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vertical greenery monitoring

Kick-off event EVERGREEN

Detailed overview of the work packages

Program day 1

12u – 13u: Welcome with lunch

13u – 13u10: Welcome by IUTA (Stefan Haep)

13u10 – 13u30: Introduction to the EVERGREEN project

13u30 – 14u: Introduction of the project partners

14u – 15u: Detailed overview of the work packages

15u – 15u15: Coffee break

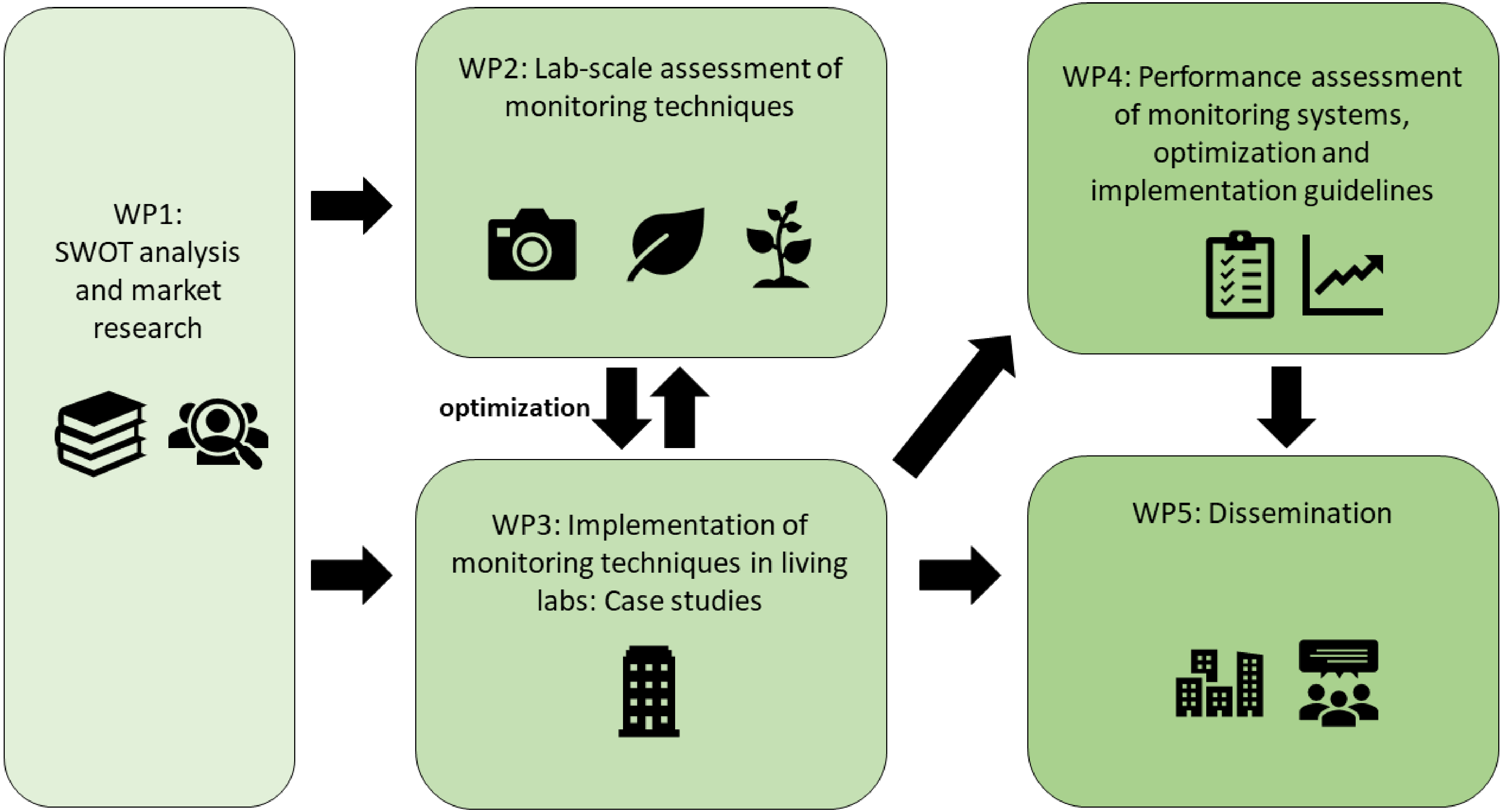
15u15 – 15u45: Practical information regarding the project

15u45 – 16u30: Discussion with stakeholders

16u30 – 17u: Tour IUTA

17u – 18u30: Reception and closing of day 1

Overview of the work packages



Timeline of the project

Present

June – July 2026

work package	activity/task	time period (project months)*											
		1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18	19-20	21-22	23-24
WP1	Task 1.1: Workshop on current practices of vertical greenery monitoring for maintenance purposes												
	Task 1.2: Literature and Market research on KPI's, monitoring techniques and devices												
WP2	Task 2.1: Lab-scale evaluation of techniques to monitor abiotic plant stress												
	Task 2.2: Lab-scale evaluation of suitable techniques to monitor biotic plant stress												
	Task 2.3: Lab-scale evaluation of suitable techniques to estimate the leaf area index												
WP3	Task 3.1: Monitoring at building level												
	Task 3.2: Case studies												
WP4	Task 4.1: Assessment of a business-as-usual vs dedicated monitoring systems and evaluation on cost-efficiency												
	Task 4.2: Guidelines for the overall implementation												
	Task 4.3: Setting a basis for predictive maintenance and performance-based procurement of façade greenery												
	Task 4.4: Comprehensive literature review on dynamic calculation methods EPBD implementation												
WP5	Task 5.1: Meetings with project consortium												
	Task 5.2: Continue dissemination via platforms												
	Task 5.3: Scientific report and final event												

*Start project: August 2024

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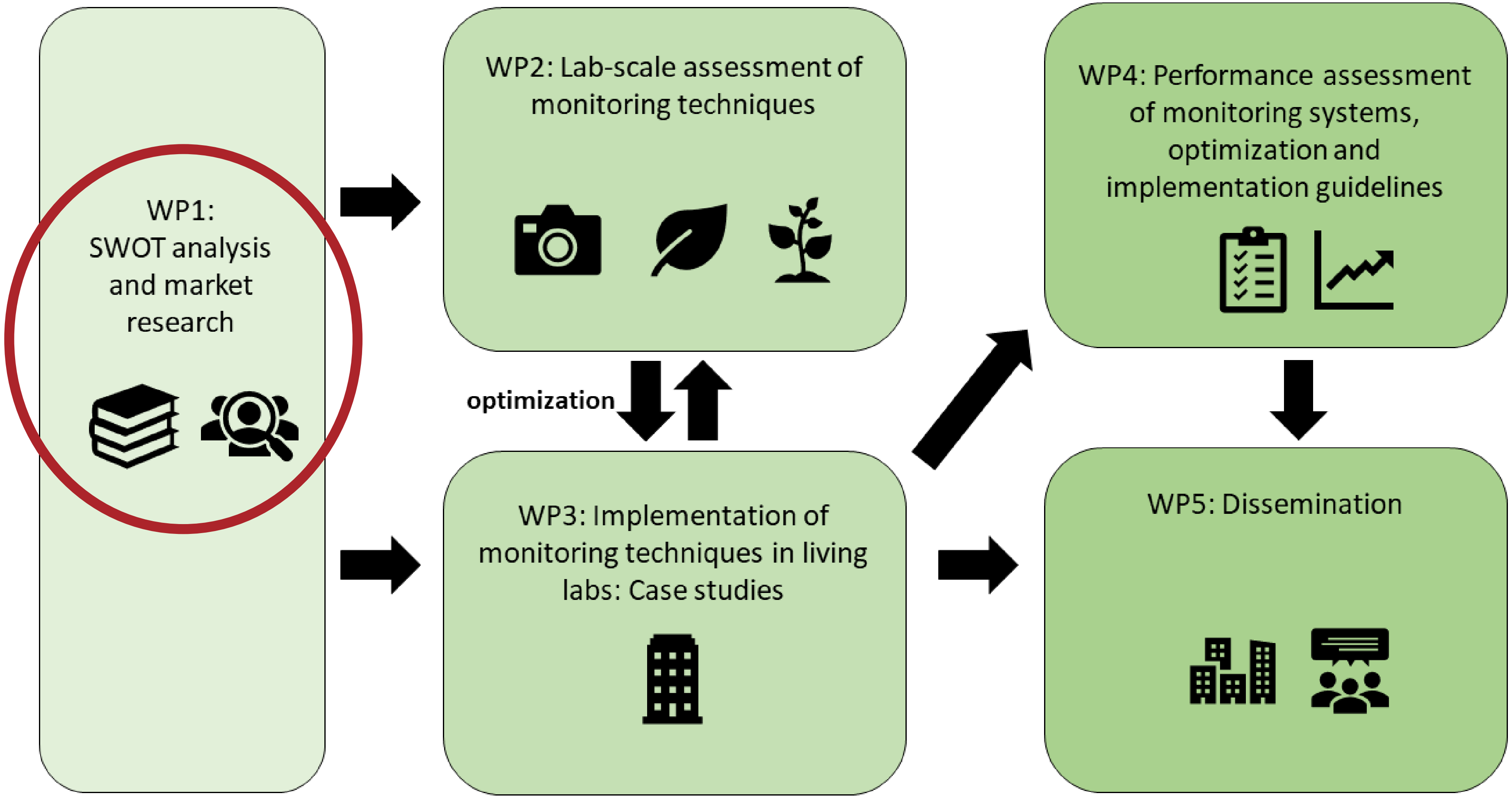
WP 1: SWOT analysis and market research



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WP 1: SWOT analysis and market research

- <u>Task 1.1: SWOT analysis with stakeholder consultation</u>

Collecting and assessing current and state-of-the-art practices in VGS maintenance and monitoring:

- Literature and market review
  - Identifying the most suitable monitoring materials and technologies
  - Techniques employed in other related sectors such as agriculture
- Analysis – (dis)advantages, practical evaluation through a.o. workshops
- => Selection and SWOT-analysis of the monitoring materials and technologies
- => See also workshop on vertical greenery monitoring methodes on Tuesday

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WP 1: SWOT analysis and market research

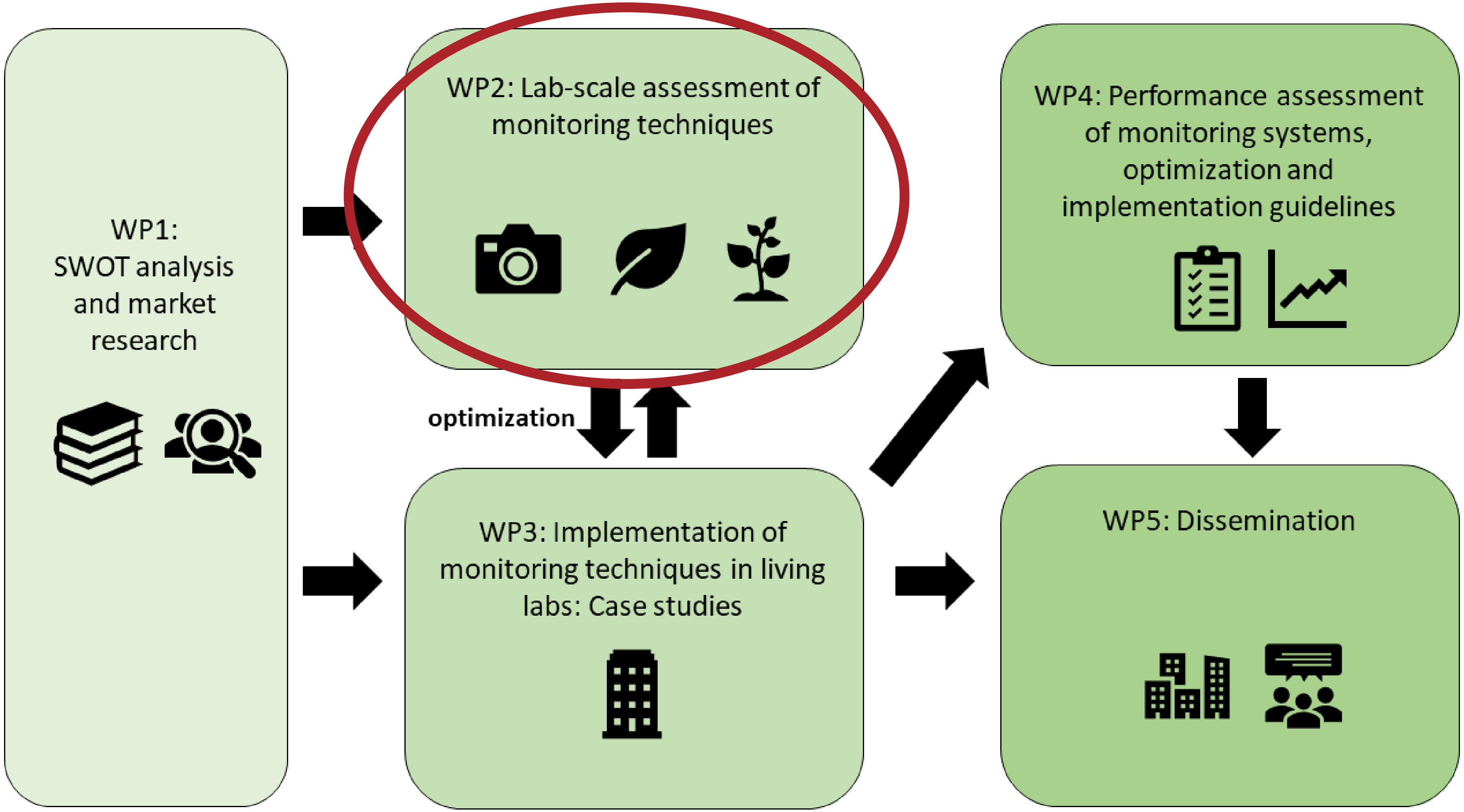
- **Task 1.2: Literature and market research on KPI’s, monitoring techniques, and devices**

→ Which parameters will we monitor, which camera’s will we use?

→ Sensors/Camera’s: Multispectral imaging (Mavic tree camera), RealSense 3D camera

→ Summary of KPI’s in bachelor thesis

WP 2: Lab-scale assessment of monitoring techniques



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WP 2: Lab-scale assessment of monitoring techniques

3 levels:

→ abiotic stress (drought, nutrient deficiency, …)

→ biotic stress (diseases, …)

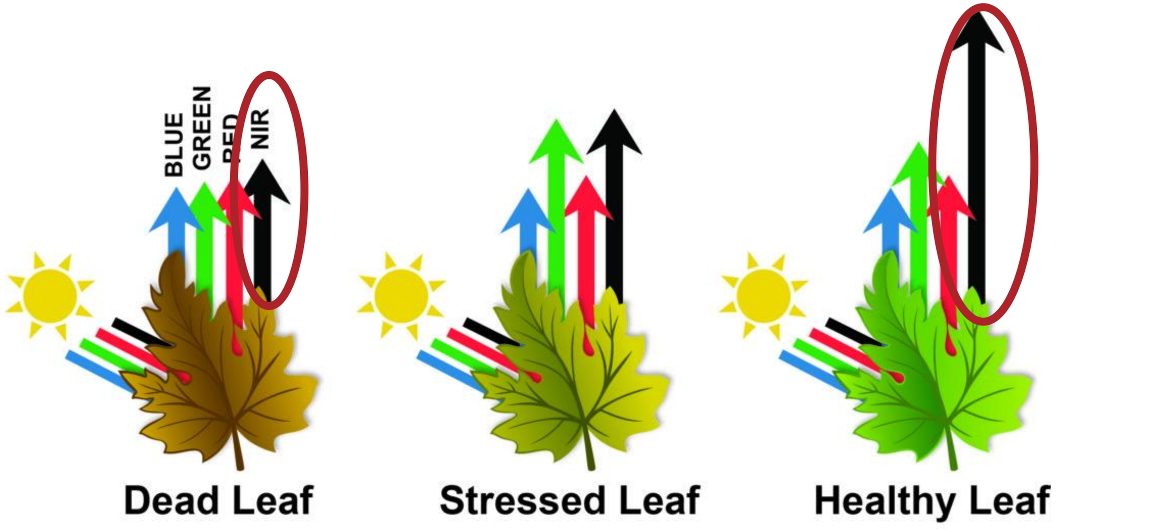
→ leaf area index (amount of leaf area)

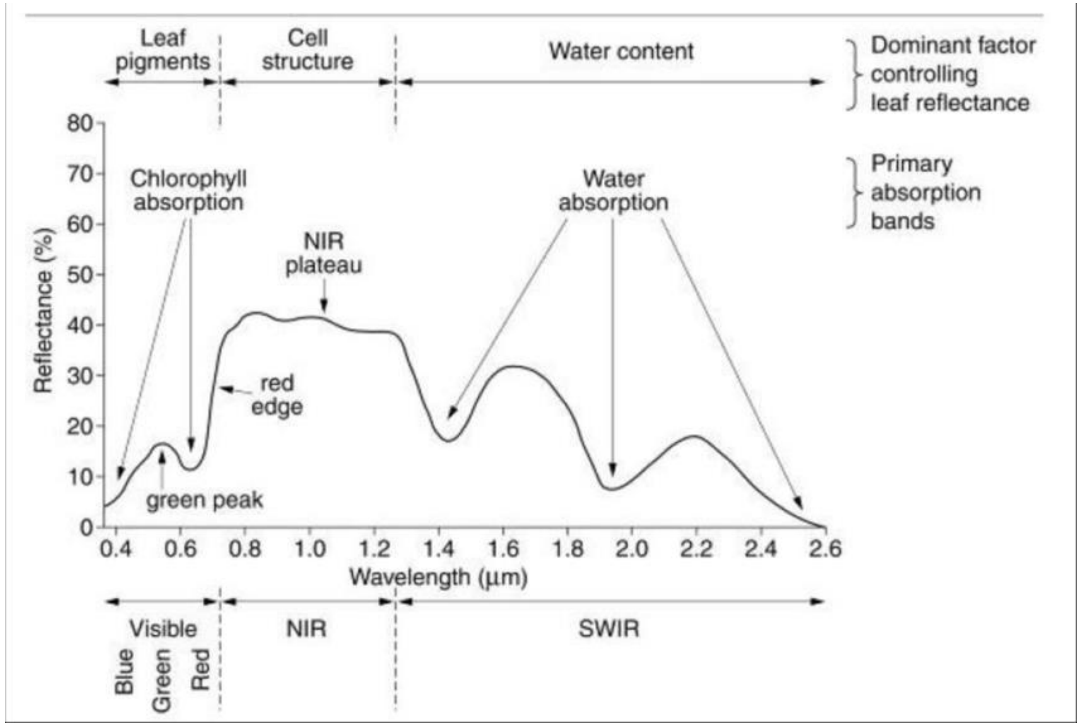
WP 2: Lab-scale assessment of monitoring techniques

- <u>**Task 2.1: Evaluation of techniques to monitor abiotic plant stress**</u>

Early detection of **vegetation stress**: inducing <u>drought</u>, <u>nutrient</u> stress on LWS panels in a controlled environment

<u>How</u> will we measure this? → **multispectral cameras & vegetation indices + in situ validation**

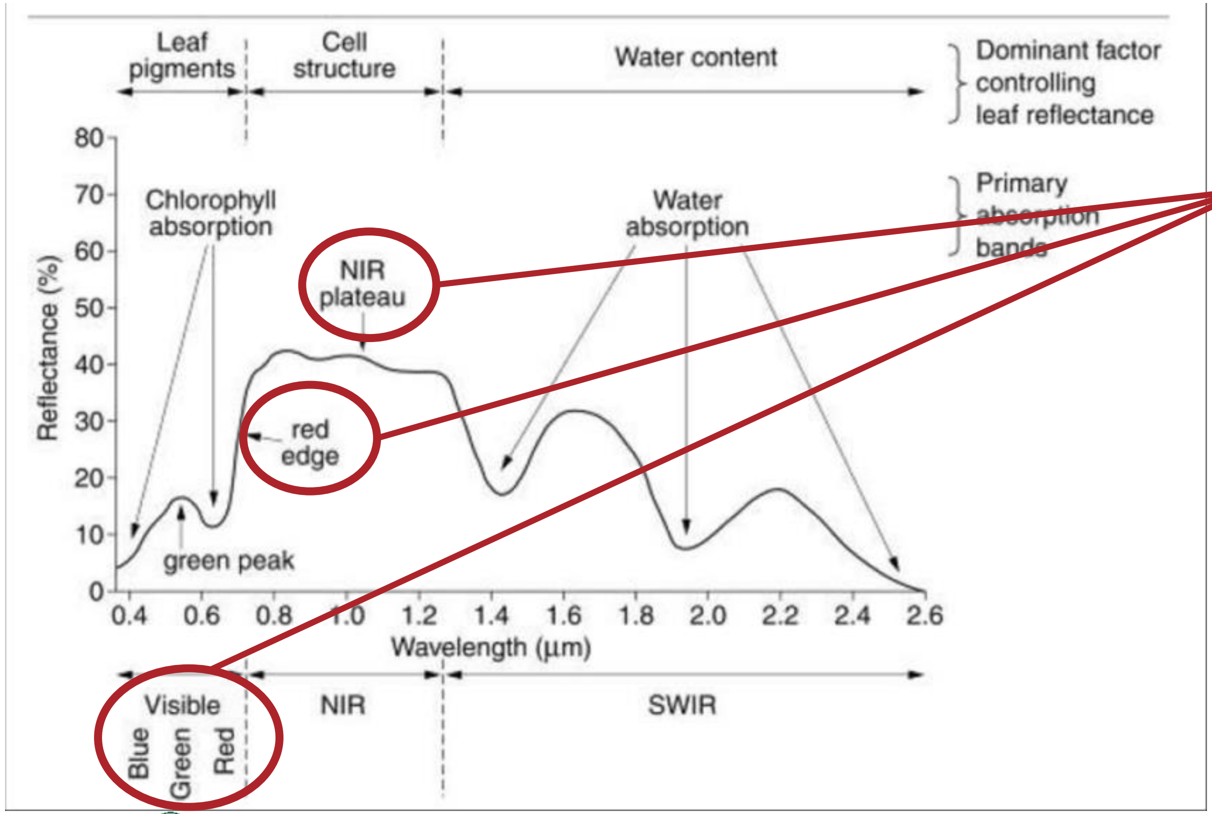




Ratio between reflectances = vegetation indices
→ they express vegetation health

WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.1: Evaluation of techniques to monitor abiotic plant stress**



Vegetation indices	Formula	Application
NDVI (Normalized Difference Vegetation Index)	(NIR – Red)/(NIR + Red)	NDVI is used to assess plant health
NDRE (Normalized Difference Red Edge Index)	(NIR – RedEdge)/(NIR + RedEdge)	NDRE is particularly useful for detecting chlorophyll content and nitrogen status in plants.
CIgreen (Green chlorophyll Index)	(NIR/Green) – 1	CIgreen is used to estimate chlorophyll content and monitor plant nitrogen levels.

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WP 2: Lab-scale assessment of monitoring techniques

- **<u>Task 2.1: Evaluation of techniques to monitor abiotic plant stress</u>**

Experimental setup LWS:

3 objects:

1. **Control**
2. **Drought stress**
3. **Nutrient stress**

4 LWS:

1. **Muurtuin =>** organic rooftop garden substrate
2. **Plant Design (Vice Verda) => sphagnum moss**
3. **Greentexx (Sioen) => plug in textile, rooftop garden substrate**
4. **Sempergreen => rock wool**

4 repetitions

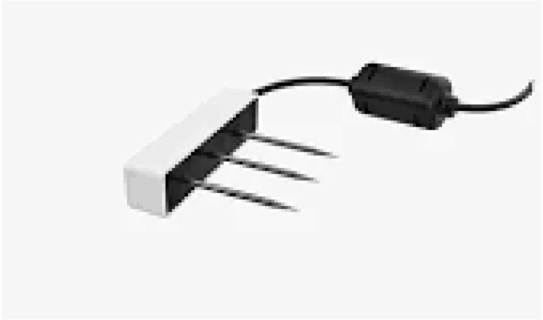
3 plant species:

1. Heucherella 'Art Deco'
2. Salvia microphylla 'Hot Lips'
3. Ajuga reptans

Start: week 47

Measurements:

- Plant measurements
  - Visual evalutation
  - Leaf pigments (sensor)
  - Real time water content measurement (leaf clips)
  - Camera (UAntwerp)
- Substrate measurements
  - Teros 12 sensors for soil moisture
  - EC-5 sensors for soil moisture



WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.1: Evaluation of techniques to monitor abiotic plant stress**

Green facades:

Research question?
What is the necessary size of the planters so that sufficient root volume is available, and also drought stress can be limited?

Article

Rooting Volume Impacts Growth, Coverage and Thermal Tolerance of Green Façade Climbing Plants

Pei-Wen Chung *, Stephen J. Livesley, John P. Rayner and Claire Farrell

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Abstract: Green façades can provide cooling benefits through the shading of walls, evapotranspiration, and insulation. These benefits depend on good plant coverage and tolerance of heat stress. This requires sufficient rooting volume for plant growth and an adequate supply of moisture. On high-rise buildings, plants can be constrained by small rooting volumes due to engineering weight limits and cost. We assessed effects of rooting volume (21, 42, and 63 L) on the growth and coverage of *Akebia quinata* and *Pandorea pandorana* and leaf stress (chlorophyll fluorescence) in response to increasing air temperatures. We showed that 42 and 63 L rooting volumes significantly increased early plant growth and the percentage wall coverage for both species. Specific leaf area was significantly greater when grown in 63 L compared with 21 L. Shoot/root ratio did not change with rooting volumes. Regardless of rooting volume, higher air temperatures on west-facing aspects led to afternoon leaf stress. In practice, for each cubic meter of rooting volume, 21 m^2 (*P. pandorana*) and 10 m^2 (*A. quinata*) canopy coverage can be expected within six months.

WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.1: Evaluation of techniques to monitor abiotic plant stress**

Experimental setup green facades:

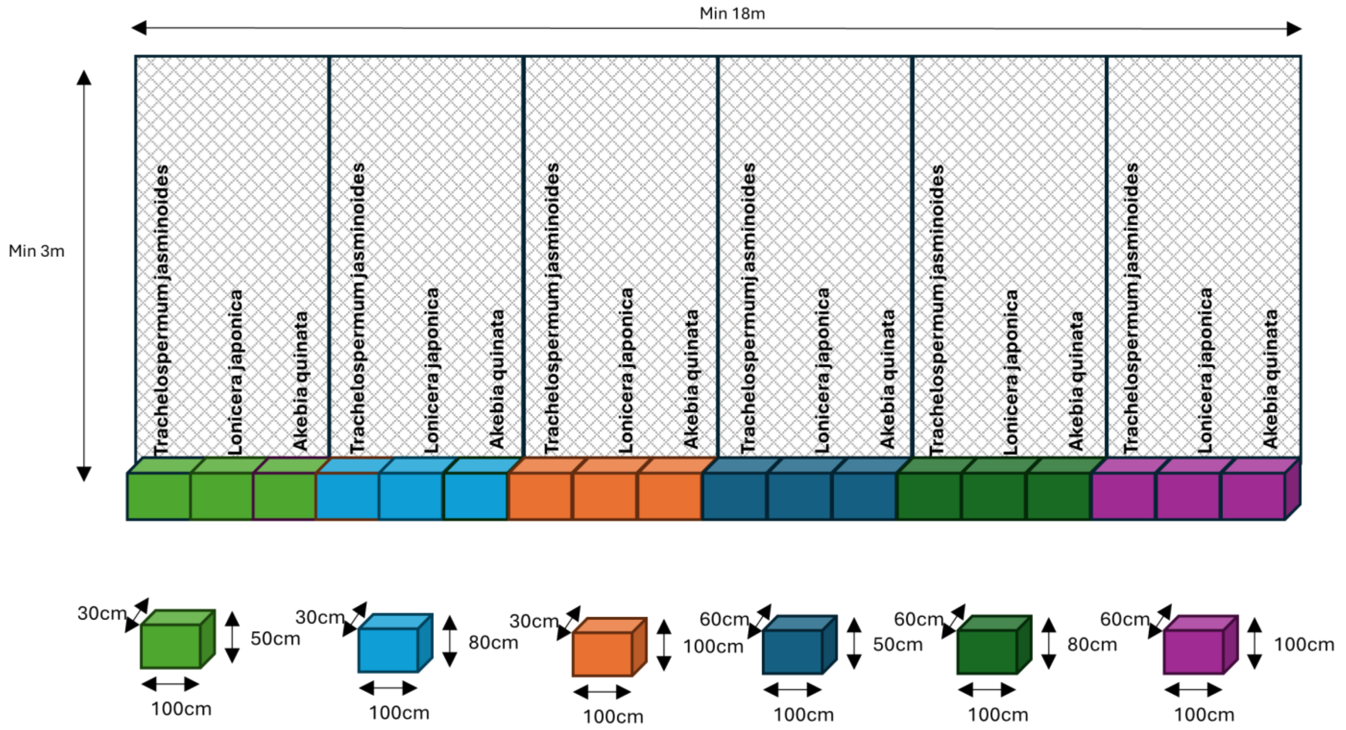
6 objects:

- **Height of 50 cm, 80 cm or 100 cm**
- **Depth of 30 cm or 60 cm**

3 plant species (dependent on location):

1. **Trachelospermum jasminoides**
2. **Lonicera japonica**
3. **Akebia quinata**

Location: to be determined



WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.2: Evaluation of techniques to monitor biotic plant stress**

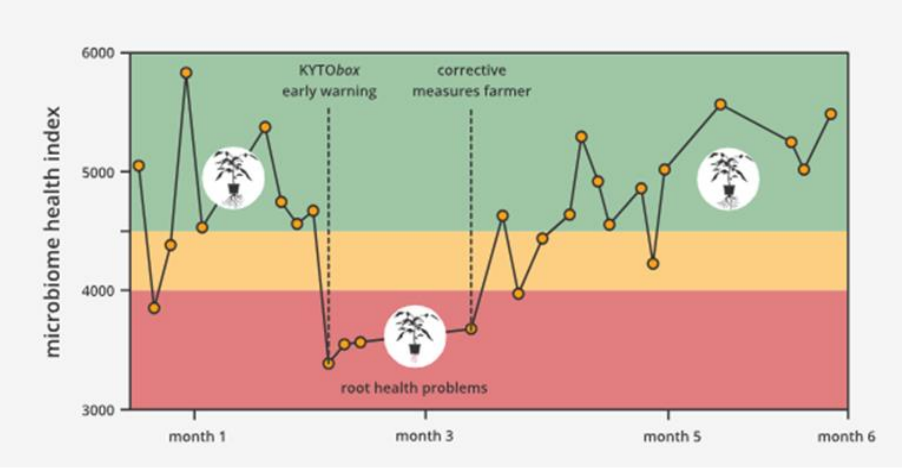
Experimental setup LWS:

- 3 objects:
    1. Control
    2. Infection with vine weevil
    3. Infection with mildew
- 1 LWS: Mobilane
- 4 repetitions
- Plant species: to be determined

Start: 2025

Measurements:

- Plant measurements
    - Visual evalutation
    - Leaf pigments (sensor)
    - Camera (UAntwerp)
- Analyses drain water: Kytos



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WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.2: Evaluation of techniques to monitor biotic plant stress**

→ Install the monitoring systems at a living wall system

→ Comparing the results of the monitoring techniques sensors with our observations

WP 2: Lab-scale assessment of monitoring techniques

Task 2.3: Evaluation of techniques to estimate the leaf area index

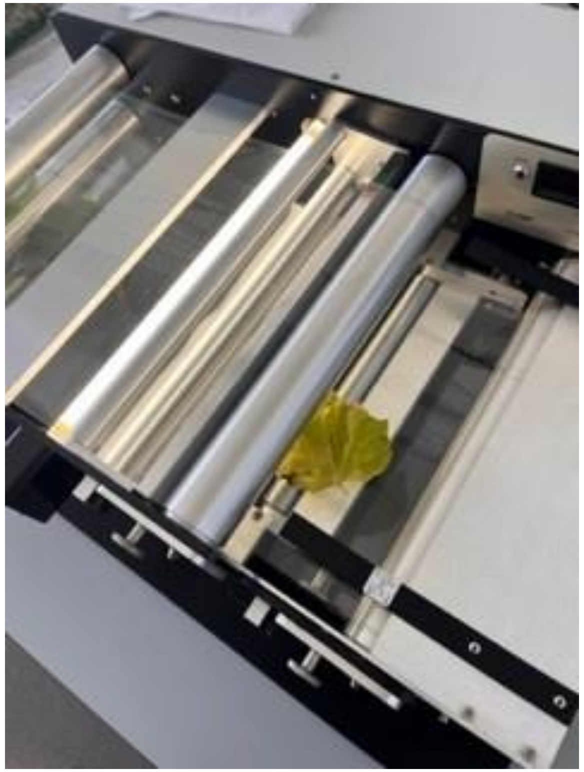
Techniques:

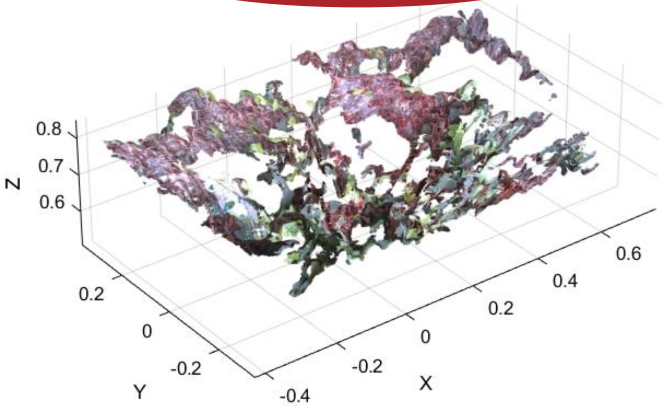
→ **3D point clouds** (stereo vision (Intel Realsense D455 camera), photogrammetry, …)

→ **LiDAR** (as validation)

→ **LAI-3100C meter** (as validation)

→ **Red-edge monitoring with MS camera**: Amount of chlorophyll (~ NDVI) = related to the leaf area index (Pérez et al. 2022)





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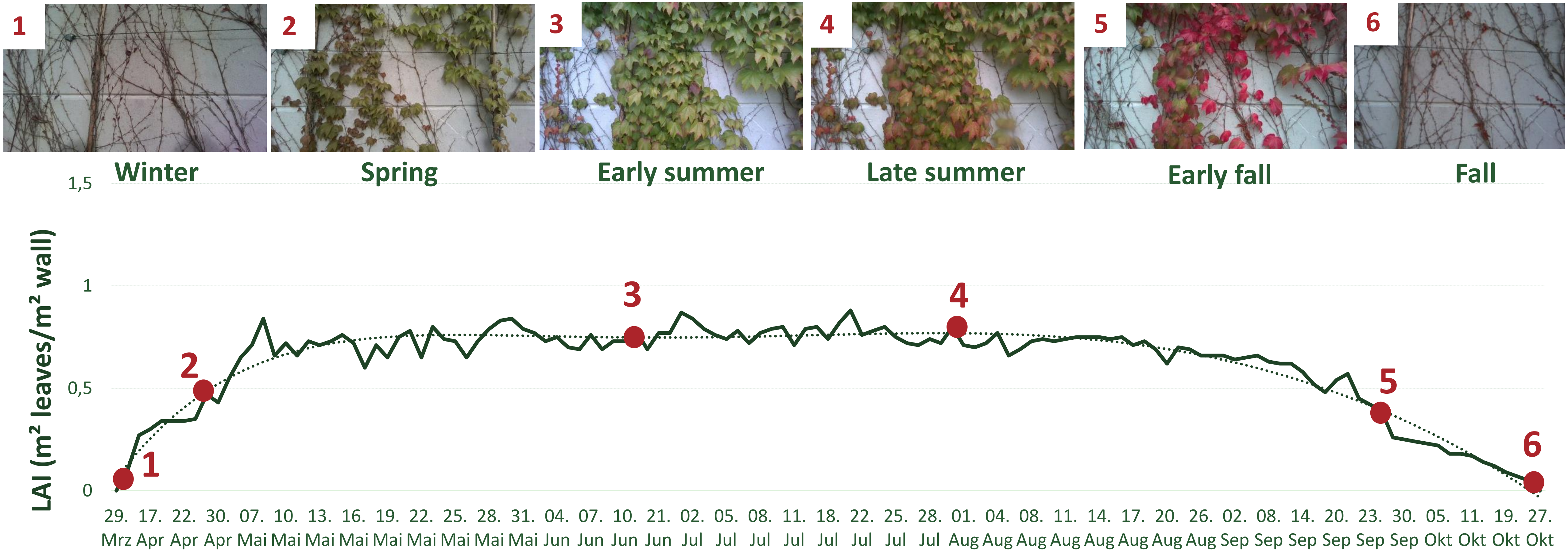
Preliminary results LAI measurements with RealSense D455 camera for wild vine (*Parthenocissus tricuspidate*)



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WP 2: Lab-scale assessment of monitoring techniques

Task 2.3: Evaluation of techniques to estimate the leaf area index (LAI)

Estimation of LAI with LiDAR Technology:

- LiDAR technique is used to determine LAI mainly in forestry and farming
- Several approaches: spaceborne, airborne or terrestrial
- Up to now, LiDAR has hardly been used for VGSs (only for 3D modeling)
- Advantage: (widely) independent on lighting conditions
- Challenges:
  clumping effect, footprint and voxel size (resolution)
  woody and substrate material, geometric projection

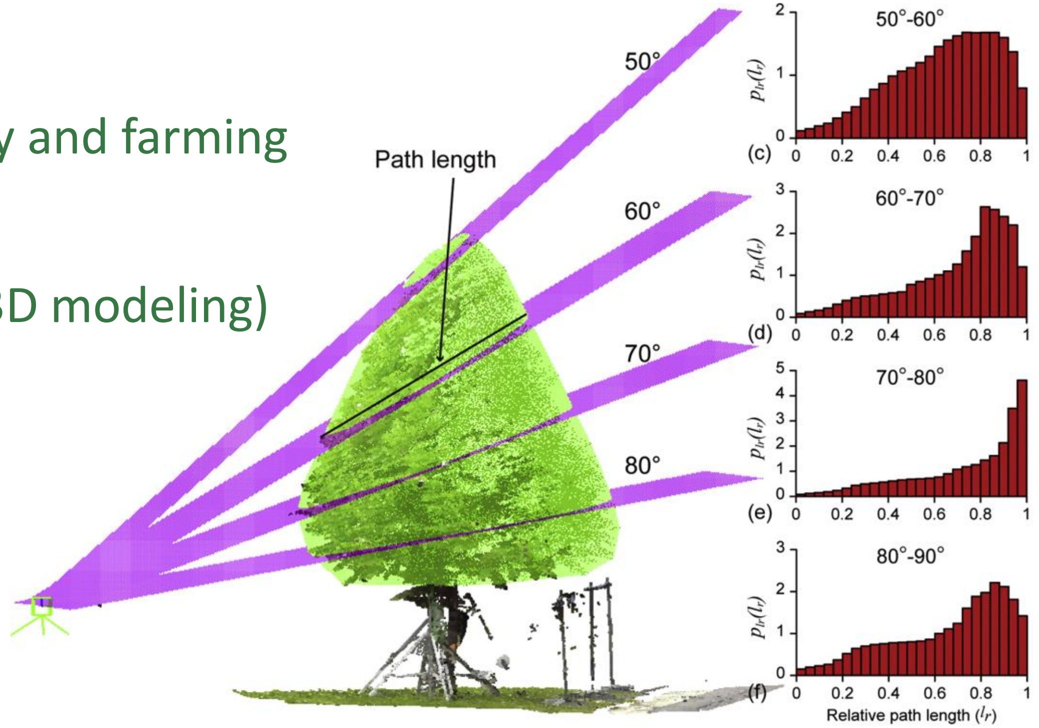

Illustration of path length distribution, adapted from: G. Yan et al., *Review of indirect optical measurements of leaf area index: Recent advances, challenges, and perspectives*, Agricultural and Forest Meteorology **265**, 390–411 (2019), https://doi.org/10.1016/j.agrformet.2018.11.033

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WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.3: Evaluation of techniques to estimate the leaf area index**

→ Evaluation of commercial LIDAR technology

→ Red LIDAR sensor (660 nm) from Pepperl+Fuchs

→ NIR LIDAR sensor (905 nm) from SICK

→ Measurements in a multispectral setup for NDVI calculation

→ Test and adaptation of sensor fusion algorithms for LIDAR point clouds

→ Responsible partner: TU Chemnitz, Center for Micro and Nano Technologies

Pepperl+Fuchs
660 nm (R) LIDAR
OMD10M-R2000-B23-V1V1D

Parameter	Red LIDAR sensor	NIR LIDAR sensor
Wavelength	660 nm	905 nm
Range	0,2 m to 10 m (ws 90%)	0,2 m to 80 m
Scan rate	10 Hz to 50 Hz	25 Hz to 100 Hz
Angular resolution	0,014°	0,042° (interlaced) to 1°
Light spot diameter	< 20 mm at 10 m	136 mm at 26 m

SICK
905 nm (NIR) LIDAR
LMS511-20100 PRO

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WP 2: Lab-scale assessment of monitoring techniques

- **Task 2.3: Evaluation of techniques to estimate the leaf area index**

→ Evaluation of a lab-scale multispectral LIDAR for research purpose

  → Spectral range 1: 450 nm bis 650 nm (VIS)

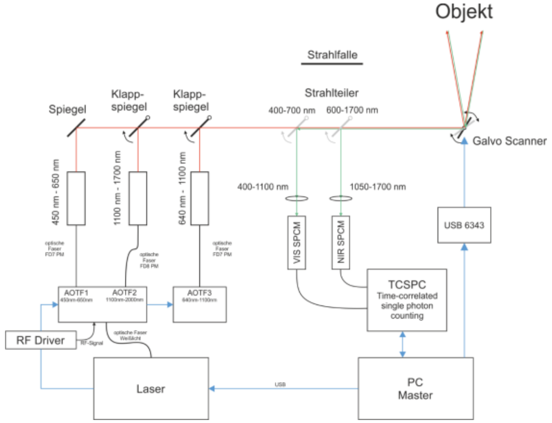
  → Spectral range 2: 640 nm bis 1.100 nm (NIR)

  → Spectral range 3: 1.100 nm bis 1.700 nm (SWIR)

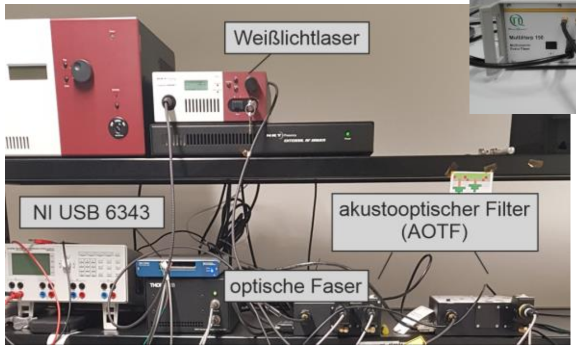
→ Setup consists of white light laser, AOTF, galvo scanner, SPCM and TCSPC module

→ Goal: Determination of LAI and further information for plant health status

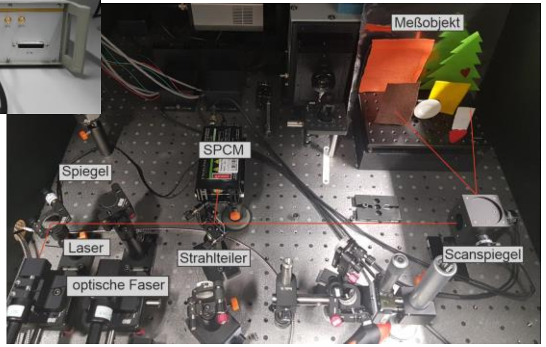
Measuring object with markings for white and black balance



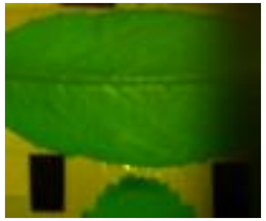
Schematics of multispectral LIDAR setup



Electro-optical components of the measuring system



Measuring system for performing spectral time-of-flight measurements



Measurement result in the NIR spectral range (101 x 85 pixels)

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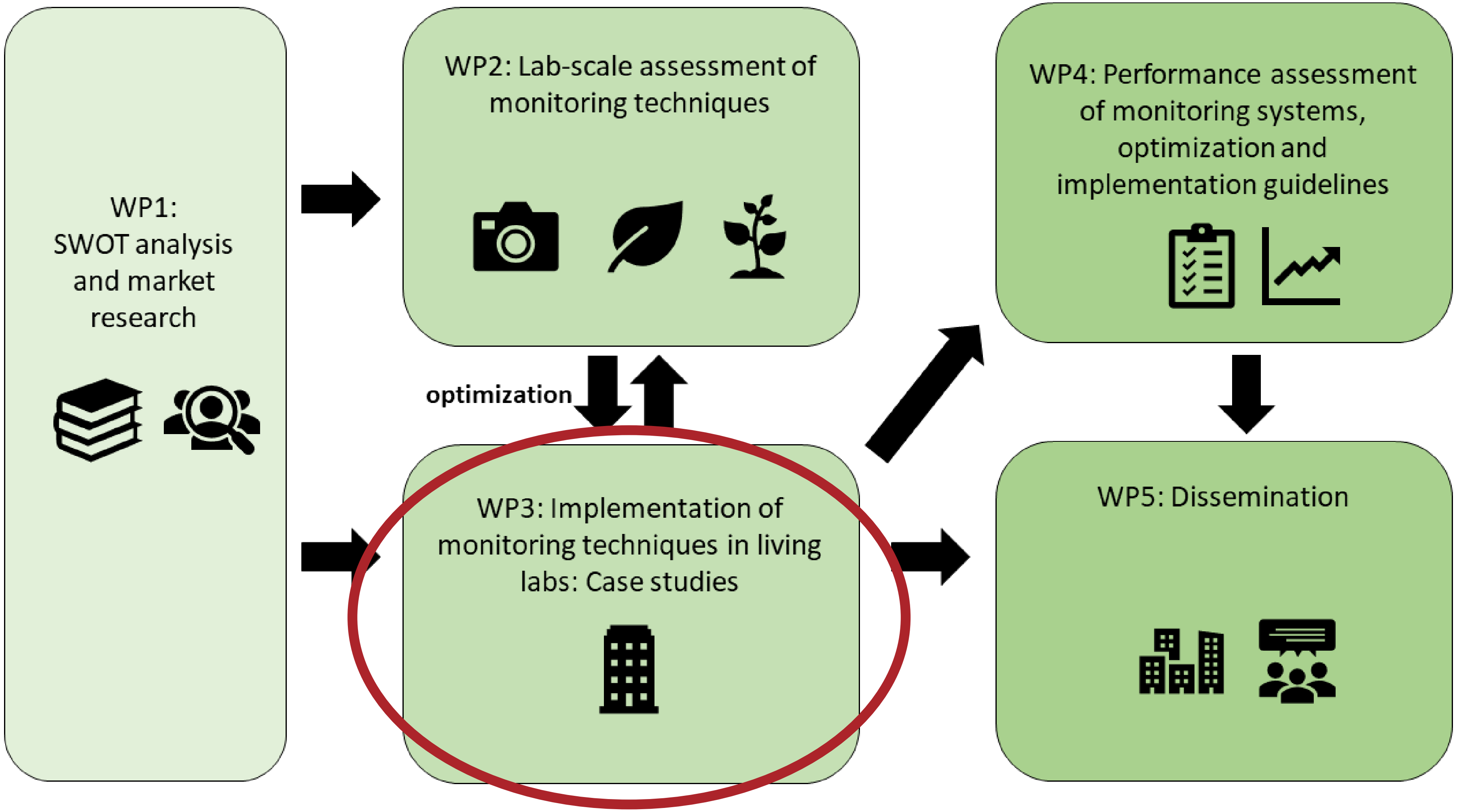
WP 3: Implementation of monitoring techniques in living labs (case studies)



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WP 3: Implementation of monitoring techniques in living labs (case studies)

- <u>**Task 3.1: Monitoring at building level**</u>

→ **Wallbot** has been installed at demo site (company B+M/BoxoM in Germany, region of Erzgebirge)

→ Using a cable system, it can move freely to different positions on a façade up to 300 m²

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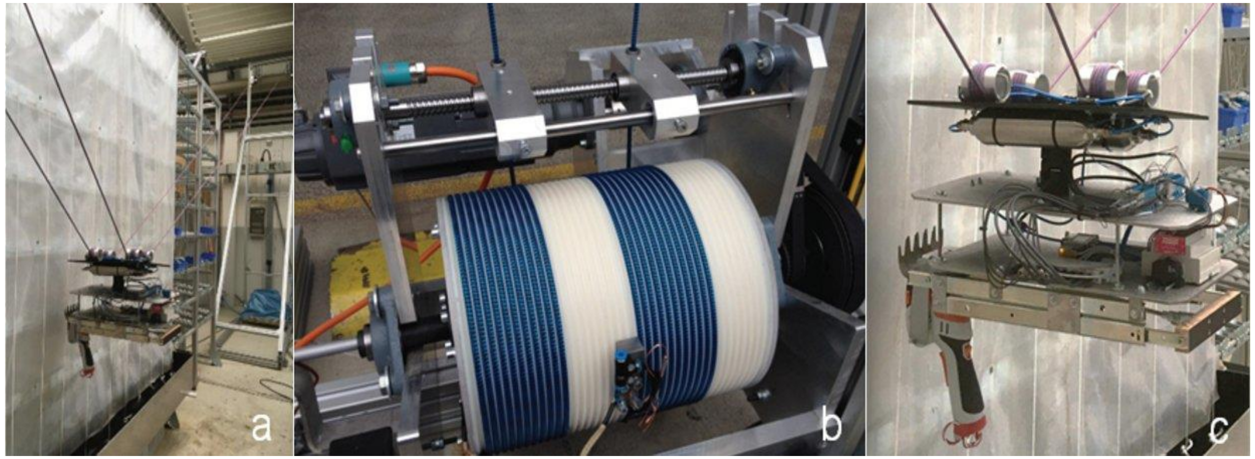
WP 3: Implementation of monitoring techniques in living labs (case studies)

- <u>**Task 3.1: Monitoring at building level**</u>

→ **Wallbot** can be equipped with different tools and monitoring devices with a payload up to 20 kg

→ Cable enables the transport of electrical energy, control signals, and fluid conveyance between the system's drives and the respective actuator or sensors mounted onto the robot

→ By mounting different monitoring devices onto the **Wallbot** and to an **industrial drone DJI M300 RTK** (payload 2.7 kg), a comprehensive overview of an entire VGS can be obtained



WP 3: Implementation of monitoring techniques in living labs (case studies)

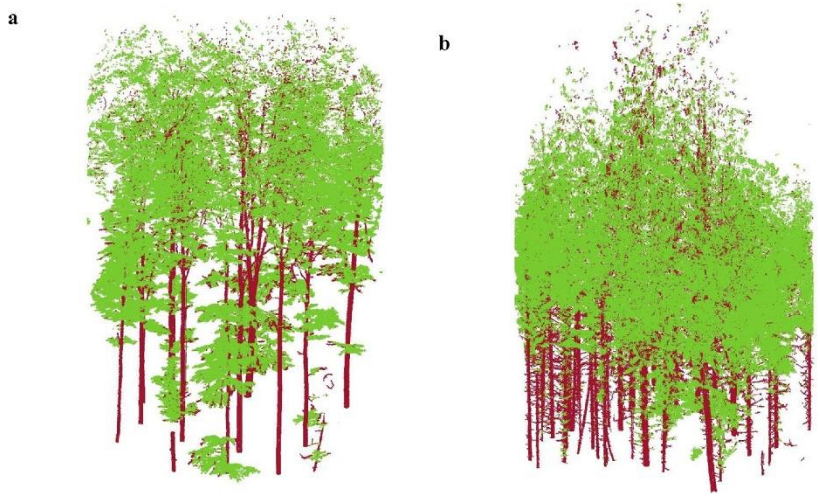
- **<u>Task 3.1: Monitoring at building level</u>**

→ Automation of multispectral LIDAR setup with motorized precision pan/tilt head

→ Point cloud measurements at wall level, processing of point clouds and data analysis

→ Goal: Automated determination of LAI with commercial LIDAR sensors in NDVI setup

→ Responsible partner: TU Chemnitz, Center for Micro and Nano Technologies



Zhu, Xi, et al. "Improving leaf area index (LAI) estimation by correcting for clumping and woody effects using terrestrial laser scanning." *Agricultural and forest meteorology* 263 (2018): 276-286.

(Source: https://www.2bsecurity.com/product/pt-2020-high-precision-pantilt/)

WP 3: Implementation of monitoring techniques in living labs (case studies)

- **Task 3.1: Monitoring at building level**

→ Evaluation of SWIR hyperspectral camera

→ Specification

  → Spectral range: 900 nm to 1,700 nm

  → Image resolution: 640 x 512 pixels

  → Detector: InGaAs with TEC (thermoelectric cooling)

  → Spectral resolution: < 5 nm at 900 nm, < 20 nm at 1,700 nm

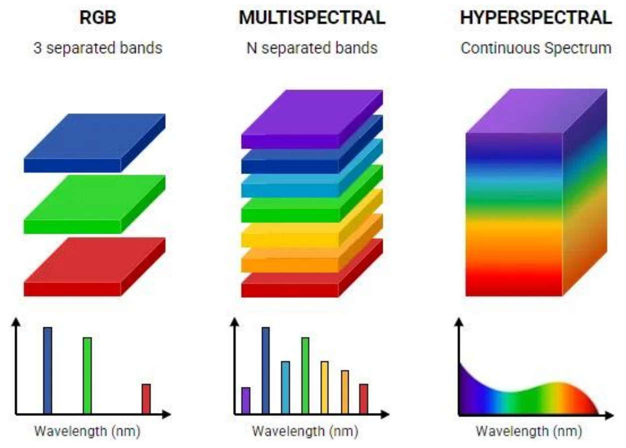
  → Working distance: 150 cm to infinity

  → Field of view: 11° (18° with FoV extender)

  → Aperture: 1 cm (high light throughput)

→ Responsible partner: TU Chemnitz, Center for Micro and Nano Technologies

Front side of hyperspectral camera
(Source: https://nireos.com/product/hera-swir/)



Information content of the spectral data cubes
(Source: https://nireos.com/)

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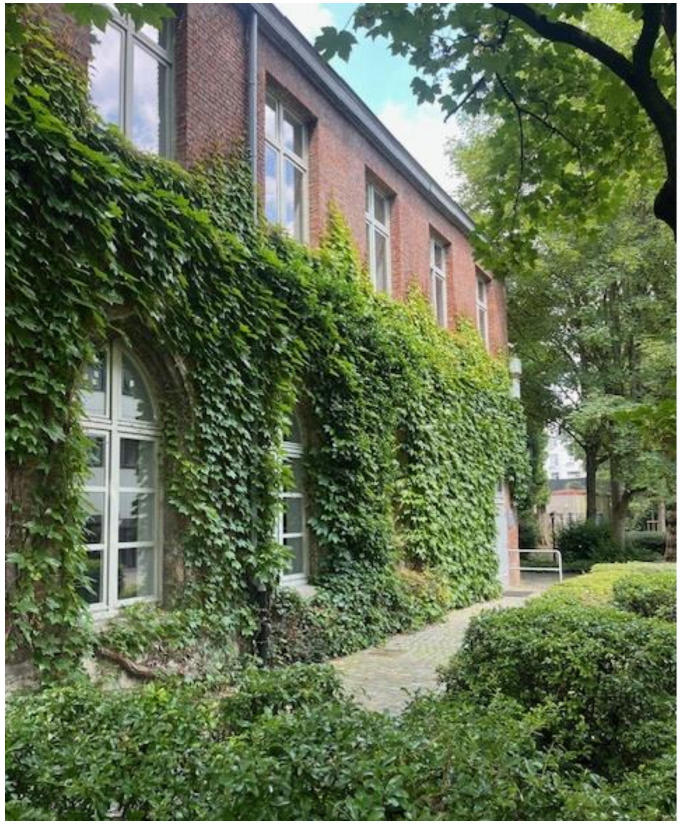
WP 3: Implementation of monitoring techniques in living labs (case studies)

- **Task 3.2: Case studies**

→ Case studies Flanders (LWS, ground-bound)

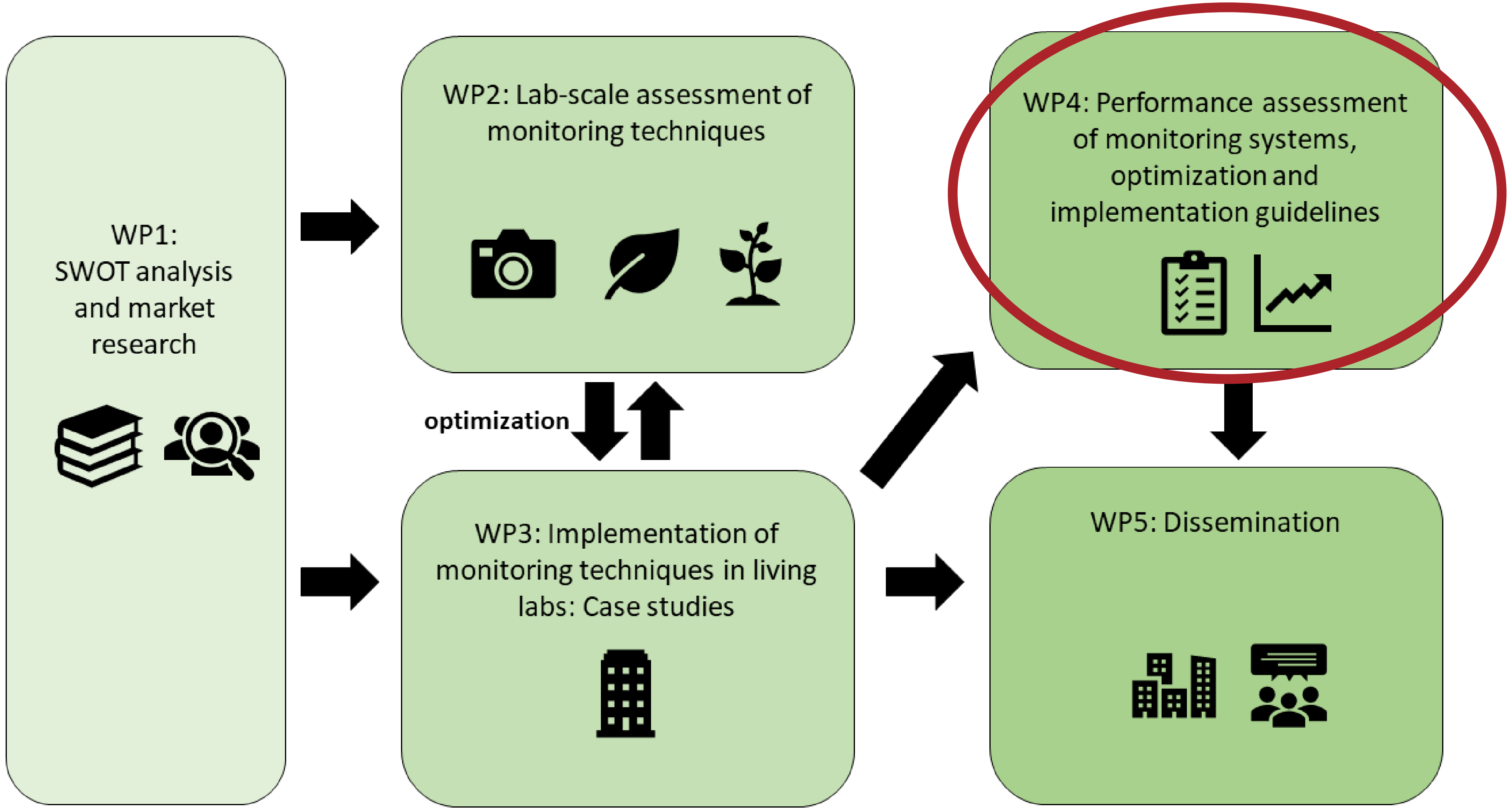


WP 3: Implementation of monitoring techniques in living labs (case studies)

- <u>**Task 3.2: Case studies**</u>

→ Case studies Germany

WP 4: Performance assessment of monitoring systems, optimization, and implementation guidelines



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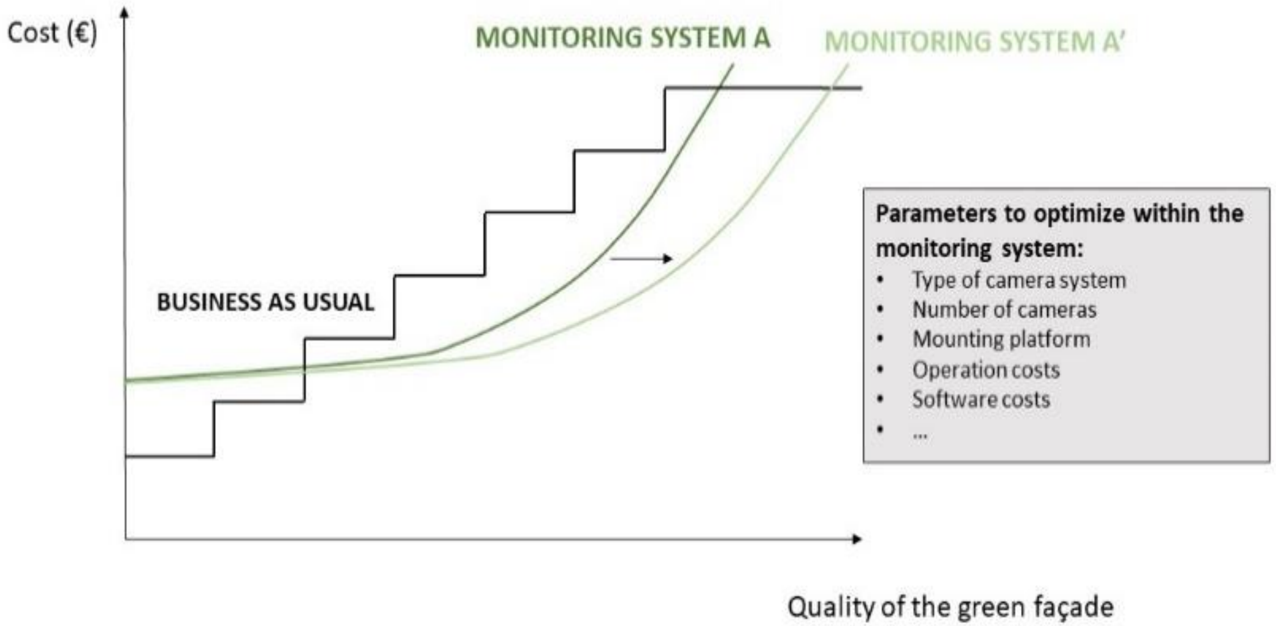
WP 4: Performance assessment of monitoring systems, optimization, and implementation guidelines

- **Task 4.1: Assessment of a business-as-usual vs. dedicated monitoring systems and evaluation on cost-efficiency**

Estimate profits related to early maintenance

- Cost-Benefit analysis (CBA)
- Simulation models
- Delphi method (structured expert consultation)



Economic feasibility of the monitoring system:

- B-A-U case → information from workshop
- Optimization of various parameters within monitoring system (type and number of sensors, mounting platform, operational costs, …)

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WP 4: Performance assessment of monitoring systems, optimization, and implementation guidelines

- Task 4.2: Guidelines for the overall implementation

Research questions:

-(how) can monitoring systems be installed on public property?

-how can vandalism be prevented/vandalism proofing happen

-how can systems be installed in case of complex building geometry (presence of terraces)

-how can very tall buildings be monitored, etc.

Goal:

1. Development of Guidelines for these concerns
2. Creation of fact sheets and/or a report on implementation issues and corrective actions or solutions.

WP 4: Performance assessment of monitoring systems, optimization, and implementation guidelines

- **Task 4.3: Setting a basis for predictive maintenance and performance-based procurement of façade greenery**

Comprehensive datasets on vegetation parameters (LAI, …) obtained from previous WP's

Outline a framework that adapts methodologies from sectors to specificities of VGS

Proactive maintenance strategy

WP 4: Performance assessment of monitoring systems, optimization, and implementation guidelines

- **Task 4.4: Comprehensive literature review on dynamic calculation methods to integrate façade and roof greenery into a new European EPBD calculation framework**

→ Energy Performance of Buildings Directive (EPBD): dynamic calculation method

?

literature review on dynamic calculation methods
+
monitoring techniques EVERGREEN (LAI, …)

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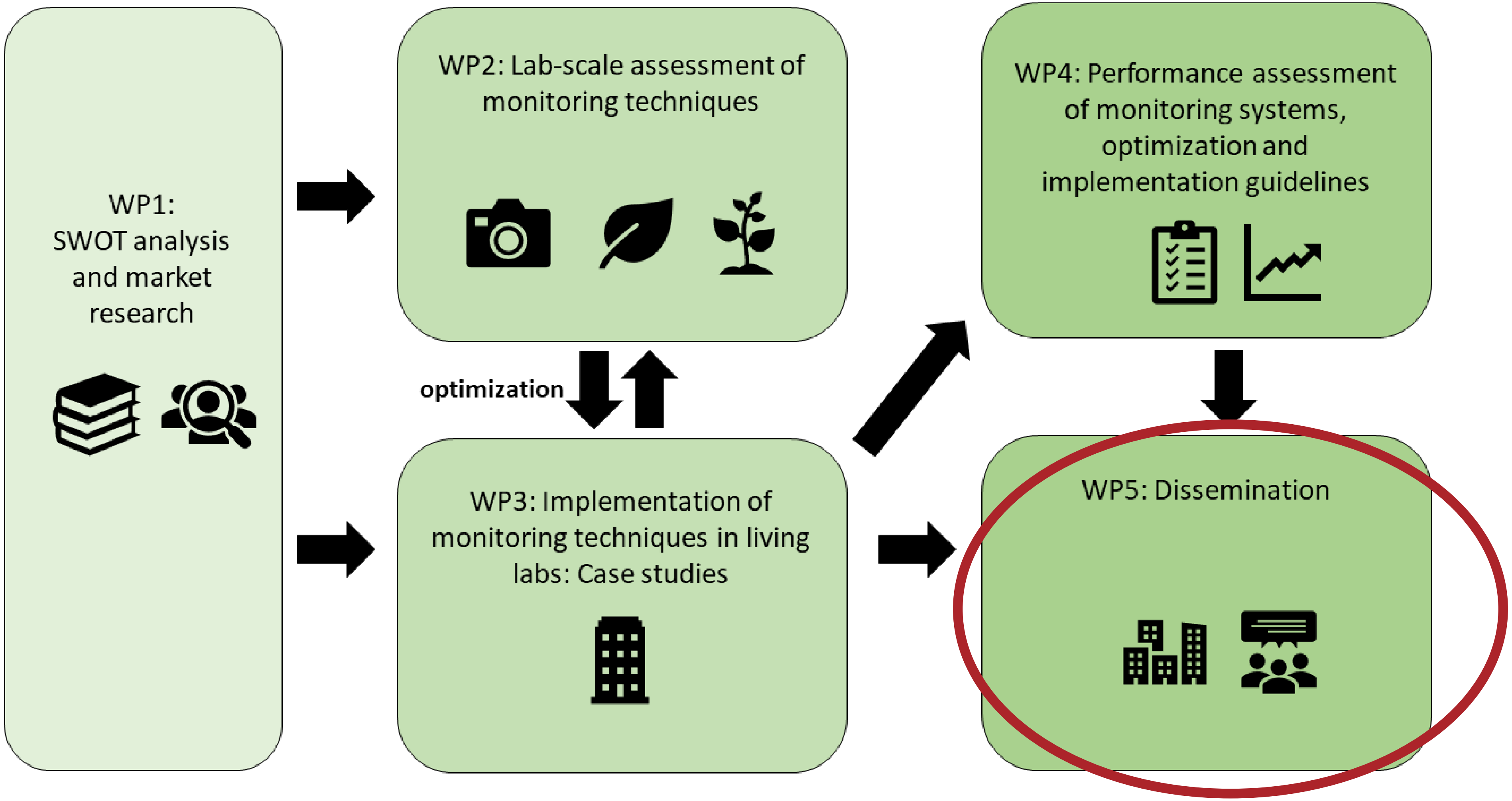
WP 5: Dissemination



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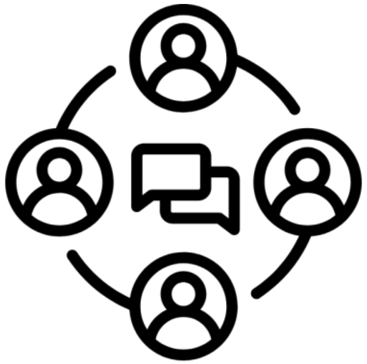
WP 5: Dissemination of project results

- **Task 5.1: Meetings with the project consortium**
  - Regular meetings with consortium and industry partners
  - Follow-up on the progress of the tasks and sharing project results
  - Different meeting levels (WP leaders, …)



- **Task 5.2: Online dissemination through knowledge platforms**

  Flanders: www.gevelgroen.be

  Germany: www.iuta.de

WP 5: Dissemination of project results

- **Task 5.3: Scientific report and final event**
  → Scientific report with project results
  → Final event: June 2026

- **Task 5.4: Online and offline dissemination activities**
  → Dissemination to different stakeholder groups (social media, newsletters, …)
  → Offline: practical seminars, lectures, academic journals

LinkedIn

ELSEVIER

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Expected project outcomes

1. A comprehensive set of **key parameters to track** to achieve robust operation, maintenance, and performance predictions of VGS systems.
2. A **literature and market survey of monitoring techniques** used outside the VGS sector, that could be applicable within the VGS sector with modifications.
3. A **lab-scale demonstration** of **state-of-the-art monitoring techniques** as a basis for dedicated and economically viable monitoring approaches.
4. **Full-scale demonstrators in living labs (+-3 per region)** to enable cross-comparison of dedicated techniques for different VGS types.
5. **Monitoring and reporting protocols** enabling exchange/comparison of measurement data and providing the basis for a European VGS database.
6. **Pre-competitive guidelines** to establish dedicated monitoring approaches in the VGS sector
7. A foundation for **proactive predictive maintenance**
8. Guidelines on **VGS integration within the EPBD**

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