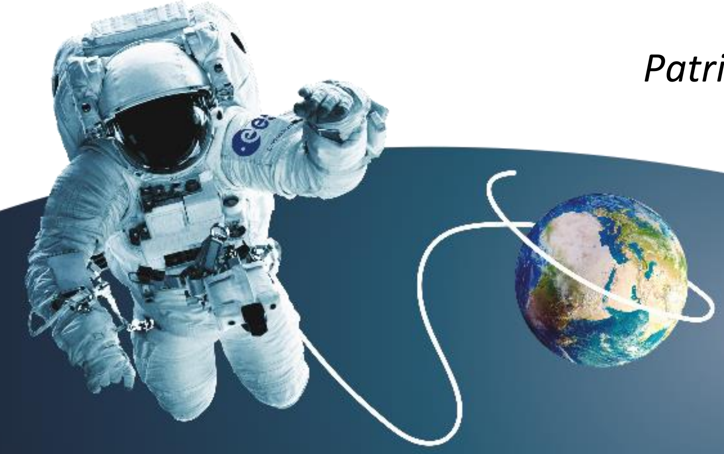
ADAPTIVE VERTICAL FARM FOR FRESH FOOD PRODUCTION IN LIFE SUPPORT SYSTEMS

Patrizia Bagnerini[1], *Mauro Gaggero*[2], *Marco Ghio*[3], *Franco Malerba*[3]

[1]University of Genoa & Space V S.r.l.

[2]National Research Council of Italy, Genoa

[3]Space V S.r.l., Genoa



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FOOD IN SPACE

To increase level of autonomy from Earth

- Low **dietary variety**.
- No **fresh vitamins**.
- Incompatible for **space tourism**.
- Impacts the **health/psyche** of astronauts.

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MAIN GOAL

To produce fresh food

- For **longer space** missions.
- For **space-tourists’** quality of comfort.
- For **better health** (vitamins require fresh vegetables).
- For **zero waste** through wastewater. recycling in space.

THE PROBLEM

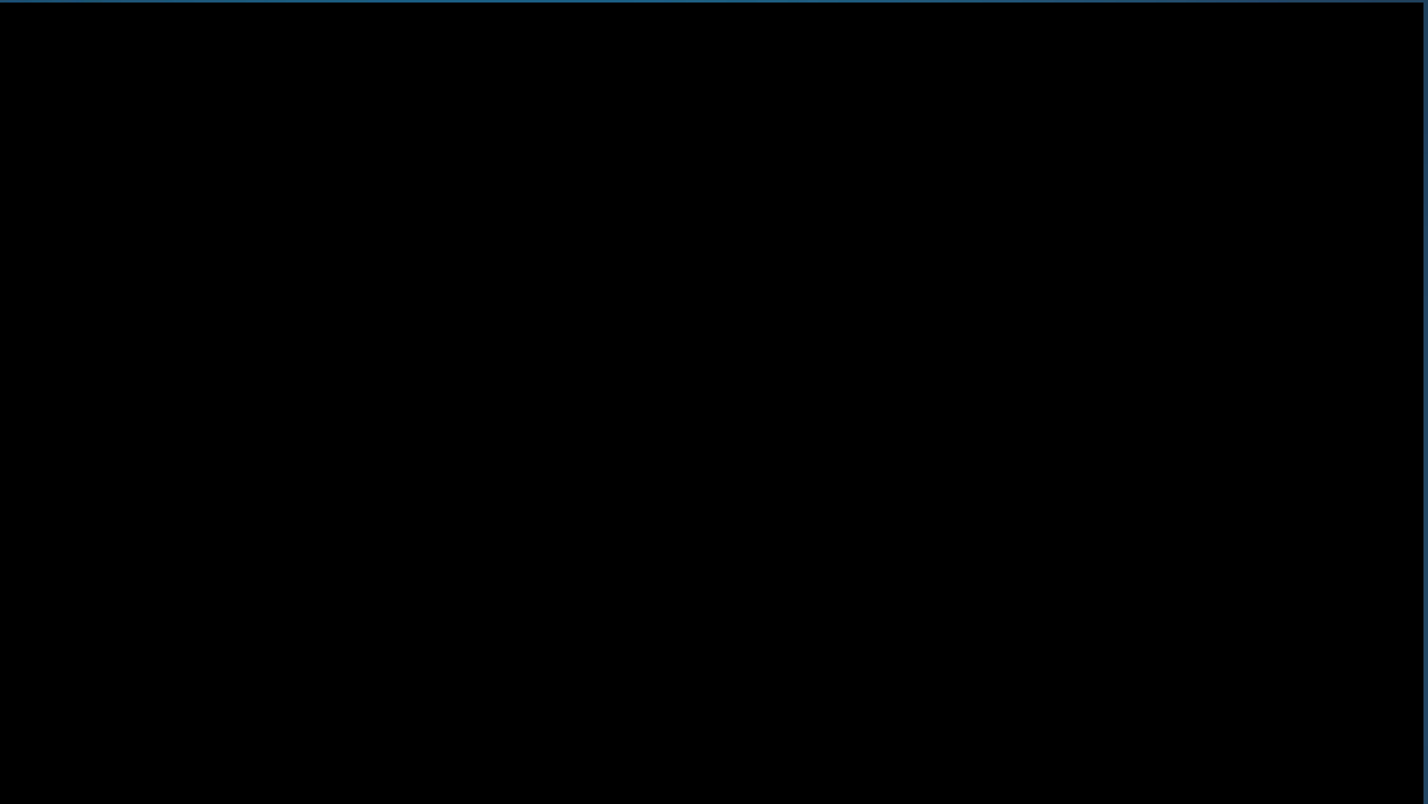
Cultivation in space

- Fixed shelves/layers.
- Prohibitive **high cost volume/unit**.
- Resource intensive.
- **Efficiency** needs to be increased.

Nanoracks

SIERRA SPACE

THE PROBLEM



Most of the volume is unused in traditional Vertical Farms

Adaptive Vertical Farm

*Crops **share** the same volume according to the level of growth.*

Crops at the beginning of their growth phase yield conditional volume to those that are more advanced.

- A **sensor system** measures the plant height.
- **AVF adapts cultivation volume** to the growth of crops.
- Formwork in each shelf to have distinct **microclimate.**
- Almost **100% of the volume** is always used.

SPACE V
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SPACE
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Space V is a startup and a University of Genoa spin-off that patented and develops the new **Adaptive Vertical Farms** for space.

Space V just joined the Turin **ESA-BIC incubator**.

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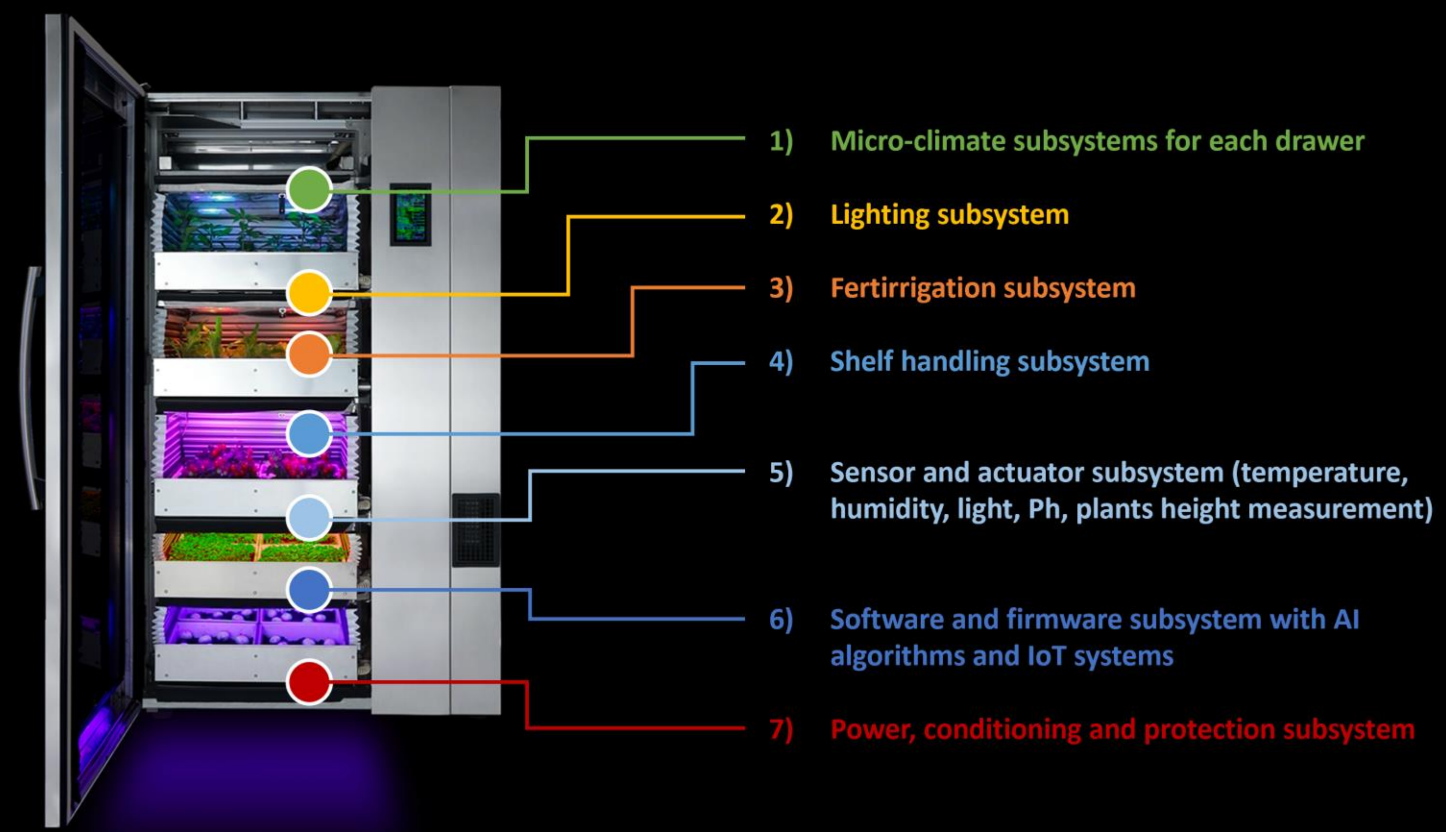
SPACE V PROTOTYPE

The AVF

Integration of multidisciplinary subsystem



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ADAPTIVE VERTICAL FARM

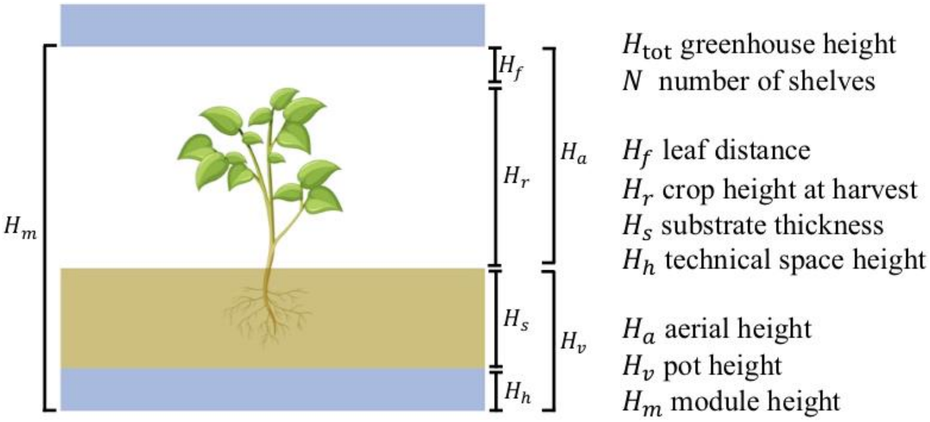
QUESTIONS:

- How to sow in order to **maximize yields**?
- What is the **gain** in production yield?
- What is the average **volume occupancy**?
- Does the gain depend on the **crop type**?
- Is there an **optimal number of shelves** for a given height?
- How does the gain increase by also adapting the **root part**?
- Does it result in a reduction in **energy consumption**?

OPTIMAL SCHEDULING OF SOWINGS

Assumptions:

- System to **measure in real time** the height of crops.
- The distance between shelves varies by means of an **automated mechanism**.
- An **aeration formwork** in each shelf can provide a constant and uniform air flow.



Suppose **we adapt** only the leaf part, but it would also be possible to adapt the root part.

OPTIMAL SCHEDULING OF SOWINGS

Time interval $[1, \mathcal{T}]$ discretized into $\Delta t, 2\Delta t, \ldots, T\Delta t$, where $\Delta t = \mathcal{T}/T$ is the sampling time. For $i = 1, \ldots, N$, $t = 1, \ldots, T$, N number of shelves:

- $x_{i,t}$ binary variable equal to 1 if the shelf i is cultivated at time t, and zero otherwise;
- $s_{i,t}$ binary variable equal to 1 if a sowing occurs in the shelf i at time t, and zero otherwise;
- $h_{i,t}$ positive real variable equal to the height of the shelf i at time t

Cost function corresponds to maximizing seedings:

$$\max \sum_{i=1}^{N} \sum_{t=1}^{T-C+1} s_{i,t}.$$

with **constraints**

Mixed-integer linear programming problem (MILP):
Formulation

OPTIMAL SCHEDULING OF SOWINGS

Space occupied **cannot exceed the total height** of the greenhouse

$$\sum_{i=1}^{N} h_{i,t} \leq H_{\text{tot}}, \quad t = 1, \ldots, T$$

If a shelf cultivated, **impossible to schedule another sowing** before harvest

$$\sum_{\tau=t-C+1:\tau\geq 1}^{t} s_{i,\tau} \leq 1, \quad i = 1, \ldots, N, t = 1, \ldots, T.$$

If a sowing is performed, the shelf **remains cultivated** up to time $t + C - 1$

$$x_{i,t} = \begin{cases} 1 & \text{if } \sum_{\tau=t-C+1:\tau\geq 1}^{t} s_{i,\tau} = 1, \\ 0 & \text{otherwise,} \end{cases}$$

$$i = 1, \ldots, N, t = 1, \ldots, T.$$

etc ..

Mixed-integer linear programming problem (MILP):
Constrains

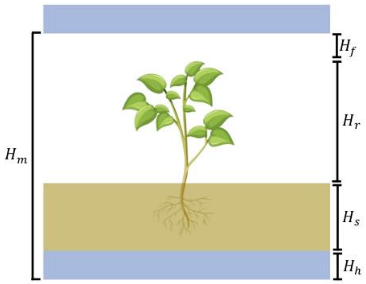
RESULTS

Scenario like in MELISSA program:

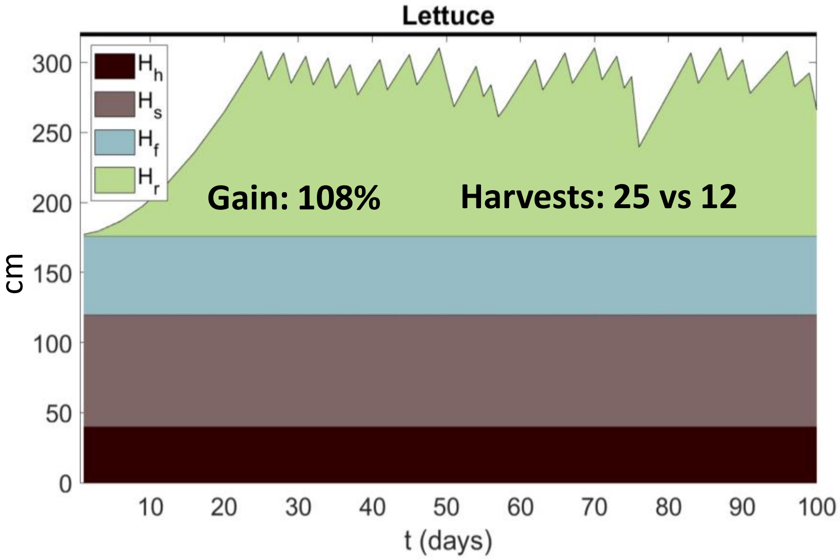
wheat and lettuce.

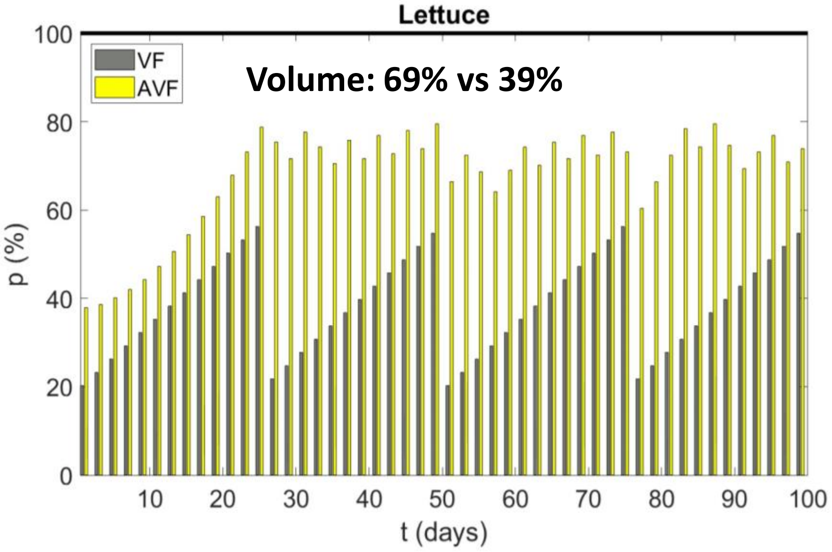
Performances have been evaluated by two indicators: **number of sowings** and **percentage of exploitation** of the vertical height in comparison with a vertical farm with fixed shelves (VF).

LETTUCE SCENARIO

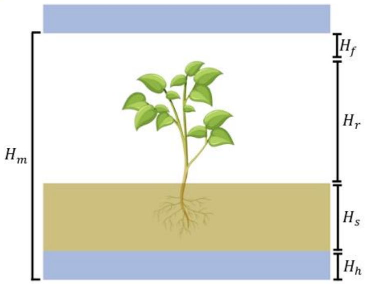


- Almost **100%** of the volume is always occupied.
- The **production yield** compared to a vertical farm of the same height increases **by 108%.**
- **Harvests** increase **from 12 to 25**.
- Without considering **leaf distance**, the volume occupied increases **from 39% to 69%.**

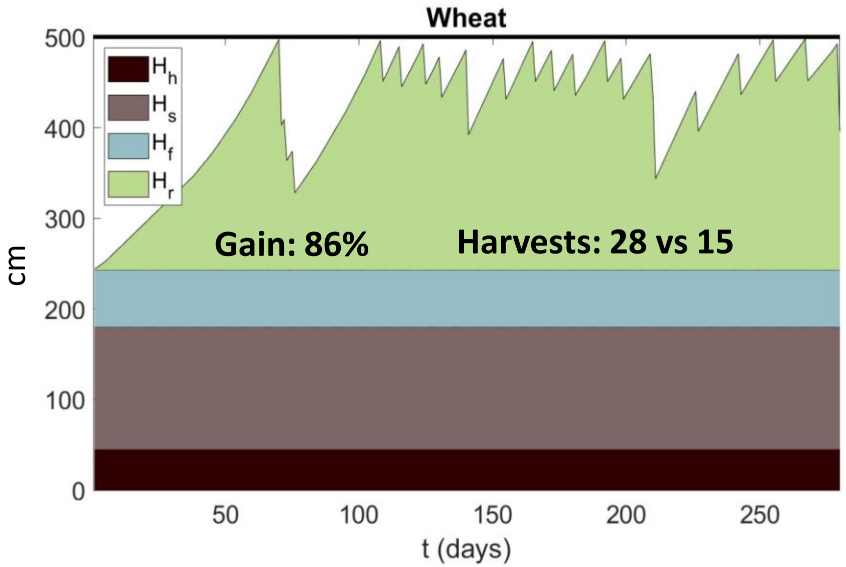


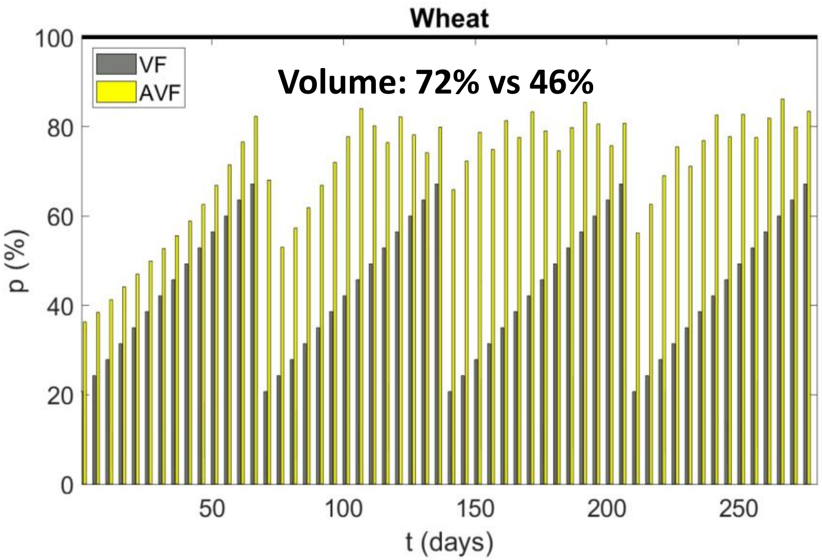


WHEAT SCENARIO



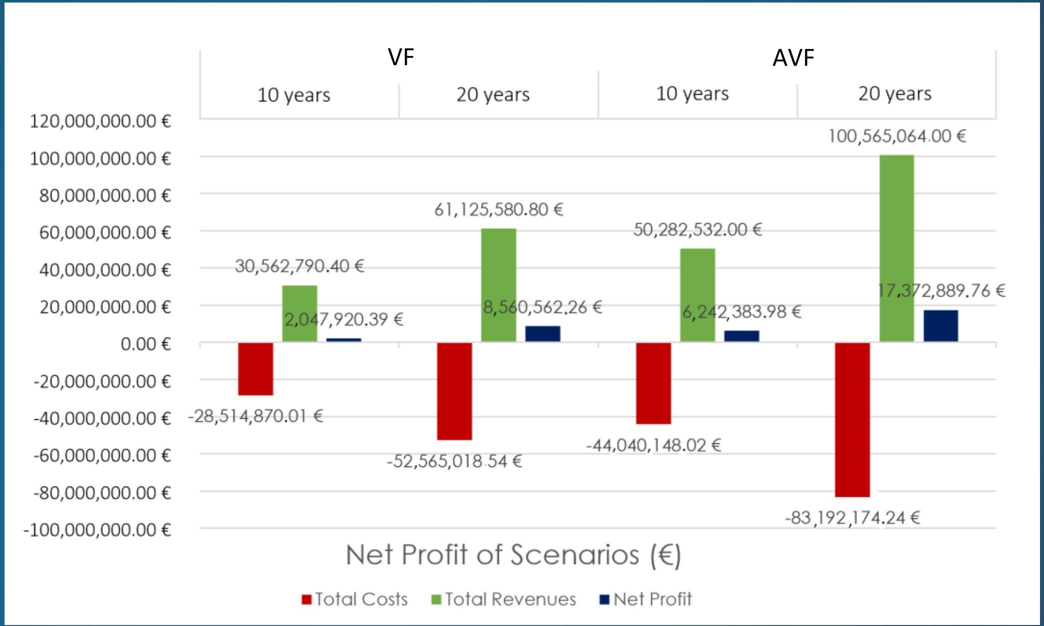
- Almost **100%** of the volume is always occupied.
- The **production yield** compared to a vertical farm of the same height increases **by 86%.**
- **Harvests** increase **from 15 to 28**.
- Without considering **leaf distance**, the volume occupied increases **from 46% to 72%.**





FALLOUT ON EARTH

- Application to terrestrial VF.
- **Techno-economic evaluation** by University of Bologna comparing AVF and VF of the same size.



In 10 years AVF shows a gain (in terms of annual profit) of 205% over VF, while in 20 years it is 103%.

CONCLUSIONS

- AVF exploits 90%-100% of the available **volume**.
- **Production yield** increases in average 80%-108% with respect to a vertical farm with fixed shelves, but it can reach 172%.
- **Energy consumption** reduced by 43% (preliminary study of the University of Genoa).

Future works:

- **Heuristic** algorithm compared to Linear Programming.
- Scheduling with **different species** in the same AVF.
- **Gain** as the number of shelves and height increase.
- Adaptivity in the **root part**.
- Spatialization of the prototype.

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MICRO-ECOLOGICAL LIFE SUPPORT SYSTEM ALTERNATIVE

THANK YOU.

Patrizia Bagnerini

University of Genoa (Italy)
& Space V S.r.l.

patrizia.bagnerini@unige.it

www.**melissafoundation**.org

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