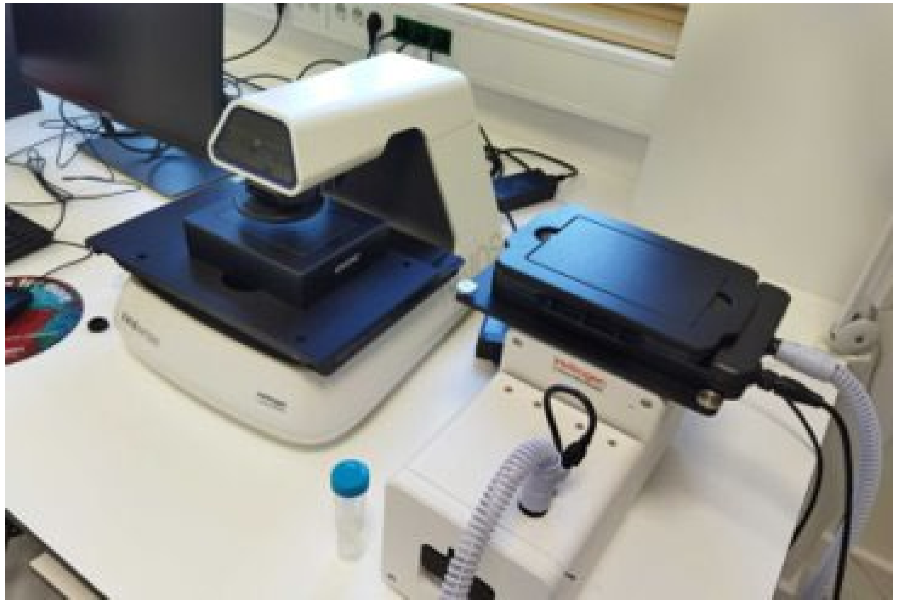
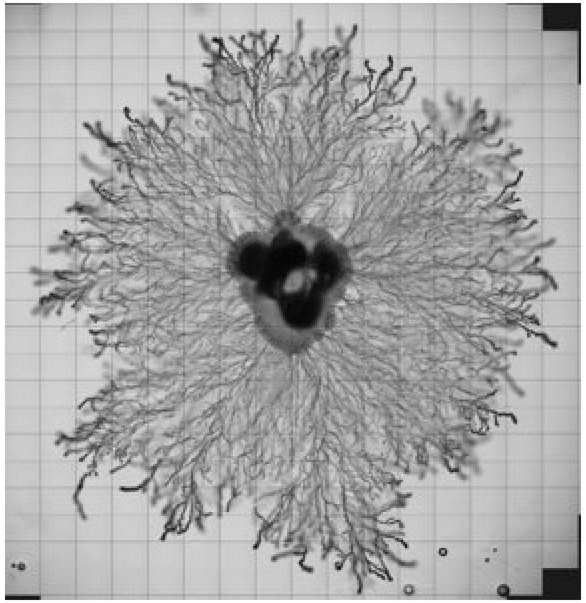
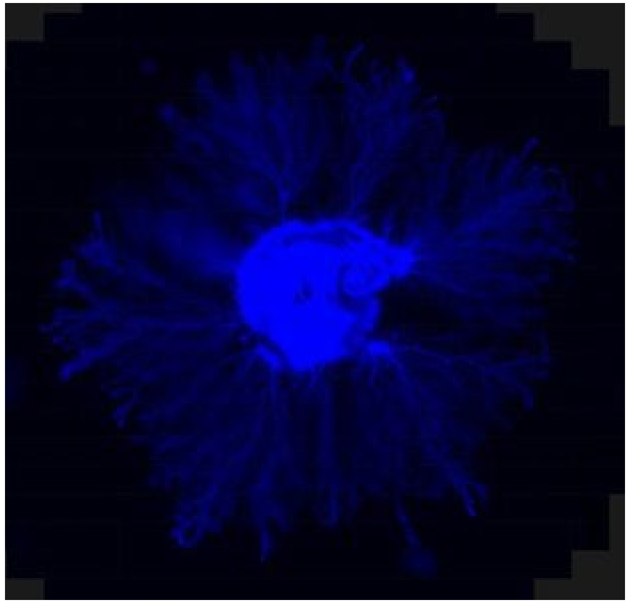
Time lapse microscopy



EVOS M7000, ThermoFisher Scientific



100x, trans, after 3 days

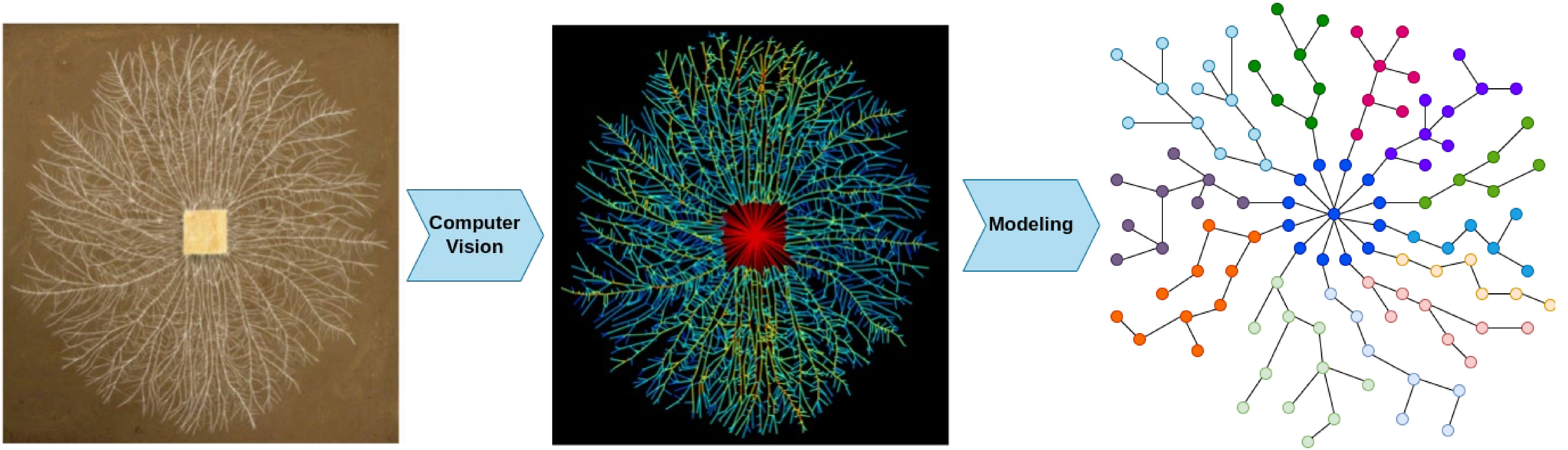


100x, DAPI, after 3 days

Inoculation of 2 ml SNA agar in 6-well plate with *A. pullulans*: 3 wells SNA, 3 wells SNA+Calcofluor White (1ul/ml)
Placed in incubation chamber at 22°C

Mathematical modelling of fungal mycelia

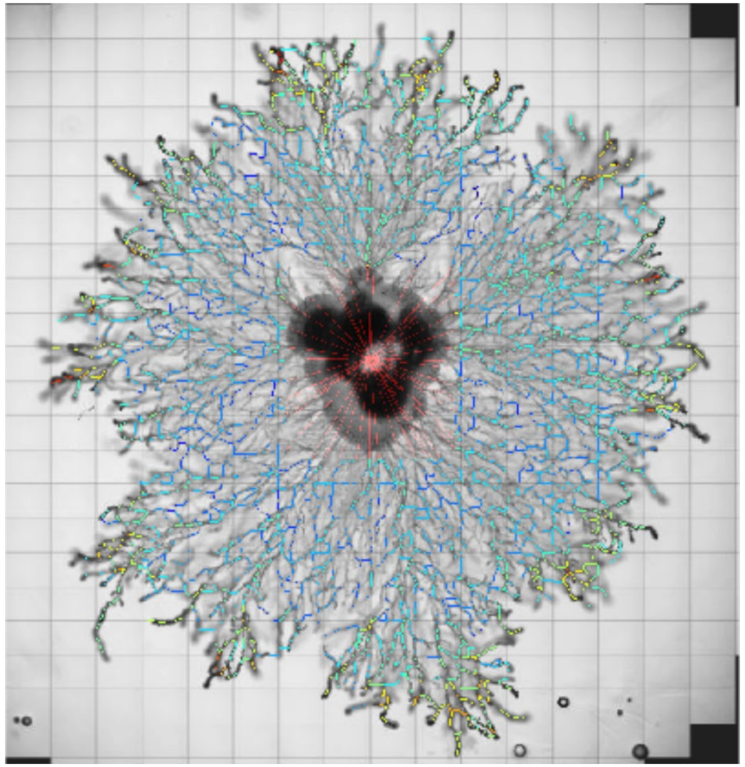
to understand the growth (tip elongation, branching, anastomosis) and function of hyphal networks



In collaboration with dr. Aleksandar Tošić

Mathematical modelling of fungal mycelia

- **continuous models**
  (provides greater insight into the growth and function of mycelia on a colony scale)
- **discrete models**
  (more dependent on statistical influence calibrated from experimental data, risk of loosing connection with the underlying mechanistic features of colony growth)



In collaboration with dr. Aleksandar Tošić

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Challenges

investigation of physical and biological constraints

viability of living cells

new fabrication technologies

process upscaling

interdisciplinary approach

safety

lack of standardization

public acceptance

Progresses in biomimetics allow for the fabrication of man-made materials and surfaces with properties similar to biological ones.

These advancements enable the development of a new generation of building materials for architecture that have remarkable properties typically unachievable with a traditional approach.

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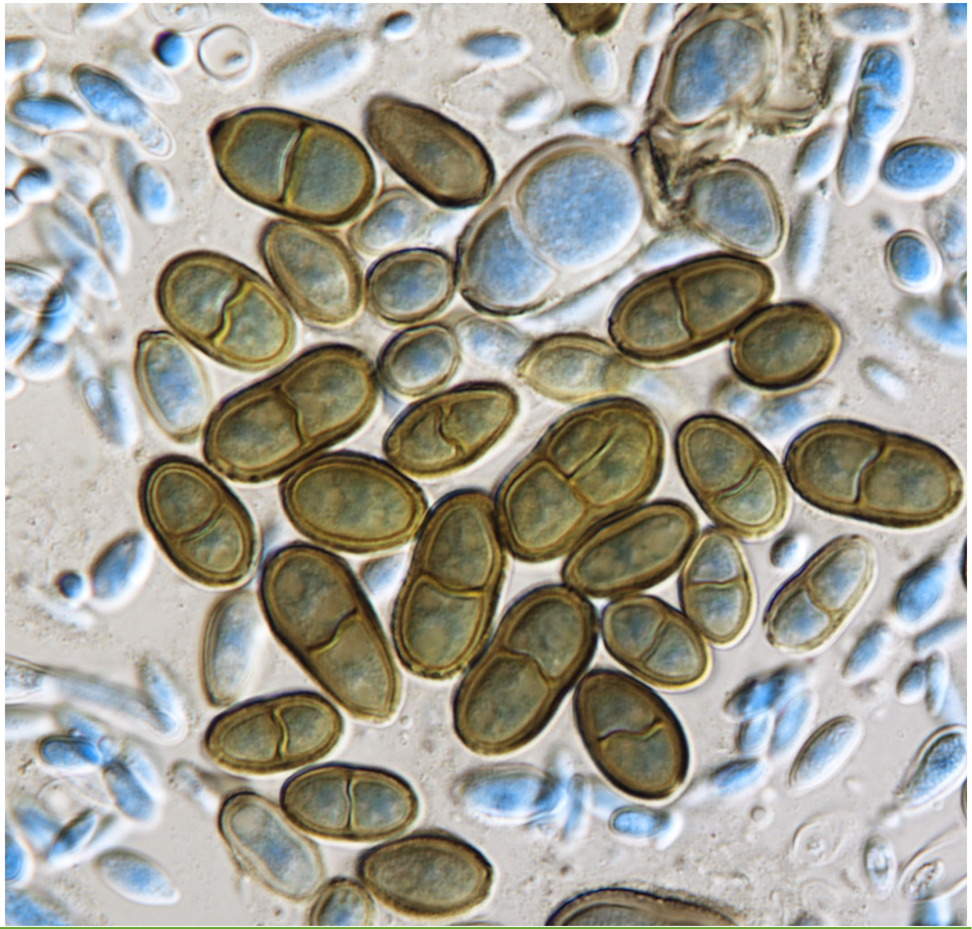

Thank you

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