Hybrid Green Roof System Combining Constructed Wetland and Semi-intensive Green Roof: Experimental and Numerical Study

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EGU25-1074

This presentation participates in OSPP

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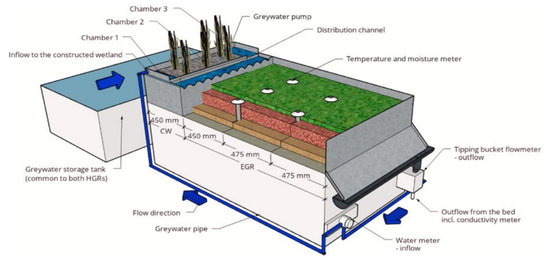
Introduction

- This research focuses on a hybrid green roof system that combines: a constructed wetland (for greywater treatment), and a semi-intensive green roof (for water retention and reuse).
- As recently tested by Petreje et al. (2023) experimentally, this system also incorporates sustainable substrates like crushed bricks and biochar, increasing material circularity.
- To better understand and optimize this system, we are developing a digital twin using numerical modeling.

Goals

- Develop a digital twin of the hybrid green roof system based on experimental data.
- Evaluate system performance and optimize irrigation strategies under different climates, adjusting frequency to reduce water use and prevent over-irrigation.
- Assess water treatment performance, particularly the system's ability to treat greywater under different operational scenarios.



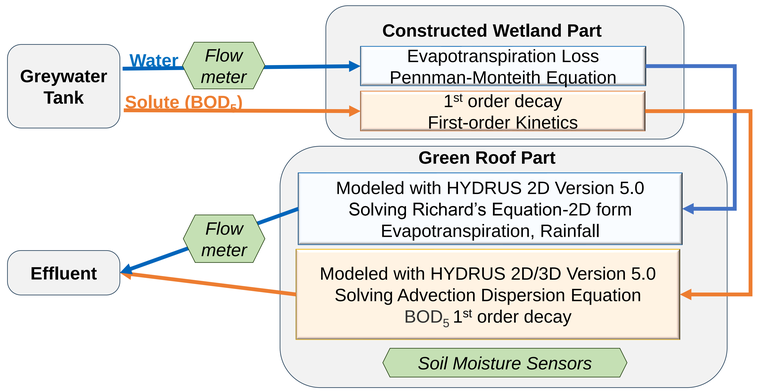
The experimental setup was constructed at the University Center for Energy Efficient Buildings (UCEEB), part of the Czech Technical University in Prague, situated in Buštěhrad, Czech Republic (Petreje et al., 2023)

References

1. Petreje, M., Sněhota, M., Chorazy, T., Novotný, M., Rybová, B., & Hečková, P. (2023). Performance study of an innovative concept of hybrid constructed wetland-extensive green roof with growing media amended with recycled materials. *Journal of Environmental Management*, *331*, 117151. https://doi.org/10.1016/j.jenvman.2022.117151
2. Seyedsadr, S., Šípek, V., Jačka, L., Sněhota, M., Beesley, L., Pohořelý, M., Kovář, M., & Trakal, L. (2022). Biochar considerably increases the easily available water and nutrient content in low-organic soils amended with compost and manure. *Chemosphere*, *293*, 133586. https://doi.org/10.1016/j.chemosphere.2022.133586
3. Petreje, M., Sněhota, M., Šípek, V., Hnátková, T., Punčochář, J., Buchtelík, S., Hardman, M., & Trakal, L. (2025). Quantifying the benefits of incorporating biochar in green roof substrates: field study on the highrise rooftop in temperate climate setting. *Biochar*, *7*(1). https://doi.org/10.1007/s42773-024-00409-z

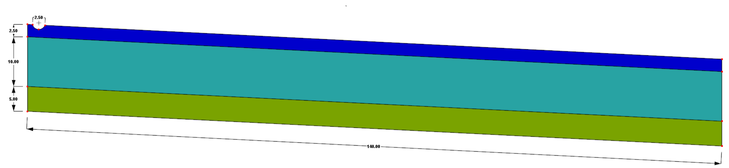
Methodology and Modeling Approach

Water Flow & Solute Transport



Model Domain & Setup

- The simulated system represents a vertical cross-section of the experimental testbed, with dimensions of 140 cm (length) × 17.5 cm (depth). The model consists of three main layers: a vegetation layer on top, followed by a substrate layer, and a mineral wool layer at the bottom.
- Boundary conditions included:
  - Atmospheric BC on the top boundary (for rainfall, irrigation, and evapotranspiration),
  - Variable flux BC at the inflow point,
  - No-flux BC on lateral boundaries, and
  - Seepage face BC at the outlet.



Input Data & Calibration

The model was calibrated using:

. Measured inflow and outflow data from the experimental setup

. Meteorological data from a local weather station, used to compute reference evapotranspiration via the FAO Penman–Monteith equation

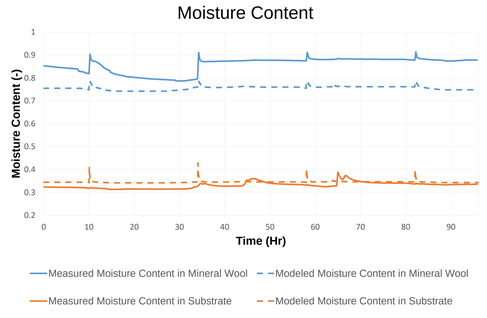
. Moisture Sensors are installed in the green roof part of the hybrid green roof.

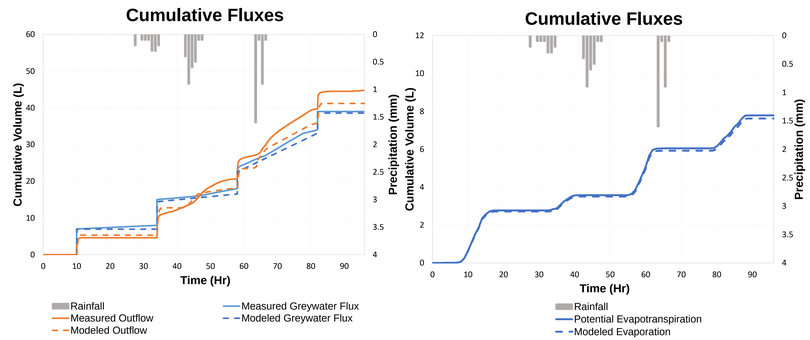
. Flow meters are installed at both inlet and outlet of the system to measure greywater irrigation fluxes and outflow from the system

Calibration was performed by comparing simulated and measured outflow data, ensuring the model accurately represented the hydraulic behavior of the system under real conditions.

Results

- The modeled and measured moisture contents in both mineral wool and substrate follow similar trends, with mineral wool maintaining higher moisture levels overall, while the substrate exhibits lower moisture content and more variability over time.
- Water predominantly flows through mineral wool layer.
- The measured and modeled fluxes of irrigation inflow, system outflow, and evaporation show strong agreement.





Summary

- Using experimental data, a first version of digital twin was developed to evaluate system performance and optimize irrigation of a hybrid green roof system.
- The model, calibrated with measured inflow, outflow, and weather data, shows strong agreement with observed moisture and flow patterns.
- Results highlight efficient water flow through the mineral wool layer and effective greywater treatment.

Outlook / Next Steps

- Model validation and sensitivity analysis to improve accuracy and identify key parameters
- Scenario simulations to evaluate system performance under various climatic conditions
- Assessment of nutrient leaching from the substrate for long-term water quality evaluation

Acknowledgement

This research was supported by project no. 101121210 "City Nature-Based solutions Integration to Local Urban Infrastructure Protection for a Climate Resillient Society" (NBSInfra). Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European research executive agency (REA). Neither the European Union nor the granting authority can be held responsible for them.