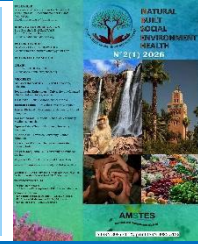




Natural Built Social Environment Health

ISSN 3085-461X

www.nbseh.org



Living Soil Museums in Ukraine: A New Platform for Soil Literacy, Citizen Science and Community Engagement

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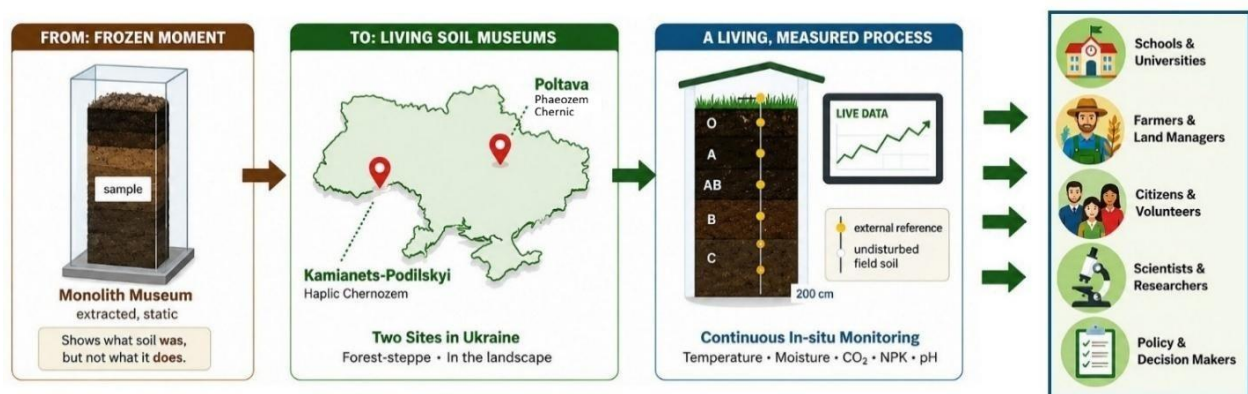
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Graphical abstract

Traditional soil museums that display only preserved soil monoliths cannot communicate what soil health actually means, because a preserved sample cannot show a living system. Here we describe the establishment of two Living Soil Museums in Ukraine built around undisturbed soils in their natural setting, created under the Horizon Europe SoilTribes project. As more such museums appear, there will be increasing value in common approaches for documenting their activities and comparing their educational and scientific performance.



DOI: [10.63095/NBSEH.26.884325](https://doi.org/10.63095/NBSEH.26.884325)

Received: 06 July 2026

Revised: 31 July 2026

Accepted: 01 August 2026

Published online: 06 August 2026

Citation: Dmytruk, Y. & Cherlinka, V., 2026, Living Soil Museums in Ukraine: A new platform for soil literacy, citizen science and community engagement. *Natural Built Social Environment Health* 2(4), 1–19. <https://doi.org/10.63095/NBSEH.26.884325>

Abstract: Soil remains one of the least visible and least understood natural resources; even as European and global policy frames soil health as a key to food security, climate resilience and biodiversity. Traditional soil museums, built around preserved soil monoliths, cannot communicate what soil health actually means because a preserved sample cannot show an alive and actively changing system. This article describes the establishment of two Living Soil Museums in Ukraine—in Poltava and Kamianets-Podilskyi—developed under the Horizon Europe SoilTribes project. These living exhibits keep an undisturbed soil profile in its natural state in the landscape and install continuous sensors for temperature, moisture, reaction and other parameters, visualized for visitors in near real time. The discussion embraces the aims, design, construction and sensor architecture of the living museums and their emerging role as platforms for citizen science for schools, farmers, volunteers and the wider public in the context of the European Union’s mission A Soil Deal for Europe. Living soil museums by no means replace conventional soil collections but offer a replicable model for deeper public engagement with our soils.

Keywords: Living soil museum, Soil literacy, Ukraine.

Introduction

Soil sustains 95 per cent of global food production [1], hosts at least a quarter of biodiversity [2], and regulates water, carbon and nutrient cycles at every scale from a single field to the whole Earth system [3]. But it is largely invisible and intangible. We can watch and feel a river changing, smell and taste polluted air; but the biological and chemical processes that determine whether a soil is healthy happen below the surface, sometimes on timescales and at depths beyond ordinary perception. Invisibility means that people find it hard to appreciate, value and, therefore, to demand protection for soil. Both European and global policy have converged on the view that this communication gap has practical consequences. The European Union's Horizon Europe Mission: 'A Soil Deal for Europe' (or *Mission Soil*) sets an explicit target of 75 per cent of EU soils to be healthy by 2030, which means doubling the current baseline [4,5]. The Mission's own implementation documents identify *soil literacy*—public understanding of what soil is and does—as a precondition for reaching that target, alongside research, monitoring and on-the-ground demonstration through 'Living Labs' and 'Lighthouses' [6]. FAO has also pursued a parallel, longer-running initiative to build public and political awareness of soil as an irreplaceable but vulnerable resource [7].

Within environmental psychology and communication, a lack of direct physical visibility and tangible immediacy is recognized as a major barrier to perception and understanding, rendering subterranean or slow-onset ecological threats psychologically distant and largely unappreciated [8]. Vital soil processes are hidden beneath the surface; their chronic depletion is overlooked by policymakers and society until catastrophic ecological thresholds are crossed [3].

Museums are one of the oldest institutional resources to make something that is otherwise inaccessible available for direct public encounter. Soil museums have existed since the late nineteenth century; but what has rarely been attempted is to create a museum around a live soil and its continuously observed processes and functions—not merely a display but a fulcrum for citizen participation in soil science. This is the aim of the first two installations of this kind established in Ukraine (in Poltava and in Kamianets-Podilskyi) and, here, we discuss our early experience.

Strengths and shortcomings of traditional soil museums: Soil museums built around monoliths—soil blocks excavated, dried or resin-stabilized—remain invaluable. Institutions such as the ISRIC World Soil Museum, in Wageningen, hold extensive reference collections that allow direct comparison of soil types from across the world and, indeed, retain profiles that may no longer exist in the field because of land-use change. Several national soil museums of this kind, including

legacy collections from the nineteenth century, have played a comparable role in preserving representative specimens for teaching and taxonomic reference.

Table 1. Traditional soil monolith museums compared to living soil museums

Feature	Traditional monolith museum	Living Soil Museum
Physical basis	Extracted, stabilized soil block	Undisturbed profile in its natural position in the landscape
Temporal character	Fixed at the moment of sampling	Continuously changing; observed over time
Biological / physical activity	Absent (removed by extraction and stabilization)	Present and monitored (gas exchange, moisture regime, biotic activity)
Data shown to visitors	Static labels. Field profile descriptions and standard analytical data may be available	Real-time and historical sensor data on a dashboard
Interactivity	Mostly observational	Visitors can query live data; some volunteer / verification activities possible
Maintenance needs	Low (conservation only)	Higher (sensors, connectivity, calibration)
Primary strength	Cross-regional comparison; taxonomic and historical reference	Demonstrating soil as a living, functioning system <i>in situ</i>
Primary limitation	Cannot show dynamic processes	Cannot easily be relocated or compared side-by-side to other soil types on one site

The strengths of this format are real. A monolith enables direct visual and tactile inspection of horizon sequences, requires no power supply or maintenance beyond basic conservation, and can be transported or loaned between institutions. It is unmatched for showing what a given soil profile looked like at the time of sampling. Its limitations follow directly from the same physical fact: a monolith is fixed at the moment of excavation. It cannot show soil water responding to a rain event, heat moving through a seasonal cycle, or biological activity varying with the weather and management, because the act of extracting and stabilizing the block removes it from the very physical and biological environment that drives these processes. Three specific consequences follow. First, *static display*: whatever the exhibit shows is one instant, not a process, so it cannot communicate the concept of soil health—a capacity of soil to function over time [9,10]. Secondly, *no real-time observation*: visitors cannot see a soil property or process change before their eyes, which removes the most persuasive demonstration available to any exhibit of a living system.

Thirdly, *limited interaction*: most monolith displays are viewed rather than engaged with, whether by comparing a live reading, making a measurement, or seeing one's own observation reflected back.

This is not a criticism of monolith collections; they answer questions different from the communication of soil health that now needs attention and which we are trying to illustrate with a living, monitored soil individual (Table 1).

Development of the first Living Soil Museums in Ukraine

Design philosophy and construction

Our first two installations were developed under the Horizon Europe SoilTribes project which supports soil literacy and knowledge co-creation [11]. The concept is that the soil profile, itself, should remain an actual, undisturbed part of the landscape rather than becoming an inert specimen. In practice, this meant excavating a space considerably larger than a conventional soil pit, both to admit visitors for *in-situ* observation and to house monitoring equipment. The resulting excavations measure 2×10m at the Kamianets-Podilskyi site and 3×8m at the Poltava site, both to a depth of 2m. At both sites the perimeter profile wall was left in place, physically continuous with the surrounding landscape so that lateral water movement and biological activity can continue much as they would in undisturbed soil.



Figure 1. Protective polycarbonate structure over the exposed soil profile on Poltava site: **a** - outside, **b** - inside .



Figure 2. Specific windows are provided to enable visitors' direct interaction with living soil



Figure 3. Interior of the shelter, featuring a perimeter ventilation gap and a glazed floor section for observing the parent material

To protect the exposed walls from the elements and to prevent collapse or erosion, a shelter was built over each excavation. At Poltava, a custom-built structure roofs the museum area with polycarbonate sheeting (Figure 1a, 1b); the soil walls are enclosed with double-glazed panels, several of which can be opened to give visitors direct contact (Figure 2). A 10cm gap runs along the perimeter of the structure to maintain air exchange with the surroundings. The floor is wood-decked except for one glazed section which reveals the parent material underfoot as well as on the profile wall (Figure 3).



Figure 4. Prefabricated polycarbonate shelter at the Kamianets-Podilskyi site: **a-** ventilation windows for natural air exchange; **b-** overview of the museum entrance

At Kamianets-Podilskyi, a prefabricated structure (Figure 4a) was mounted on a surface-level foundation without excavating along the museum perimeter; its roof and walls are both

polycarbonate, and windows provide ventilation (Figure 4b). The floor is, likewise, wood-decked and stairs give access to the museum interior (Figure 5). At present, the profile walls at the Kamianets-Podilskyi site remain exposed to the air, without any glazing; the site is being monitored and glazed panels will be fitted, as at Poltava, should there be any deterioration.

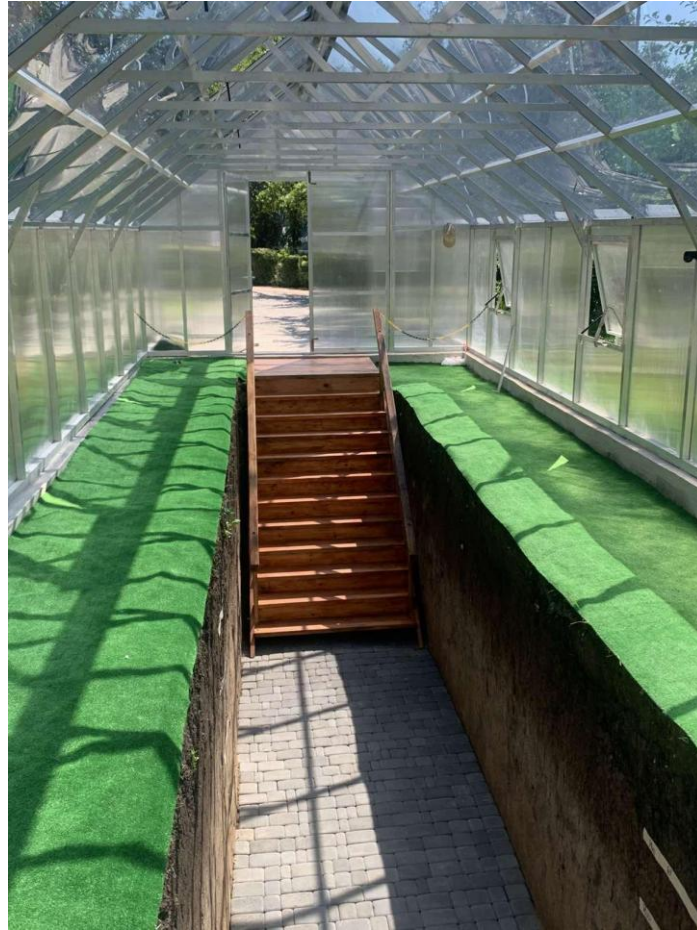


Figure 5. Wooden stairs and unobstructed soil profile wall sections

At both sites, one section of the profile wall is kept unobstructed to accommodate the sensors used for continuous soil monitoring (Figure 6). These sensors are emplaced in the profile at the time of construction and because the profile is not subsequently reopened; this is also the only stage at which there is physical access to its interior—day-to-day operation depends entirely on these embedded sensors (described below under Making Soil Visible). Both shelter designs maintain air exchange with the surrounding atmosphere and lateral exchange of matter and energy with the surrounding landscape, although, inevitably, the roof intercepts radial (vertical) fluxes through the soil body.



Figure 6. The opposite-to-stairs wall equipped with a sensor panel for monitoring

Poltava site: The Poltava installation, hosted by Poltava State Agrarian University (Figure 7) with the involvement of the NGO Terra, was officially opened on 17 June 2026 (Figure 8). The soil is classified as a Chernic Phaeozem (Siltic) [12] and is broadly representative of the forest-steppe zone of Left-Bank Ukraine.

To ensure optimal comfort and engagement, the capacity of both venues is capped at 15–18 persons. Moreover, aligned with the SoilTribes concept, half of the scheduled activities at each site will integrate cultural and artistic events.



Figure 7. Location map of the sites: 1 - Kamianets-Podilskyi, 2 – Poltava



Figure 8. Official opening of the Poltava museum, 17 June 2026

Kamianets-Podilskyi site: The second installation is associated with HEI Podillia State University in Kamianets-Podilskyi (Figure 7). The museum was likewise established with the involvement of the NGO Terra as the operating partner. The soil is a *Haplic Chernozem* (siltic) [12] —a soil type less common in the Western Forest-Steppe but of particular interest as a recognized benchmark soil (Figure 9).



Figure 9. Exposed Haplic Chernozem (Siltic) profile at the Kamianets-Podilskyi museum



Figure 10. Structural stabilization of the exposed profile wall using a double application of PVA solution

Living Soil Museum as a citizen science springboard

Because a Living Soil Museum maintains an actively monitored, alive soil, it can offer visitors something closer to a genuine scientific task rather than mere explanation. Citizen science in soil monitoring has, over the past decade, grown from a marginal add-on to environmental education into a recognized complement to formal monitoring networks—partly because volunteer observation can achieve an observation density that professional survey campaigns rarely can and, partly, because European soil policy has explicitly recognized that soil health cannot be assessed, or defended politically, by professionals alone [6]. More widely, citizen science has already achieved long-term societal outcomes [13].

The scale of present citizen-science activity concerning soil is, itself, informative for assessing where Living Soil Museums can add value. A 2023 review for the EU Soil Observatory's ECHO project screened 91 soil-related citizen-science initiatives identified through literature searches, project databases, citizen-science platforms and expert outreach via the European Soil Data Centre (ESDAC) network; 71 initiatives were retained for detailed analysis and inclusion in the ECHO repository [14]. Two findings are germane. Firstly, Europe accounted for 66 per cent of identified initiatives, with Africa and South America together accounting for only 3 per cent—meaning that any single new site adds to a sparse global base rather than to an already-saturated one. Secondly,

and more importantly for design purposes, only 13 of the 71 catalogued initiatives involved citizens in genuinely collaborative or co-created roles (contributing to the design or interpretation of the research), as opposed to simple data contribution; partly because of a lack of durable, trusted local infrastructure that can sustain deeper participation [14]. A permanent, staffed installation such as a Living Soil Museum could provide exactly that kind of local infrastructure.

Actual participation

The Living Soil Museum serves not only as an educational facility but also as a permanent Soil Knowledge Hub, integrating scientific evidence, citizen engagement and policy dialogue (Table 2).

At least three kinds of citizen engagement around the two sites are already evident:

School and university groups. The Living Soil Museums were commissioned by the end of June 2026 when Ukrainian schoolchildren and students had already completed the academic year; their involvement in the museums' activities will therefore begin in September 2026. Meetings were held with the rectors of the leading universities in Poltava and Kamianets-Podilskyi to discuss using the museums to strengthen the educational process through practical classes. Similar meetings are planned with secondary-school science teachers, so as to align student excursions to the Living Soil Museums with relevant lesson topics. The museum's dashboard offers a ready-made dataset for basic data-literacy exercises that most schools cannot generate independently, enabling pupils to compare a professionally instrumented reference profile against any measurement they take themselves, whether on a school plot or using a smartphone.

The Living Soil Museum was presented during the Dual Education Forum at Poltava State Agrarian University on 25 June 2026, demonstrating its role as an innovative platform integrating scientific knowledge, artistic interpretation and citizen science. This and other events demonstrate that, as both an exhibition and an experimental environment, the museum provides practical learning opportunities and fosters dialogue between universities, business and local communities. Its integration into educational programmes will strengthen interdisciplinary training and promote sustainable soil management practices.

Table 2. Functional domains and representative activities of a Living Soil Museum

Functional domain	Representative activities	Primary participants	Scientific / societal value
Real-time soil monitoring	Observation of real-time sensor data (soil moisture, temperature, CO ₂ concentration, electrical conductivity, etc.); interpretation of temporal trends	General public, students, researchers	Makes dynamic soil processes observable; improves soil literacy and understanding of soil functioning
Citizen science	Simplified field measurements, participatory observations, contribution of local environmental data	Schools, community members, NGOs	Encourages public participation and environmental stewardship while improving data literacy
Formal education	Curriculum-linked practical classes, university field exercises, teacher training	Schools, universities	Supports inquiry-based learning and integration of soil science into education
Professional learning	Demonstrations of soil health indicators, workshops for farmers and advisers, interpretation of reference soil profiles	Farmers, consultants, land managers	Promotes adoption of soil health assessment and sustainable management practices
Cultural interpretation of soils	Soil art exhibitions, artist residencies, soil colour palettes, storytelling, exhibitions on soil heritage, performances inspired by soils	Artists, cultural institutions, general public	Connects scientific knowledge with cultural values and emotional engagement, strengthening public appreciation of soils
Community engagement	Public lectures, open days, thematic festivals, volunteer programmes, World Soil Day celebrations	Local communities	Builds long-term relationships between science and society
Historical and environmental memory	Interpretation of paleosols, land-use history, archaeological evidence, post-disturbance soil recovery	Public, students, decision-makers	Demonstrates soils as archives of environmental and cultural history
Climate communication	Demonstration of soil respiration, carbon cycling, greenhouse gas exchange, soil moisture dynamics	Community members, policy stakeholders	Makes climate-related soil processes tangible and understandable
Innovation and digital engagement	Interactive dashboards, augmented reality, mobile applications	Public, young audiences, visitors	Increases accessibility and attractiveness of soil science

Farmer, management and policymaker engagement. For farmers, the opportunity for direct observation of the relationships between soil morphology, biological activity, the water and nutrient cycles may provide a more convincing incentive for voluntary soil health assessment than abstract policy recommendations or regulatory requirements alone. The museum also serves as a science-policy interface where local authorities, land managers and policymakers can understand better how soil functions underpin agricultural productivity, ecosystem services, climate resilience and environmental security. This shared understanding facilitates evidence-based decision-making for land restoration, conservation priorities and investment in nature-based solutions; although the museum should clearly communicate that it demonstrates fundamental soil functions—such as water regulation, carbon cycling, biological activity and buffering capacity—rather than predicting crop-specific fertility or management recommendations for individual fields. Soil function provides the ecological foundation upon which productivity depends, but crop performance remains strongly influenced by local soil variability, climate, management practices and other site-specific factors. Maintaining this distinction is essential to preserve scientific credibility while maximizing the museum's educational and societal value.

Reference-anchored citizen monitoring. The Living Soil Museum can function as a well-characterized reference point within a broader citizen-monitoring framework. Continuously measured parameters relevant to soil health and function are displayed on-site and online, and explained through guided interpretation (scientist-led sessions and interpretive panels), so that visitors learn *to read* the data, not simply view them. Visitors and participating museum-linked partner farms and schools are trained in a standard, low-cost measurement protocol (fixed sampling depth, fixed method and reporting template). Observations collected off-site are submitted through a defined channel (*e.g.*, a simple digital form or the project's Web-GIS portal) and pooled into the baseline soil-monitoring dataset, extending spatial coverage beyond the two museum locations. Obviously, comparability achieved this way applies most directly to soils of similar type and moisture regime to the reference profiles but, beyond their local educational role, both museums are integrated into the broader SoilTribes ecosystem, which provides opportunities for knowledge exchange. Through the project's network of Soil Lab Activators, connecting hundreds of registered stakeholders and dozens of third-party soil-literacy initiatives across multiple European countries, the museums can disseminate educational materials, participate in joint online workshops, webinars and citizen-science campaigns, and share methodological experiences with other Living Labs and soil literacy initiatives [15]. In this way, the museums function as Ukrainian demonstration and knowledge hubs contributing to the European soil-literacy community despite geographical and security constraints. Digital dissemination—including virtual guided tours, live

streaming of soil sensor data, interactive educational modules and open-access training resources—offers a realistic pathway for engaging international audiences while maintaining strong links with local communities.

Making soil visible: Real-time monitoring, interpretation and outlook

Soil monitoring system: What is measured, why it matters and how it works

The concept of a Living Soil Museum is that visitors interact with a living soil rather than static specimens. Each of the two sites carries the same sensor architecture in two co-located configurations: one set embedded in the exhibited profile inside the pavilion, which drives the live visitor-facing display; and a second, equivalent set installed in undisturbed soil immediately outside the pavilion, which provides a field reference unaffected by the enclosed exposition environment. Both configurations monitor soil temperature at multiple depths, soil moisture and reaction, with data transmitted to a cloud platform for near real-time display. Several additional parameters including near-surface CO₂ concentration and available nitrogen, phosphorus and potassium, are also measured using lower-cost industrial sensors. At this stage, they are better suited to showing relative trends than to reporting precise, absolute values, but procedures for their calibration and periodic verification against reference laboratory analyses are being progressively refined.

Within the exhibited profile, the sensor suite provides a continuous vertical record from the surface boundary layer to a depth of 2m; the paired external set records the same parameters in undisturbed soil, so that the exposition regime and the undisturbed field regime can be read side by side.

Sensor instrumentation and vertical profiling

Vertical thermistor chain: A vertical chain of 11 digital temperature sensors (DS18B20) records temperature at 0, 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200cm. In the exhibited profile, this chain characterizes the thermal regime of the sheltered exposition and is the parameter best suited to demonstrating temporal dynamics to visitors; the identical chain in the external reference soil captures the undisturbed field temperature profile, so that the two series together let visitors and staff distinguish the exposition environment from the natural soil regime.

Gas and microclimate probe: An SCD41 sensor positioned just below the surface of the exhibited profile (5–10cm) records CO₂ concentration, temperature and relative humidity. In the enclosed pavilion, this CO₂ reading characterizes the near-surface microclimate, influenced by ventilation

and visitor presence, rather than soil respiration in the strict sense; representative measurement of soil respiration requires a chamber (flux) method, planned as a subsequent stage of the project.

Multiplexed physicochemical probe: An integrated 7-in-1 RS485 (Modbus) probe records, at one-minute intervals, macronutrient indices (nitrogen, phosphorus and potassium), pH, electrical conductivity, volumetric water content and soil temperature. A probe of this class is deployed both in the exhibited profile and in the external reference soil. Because industrial sensors of this type carry known, systematic offsets relative to laboratory methods, their readings are treated as indicators of relative dynamics rather than as absolute values. They are being progressively calibrated and verified against reference soil analyses; volumetric water content and electrical conductivity, likewise, require soil-specific calibration and temperature correction for absolute interpretation.

At the surface, a pyranometer (RS485, range 0–2000 W/m², spectral response 400–1100 nm) records incident solar radiation. Although this spectral range extends beyond the strict PAR band (400–700 nm), the sensor serves as a cost-effective proxy for surface PAR estimation after calibration, while providing the necessary radiative context to interpret the site's thermal and moisture regime.

Visualization interface and meteorological integration

All telemetry is visualized on a 65-inch interactive display inside the pavilion. Operating continuously and equipped with motion-activated wake-up sensors, the display hosts a dynamic, bilingual (Ukrainian and English) dashboard that displays real-time data plots, numerical readouts and explanatory contextual annotations.

Off-grid power supply and cloud communication

Each pavilion operates completely off-grid, powered entirely by an independent photovoltaic system consisting of eight flexible solar panels with a combined output of 800W, which continuously charge a portable power station with a capacity of 2.048kWh. Data transmission to the cloud database and the web portal is handled via a 4G LTE cellular router equipped with a dedicated SIM card, removing the need for local Wi-Fi or institutional network access. Data packets are uploaded at 1-minute intervals.

Data pipeline and automation workflow

Data acquisition and visualization are fully automated. The live dashboards deployed on both the public web portal and the pavilion's internal display automatically query the updated database, rendering real-time visualizations.

From number to understanding:

Two design choices determine whether continuous monitoring actually improves a visitor's understanding, as opposed to simply adding a screen to an otherwise conventional exhibit. The first is real-time or near-real-time display: a dashboard inside the exhibition space, updated frequently enough for a returning visitor to notice a change since the previous visit. The second is interpretation rather than raw display: a bare number such as '14°C at 40cm depth' communicates little to a non-specialist visitor without some reference point—a seasonal range, a simple qualitative band, or a comparison with a familiar surface condition—that makes it possible to judge whether the value is unusual, expected, or a sign of something worth discussing with museum staff. Both sites currently emphasize the first of these two design choices (live display) more strongly than the second (interpretive framing); strengthening the interpretive layer is an attractive, low-cost next step.

Future possibilities

The two new Living Soil Museums are initial implementations. Their current configuration demonstrates the feasibility of continuous, *in situ* soil monitoring within a museum environment, but several complementary directions of travel could substantially broaden their scientific and societal value.

From a technological perspective, future development will include remote access to monitoring data, allowing schools, researchers and interested citizens to follow temporal changes from beyond the museum itself. Such expansion would require solutions for long-term data management, quality assurance and digital infrastructure. Equally important is further improvement of data interpretation. Presenting measurements is not enough: future systems should translate sensor observations into understandable explanations of soil processes, ecosystem functioning and climate-related dynamics.

A second direction concerns education and public engagement. Living Soil Museums have the potential to evolve from exhibition spaces into springboards for inquiry-based learning, citizen science and interdisciplinary collaboration. Integration with formal school curricula, teacher

training, community monitoring programmes and cultural or artistic interpretation of soils could strengthen soil literacy while maintaining scientific accuracy.

Finally, as additional Living Soil Museums emerge, there will be increasing value in developing common approaches for documenting their activities and comparing their educational and scientific performance.

These perspectives should be regarded not as commitments, but as realistic pathways through which the Living Soil Museum concept may continue to develop. Like most similarly-funded pilot installations, ours faces a structural mismatch between short project funding cycles and the multi-year institutional commitment that a genuinely long-term monitoring record requires. Neither installation has yet operated long enough to demonstrate how it performs across several full seasonal cycles, let alone across the kind of multi-year record that would let it also serve a research function in its own right.

It is also important to state plainly what a Living Soil Museum is not. It is not a replacement for monolith collections, which retain unmatched value for cross-regional comparison and historical reference, nor is it a substitute for the dense, statistically representative monitoring networks (of the kind operated at EU level through the LUCAS Soil survey and coordinated nationally in many member states) that policy actually depends on for aggregate assessment. Its contribution holds value in another capacity: making the concept of soil function tangible to a visitor at one specific place, in a way that a laboratory report or an aggregated statistic cannot.

The most direct opportunity for future work is replication and comparison: applying a shared, explicit set of design criteria to any future Living Soil Museum, so that new installations can be planned against a known standard rather than each starting from first principles, and so that the two Ukrainian sites can eventually be compared, on equal terms, with any comparable installation built elsewhere.

Acknowledgement

This work was supported by the European Union through the SoilTribes project (Grant Agreement No. 101157729) under the sub-grant agreement No. 79dd5798-f26d-43c8-a374-5a964cac5bad (SOIL ARK: Shaping Soil Futures Together). Views and opinions expressed are those of the authors and do not necessarily reflect those of the European Union or the European Research Executive Agency (REA). Neither the European Union nor the REA can be held responsible for those views and opinions.

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