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Exploring the artistic dimensions of soils in the vadose zone

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Abstract

The rise of industrialized agriculture, coupled with a global demographic shift toward urbanization, has marginalized every-day connections between individuals and soils. This societal shift has led to a decline in the appreciation of and cultural identity with soils. Amid a broader movement aimed at fostering soil awareness and environmental action, many artists and designers have been instrumental in bringing soils to the cultural mainstream, figuring their esthetic, social, political, and ecological dimensions. Contemporary artists place great importance on the underlying idea of animating soils through artistic practice, often transcending the physical artifact itself to assign agency to soils and the myriad beings that occupy them. Artists harness a multitude of media to articulate human-soil relationships. From the early environmental art movements of the 1960s and 1970s to contemporary works centered on urban and industrial brownfields, soils' multifaceted roles in CO_2 transformation, water and nutrient cycling, agriculture, and as living bodies buffering against pollution have become ground for public discourse. What could this mean for the vadose zone in terms of reflecting on material flows in porous media beyond understandings of soil physics? In this paper, we draw on over 20 years of experience in studying the portrayal of soil in various arts genres to deliberate the potential of creative thinking about and thinking with the vadose zone.

1 | INTRODUCTION

Study of the vadose zone seeks to understand the material dimensions of soils as they are expressed by the laws of physics. Historically, these dimensions have been mathematically modeled using remote sensing and geospatial data to enhance understanding of processes in the soil profile that fluctuate between phases of saturation. We believe there are other ways of observing, interpreting, and thinking with such processes, that there are esthetic and philosophical dimensions to material ebbs and flows, and that processes of wetting and drying, leaching, and capillary rise encompass a poesy and aesthesis as well as mathematical truth.

Throughout human history, esthetic applications of soil have left indelible marks by diverse cultures. The cultural utilization of soil materials as a medium of craft and symbolic and esthetic expression, be it as pigment (as explored by Ugolini et al. [2010]) or as structural material, has a history predating its use in agriculture. However, the advent of industrialized agriculture and urbanization resulting from violent settler-colonial expansion has all but obscured cultural connections to soils and their material and ecological properties. Most members of contemporary societies have been cut off from regular interaction with soils, failing to recognize flows within the soil unless they appear as catastrophic mudslides or flooded streets. In this detachment from ancestral, agricultural, spiritual, or material-structural

ties to the land, the esthetic and cultural significance of soil has dwindled, leading to a sensory gap between many humans and the Earth. Soil, as material body and habitat teeming with life and meaning, is often reduced to "dirt." Klingan et al. (2014, p. 25) lament that "the leakage of open mining pits and hydraulic fracking of rocks," among other calamities, have turned the permeable, life-supporting safe space of the critical zone into a "mud zone."

Paradoxically, despite this waning appreciation, contemporary soil protection paradigms predominantly rely on soil scientific evidence, sidelining cultural values and local knowledge and conservation strategies that could reinvigorate human perception of soils and foster better treatment of terrestrial landscapes under the current pressures of climate change and land degradation. Other publications have addressed this disparity, advocating for stronger integration of soil science into education at all levels (as proposed by Herrmann [2006] and Smiles et al. [2000]) and the development of more accessible public resources (as exemplified by van Baren et al. [1998]). Other authors have argued that soils must be considered based on their social, political, and cultural dimensions (as championed by Greenland [1991]; Lyons [2020]; Meulemans et al. [2018]; Puig de Bellacasa [2015]; Salazar et al. [2020]; and Winiwarter [2006, 2019]). Additionally, these and other authors underscore the potential role of art as a tool for environmental communication and consciousness-raising (explored by Feller et al. [2010], Toland & Wessolek [2010a, 2010b]; Toland et al. [2018]; Ugolini et al. [2010]; and van Breemen [2010]). It is this latter point that has formed the core of our inquiries over the last 20 years. While soil scientific research offers lawmakers and the public a foundation of numerical analyses and expert projections, art plays a pivotal role in conveying environmental issues to a broader audience, acknowledging other forms of material and cultural knowledge and local soil expertise. Art thrives as a realm of free experimentation where ideas can be independently and critically tested before entering mainstream discourse, reflecting on shifts in cultural understanding of soils as well as actively reimagining "soil literacy" in public spaces.

The significance of art and design in science, technology, engineering, and mathematics (STEM) fields such as information technology, robotics, and materials science, but also environmental engineering and earth sciences is evident at renowned festivals such as Ars Electronica in Linz, Austria; Transmediale in Berlin, Germany; Pixelache in Helsinki, Finland; and RIXC Art Science Festival in Riga, Latvia, among others. Wilson (2002a) suggests that art and science encompass intersecting cultural duties, working together to promote environmental consciousness. It is thus a cultural necessity for both scientists and artists working with soils to bridge communication gaps, enhance public awareness, and develop more inclusive approaches to soil conservation.

In the past, Bouma and Hartemink (2002) have underscored the necessity for interdisciplinary research programs to facilitate communication among soil scientists, planners, policymakers, and other stakeholders. Yaalon (1996) similarly emphasized the transfer of soil technology between industrialized and developing nations. Establishing robust research partnerships is crucial for the effective exchange of knowledge between scientific and artistic disciplines. Organizations like the Leonardo International Society for the Arts, Sciences and Technology, the Art and Science Collaborations Inc., and the arts and ecology programs at educational institutions of all levels attempt to bridge communication divides. In addition to the international festivals mentioned above, long-term initiatives such as Cape Farewell and the 350.org campaign, the Anthropocene Curriculum and Commons of the Max Planck Institute and House of World Cultures, the alternative public pedagogies of Floating Berlin, and the internationally touring exhibition "an example to follow/ETF!" have successfully brought together artists, scientists, and educators over many years to raise awareness about climate change, including the many challenges facing soils. Most significantly, the 2015 UN International Year of Soils and 2015–2024 Decade of Soils provided a momentous opportunity for many interdisciplinary institutions, public programs, and individual protagonists to address soil conservation on a broader cultural scale. Since 2015, soils can be found on most agendas at cultural institutions of all sizes and levels of prominence, from neighborhood-run galleries and community gardens to major museums and festivals. Through interdisciplinary engagement and a general sense of urgency, soils have (re-)entered the mainstream.

This paper serves as one step in a process of reverse knowledge transfer, introducing examples of soil art to a primarily scientific audience. Conversely, we are intrigued by the creative facets of scientific research and how they can enrich artistic practice. Our overarching goal is to encourage collaborative endeavors between scientists and artists, aiming not only to enhance public understanding but also to pool methodological know-how in confronting issues of contamination, erosion, and lobbying for legal protection. By amalgamating the insights gleaned from several contextual reviews and opinion papers we have coauthored over the last 10–15 years, our work as both commissioners and co-commissioners of the

Core Ideas

- Soil scientists need to actively engaging with artists, designers, and cultural practitioners to bring soil topics to a wider audience.
- We support fostering teaching collaboration across disciplines and transdisciplinary exchange.
- We aspire to reform the structure of research funding.

German Soil Science Society's Commission on Soils in Society and Education (2011–2015) and Alexandra Toland's work as co-commissioner of IUSS Commission 4.5 History, Philosophy, and Sociology of Soil Science (2022–2026), as well as several innovative field experiments of our own and with students, we reflect on different opportunities for collaboration between and across disciplines dedicated to understanding soils. Our ambition is thus to foster a deeper appreciation for the interplay between the arts and sciences, a combination that holds much potential in advancing appreciation for the vadose zone and for soil protection practices more broadly.

1.1 | Authors' motivation

Gerd's professional background is soil physics and hydrology, complemented by studying fine art techniques and art history. Alexandra's background is rooted in the visual arts and environmental humanities, complimented by an engineering degree in landscape planning. Their collaborative research is uniquely shaped by the integration of art and design methods, drawing inspiration from fine art painting, which inherently explores the dynamics of flows and material transformations and performative and conceptual art, which situates soil as subjective and social entity. Their experiences and interests are rooted in an urban ecological context, emphasizing not only the dynamics of moisture, nutrients, and pollutants but also delving into the realms of site-specific history and politics. They explore how these factors impact both human and more-than-human populations. Specifically, both authors look at how artists appropriate scientific ideas in their work and how these in turn resurface in scientific debates on the vadose zone. How can art contribute to the protection of soils and the safeguarding of water resources in soils, not merely by fostering public comprehension and elevating cultural appreciation, but also by devising innovative approaches to confronting complex challenges of climate change, water retention in landscapes, and energy transformation? And how can such approaches be integrated into teaching and research? Drawing on insights from several renowned artworks as well as our own artistic experimentations, we argue that art plays an integral role in generating dialogue between soil science and society at large, which could innovate new understandings of the vadose zone.

2 | SOIL IN CONTEMPORARY ART

Depictions of soil and geologic forms may be identified in almost all major artistic genres. From landscape painting spanning works of Renaissance painter Pieter Bruegel the Elder all the way to Grant Wood's farmlands of the 20th century, from Chinese shan shui ink paintings to Japanese Dorodango mud balls, from the Land Art movement of the 1960s and 1970s to contemporary media art experiments to sonify and digitize soil environments, to more recent environmental and ecological art, it is important to distinguish between artworks that utilize a symbolic reference to "earth," and those that contextualize "soil" as a distinct geophysical and biochemical body. In past writings, we have thus defined soil art as "art consciously in or with soil or about soil conservation issues, expressed via a wide range of artistic disciplines resulting in a multisensory esthetic experience" (Toland & Wessolek, 2010a, 2010b). Multisensorial approaches to soil art include, for example, artists working with soil scent, soil, and terroir; cultural practices of eating clays (geophagy); soil sounding and sonification; and multisensorial sculpture (Toland & Wolter, 2023).

Two main approaches to soil art can be articulated as follows: artwork that is primarily concerned with the formal esthetic and material properties of soils, for example, as they are dealt with in ceramics, architectural practice and pigment making, and artwork that is ecologically restorative and recognizes the many roles and functions of soils in the environment. Matilsky (1992) makes a similar distinction between artists who have "proposed or created ecological artworks that provide solutions to the problems facing natural and urban ecosystems" and artists who hone their skills to attract attention or create awareness of environmental issues by "framing the problems through a variety of media." The early land artists, for example, were mainly occupied with material forms, importing a visual vocabulary from the minimalist and post-modern movements into remote natural settings. Artists such as Michael Heizer, Walter de Maria, Robert Morris, and Robert Smithson, for example, provoked new ways of perceiving the environment by bulldozing monumental shapes into the landscape and exhibiting heaps of soil and rocks that were intended to be seen as sculptural works. Several contemporary artists have emerged in recent years to highlight the material qualities of soils. Notably, Lara Almarcegui's installation at the Vienna Secession in 2010, Delcy Morelos' installation of "Earthly Paradise" at the 59th La Biennale di Venezia in 2022, and Daniel Lie's "Unnamed Entities" at the New Museum, New York, in 2022 use tons of soil and construction fill in large-scale room installations that provoke viewers to rethink the value and meaning of soil as living materials in constant cultural circulation.

Around the same time as the Land Art movement, beginning in the late 1960s and 1970s, a more reactionary group of environmental artists, including Alan Sonfist, Newton and Helen Mayer Harrison, Agnes Denes, and Joseph Beuys, began focusing their artistic efforts on repairing and restoring ecosystems and creating attention to environmental degradation. In both of these conceptual approaches, soils are imagined otherwise, providing new perspectives on soils in the environment and our relations to it. Different artistic

motifs speculate the essence of specific soil functions that can be related back to soil scientific understanding of soil functions. For instance, concepts of fertility are dealt with in the works of Charles Simonds, Ana Mendieta, Shai Zakai, Roxanne Swentzell, Annie Sprinkle, and Beth Stephens. The archival and heritage function of soils are prominent in the projects of Betty Beier, Marianne Greve, Cannupa Hanska Luger, Mandy Martin, and Ekkeland Götze. Despite "a profusion of terms" (Bower, 2009), including land art, earth art, environmental art, and now soil art, the term eco-art historically refers to art with and for nature as opposed to art simply about or in nature (Aagerstoun, 2007). In areas with weak mitigation policies, eco-art has come to fill a planning void in degenerate landscapes. Land remediation and mitigation is disguised as sculpture and performance art. Some interdisciplinary projects are unique in that they are either initiated by or include artists in solving local and regional environmental problems. For example, the Acid Mine Drainage & Art project (1994–2005) in Vintondale, PA, is a tribute to the cultural and environmental heritage of the mining region. Artist Stacy Levy designed a passive water treatment system, or "Litmus Garden," to help communicate soil processes of buffering and filtration. Initiated by art professors Tim Collins, Reiko Goto, and Bob Bingham formerly of the Carnegie Mellon Studio for Creative Inquiry, the Nine Mile Run greenway restoration project in Pittsburg, PA, also addresses complex soil remediation processes. On a smaller scale, artist Georg Dietzler has confronted soil contamination issues by using myco-remediation (i.e., remediation facilitated by fungi) in his long-term installation projects. In works such as Self-Decomposing Laboratory (1999) and Moveable Oyster Mushroom Patch (1996–1997), Dietzler makes use of the edible oyster mushroom (*Pleurotus ostreatus*) to break down organic pollutants such as polychlorinated biphenyls. In a similar bioremediation project, the "Revival Field" (1990–1993), artist Mel Chin planted a field of heavy metal-absorbing "hypo-accumulators" at the Pig's Eye Landfill in Minnesota. In another project, "Paydirt," Chin launched a public awareness campaign about the high lead content in New Orleans' soils, a problem that has increased long after the floodwaters of Hurricane Katrina receded.

The following works in particular stand out as "vadose zone artworks" in our opinion, because of the ways they esthetically and symbolically deal with the physical materiality of urban soils, as public urban intervention, as time-based works, and as multisensory social experience. In the first example, permeable pavements, bioswales, berms, and basins serve as sculptural mediums to draw attention to urban soils and water cycles in public space. In the early 1980s, Gary Riveschl showcased the imperative need for opening pavements to provide nature an opportunity to rejuvenate and to allow rainwater more space for infiltration in his series of groundbreaking (literally) "break out" installations and sculptural interventions in cities (Figure 1). During this period, political advocates from green parties began advocating for the restoration of natural hydrological systems within cities. Over the past two decades, designing rainwater infiltration solutions for urban areas has evolved into a standard practice, aimed at closing the hydrologic cycle. In the last decade, city planners have embraced the concept of "sponge cities" to design increased rainwater retention that can better buffer the extreme runoff of intense rainfall events. Cities are now expected to retain as much rainwater as possible for the purpose of cooling urban environments and allowing for better tree transpiration and more green space. Riveschl's work was a pioneering call for more pockets of unpaved soils in cities, suggesting that rainwater infiltration and soil hydrology is not only a topic for urban planners and soil cartographers but for everyone who lives in cities and is affected by climate change and its effects on the hydrologic cycle.

FIGURE 1 Gary Rieveschl, Breakout, 1981.

The second example focuses on the time-based phenomena of soils, bringing to life moisture flows within the vadose zone through practices of listening. Fluxus artist Dick Higgins, as cited in Dezeuze (2014), "Origins of the Fluxus Score," once suggested that "musical activity takes place in time, and . . . anything that just breaks up time happening in it, absorbing it, is musical." Toland (2023) has argued that according to this logic, the events that take place in a single pedon are musical. The musical score of an individual soil biography is written down in soil horizons, which detail recognizable patterns of chemical and physical events in the distribution of various materials. Works that sonify these events are particularly interesting for studying the vadose zone in that they open soil physics and hydrology to the fields of acoustic ecology and media art. Notably, the Waterviz project (https://hubbardbrook.org/waterviz/) at Hubbard Brook merges hydrology, art, music, and data design to collect real-time hydrologic data like precipitation, streamflow, soil water, and groundwater from the Hubbard Brook Experimental

Forest in New Hampshire. Using digital sensors that transmit high-frequency data wirelessly to an internet-connected computer model, water cycle components are calculated and used for visualization and sonification. The resulting artistic visuals and soundscapes accurately represent current hydrological processes. Conceived by Dr. Lindsey Rustad, artist Xavier Cortada, musician and sound artist Marty Quinn, and research assistant Torrin Hallett, Waterviz offers a unique opportunity to intuitively experience the ongoing water dynamics in a forested watershed, intertwining science, art, and music for a transformative listening experience.

In a further example that uses real-time data to capture the acoustic phenomenology of soils, the "Sounding Soil" project stands out in both its scientific precision and esthetic quality. From 2017 to 2020, Swiss artist Marcus Maeder led a 20-member team as part of a research consortium between the Zurich University of the Arts ZHdK (Institute for Computer Music and Sound Technology), the Swiss Federal Institute for Forest, Snow and Agriculture Research, the Swiss Federal Institute of Technology Zurich, the National Soil Monitoring Office, and the Biovision Foundation for Ecological Development to develop methods for acoustic analysis of biological activity in topsoils. In 2017, Maeder and colleagues chose 20 test sites based on land use and humus types and set up piezoelectric sensors that converted soil vibrations into electrical signals, captured as sounds. Recordings were taken 30-cm deep and 60-cm wide, representing the biologically active part of the soil. Soil samples at the recording sites were taken with a puncture cylinder and then analyzed in the lab using the Berlese and Winkler method, soil fauna was extracted, taxonomically identified, and counted (Maeder et al., 2019). In October 2018, an immersive installation at the Paul Klee Centre in Bern featured a converted shipping container with a green roof and dimly lit listening room with light and sound that represented the recording sites at different depths. The soil sounds included clicks, taps, vibrations, hisses, and mechanical scratching that were augmented with weather and aboveground sounds to create holistic listening experience, inviting visitors to reimagine soil as a soundscape. The interdisciplinarity of sounding soil and Waterviz further invites soil scientists to work with time-based media artists in exploring what Sterne (2012) describes the "acoustic environment as a field of study, just as we can study the characteristics of a given landscape."

Finally, the American artist Asad Raza combines social interaction, relational esthetics, scientific recommendations, and technogenic soil substrates in his work. Often exploring dialogical exchanges and rejecting disciplinary boundaries, Raza conceives of his art as a metabolic, active experience. The installation work, "*Absorption*," in which a group of so-called "cultivators" tend to a room full of "neosoil," has been shown at the 34th Kaldor Public Art Project in Sydney, Australia, in 2019, at Gropius Bau in Berlin in 2020, at the Ruhr Biennale in Essen, 2021, at the "Down to Earth exhibition" in Dresden, Germany, in 2022, and at the "We are Compost/Composting the We" exhibition at the Centre for Contemporary Art in Glasgow, UK, in 2022, on the occasion of the 22nd World Congress of Soil Science. Keynote speaker Suzi Huff Theodoro and other soil scientists debated the potentials and limitations of human-made soils in cities and other disturbed areas. All iterations of the exhibitions, including podium discussions and other dialogic events, were organized and conceptually realized in cooperation with soil scientists from local universities.

Figure 2 shows an example of the "Down to Earth" exhibition at the Gropius Bau in Berlin, Germany. A locally unique "neosoil" manufactured out of local materials such as food waste from local cafeterias, coffee grinds, cocoa husks, hair from salons, and construction sand and other fill was mixed together and carefully installed within the gallery space, cared for by the "cultivators" throughout the duration of the exhibition, who explained basic soil properties such as texture and pH, raking it, and finally giving it away to visitors to use in their own gardens. The project allowed visitors to experience the soil as a living body that is constantly changing and reacting to its myriad inputs and interactions. More than anything, as the title, *Absorption*, alludes, both the soil and its cultivators act as a conduit for conversation and community. Not only is water absorbed, but also sound, smell, memory, and attention.

A smaller scale but similarly thought-provoking work, "Pieces of meadow" by Veronika Pfaffinger (Figure 3), demonstrates the living and virtual dimensions of soils. Pfaffinger's work was exhibited at the Technische Universität Dresden (TUD) Down to Earth exhibition, initiated by Prof. Karl-Heinz Feger, the former President of the German Soil Science Society, in cooperation with Gwendolin Kremer, curatorial director of the "Kustodie" of the TUD. (https://tu-dresden.de/tu-dresden/nachhaltigkeit/termine/rahmenprogramm-down-to-earth).

3 | VADOSE ZONE ART

While the uppermost layer of topsoil is a rich place teeming with life, its lowermost edge hangs over a wet roof of interwoven capillaries that suck up the ground water into pore spaces like millions of tiny cocktail straws dipped into the life-spring below. The capillary rise of water against the force of gravity in the intricate capillary fringe is determined by the size and distribution of the pore spaces. These are determined by the size and aggregation of soil particles, which in turn are determined by the age and origin of parent materials present in the subsoil. A gravelly glacial sand, for example, makes for a coarser fringe than an aeolic loess, sticky clay, or muddy peat. As a rule of thumb, the smaller the pore diameter, the higher the capillary rise. Depending on the girth of the vadose zone,

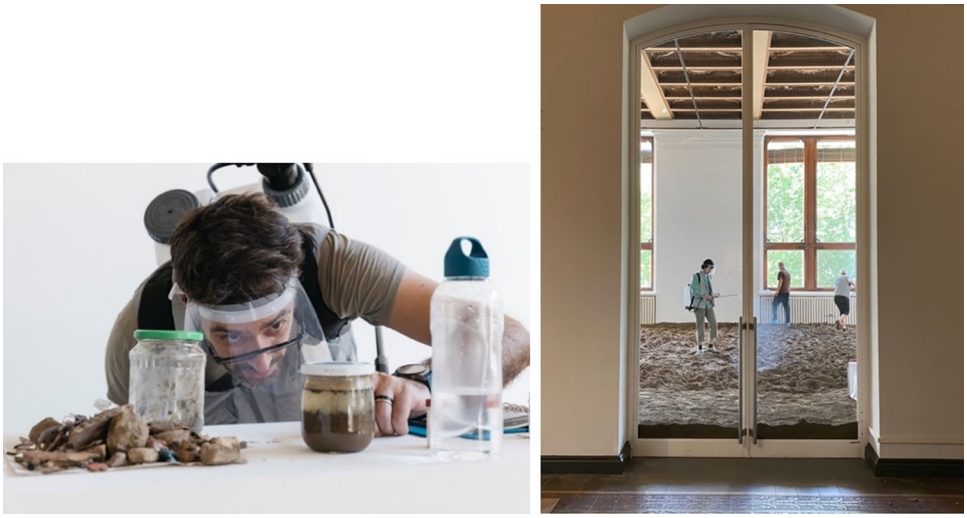

FIGURE 2 Left: Asad Raza, Absorption, Down to Earth. Climate Art Discourse unPlugged, Gropius Bau, Berlin, 2020. Photo by Ray Stonada (courtesy of the artist); Right: Asad Raza, Absorption, installation view Down to Earth. Climate Art Discourse unPlugged, Gropius Bau, Berlin, 2020. Copyright Berliner Festspiele/Immersion, photo by Eike Walkenhorst (courtesy of the artist).

FIGURE 3 Sculptures "Pieces of meadow" (each 40 cm × 40 cm × 220 cm) by Veronika Pfaffinger as part of the exhibition "Down to Earth" (2022) at the Technische Universität in Dresden (TUD), Germany (photo: courtesy of the artist).

from just a few centimeters to many meters thick, depending on the topography of the landscape and the depth of the groundwater, the capillary fringe can fluctuate daily, such as in soils of floodplains. It can also hold distant memories of time-based moisture, such as for soils on semiarid plains. In many ways, we can understand the vadose zone as a kind of moisture storage bank for all life on earth—a place where precious water is deposited, stored, drained, and refilled as it slowly travels to the groundwater aquifer.

Interest in vadose zone topics began for the author Gerd Wessolek already as a PhD student. While his scientific research focused on soil hydraulic and thermal properties, hydro-pedo-transfer functions, and water and solute transport, he felt it was important to explore these topics in free-style visualizations that captured the essence of the flows and leaks in the vadose zone. In 1995, he ventured into vadose zone research through watercolor painting, itself another material practice of the study of flows, stickiness, and leakages. This endeavor coincided with a surge in water consumption in Germany, leading to the construction of new wells in the northern regions of Hannover to meet the growing demand. The wells were often installed in landscapes with gleyic soils used as grassland or meadow because of the shallow groundwater table. As a reaction of water pumping, the water table dropped, and capillary rise became zero. The former grassland sites became much drier and, consequently, were ploughed and transformed to arable land. This transformation process resulted in an increasing groundwater recharge and high nitrate mineralization losses of the soil organic matter passing down to the groundwater. This scientific story is summarized in Figure 4 showing four typical land use situations for the same site. The arrows indicate the direction of water and solute transport in a textbook style but with esthetic elements. This picture is an example of soil science art (SSA) used as cover page for a scientific report that was financed by the German Research Foundation (DFG). The scientific results were originally published in Renger et al. (1986) and Strebel et al. (1989).

The next example shows two artworks reflecting on how soil aggregation determines soil classification, proposing that there is an esthetic dimension to soil physics (Figure 5). The left image contains an original soil profile fixed in the middle of the canvas, combined with fundamental equations used in soil physics and hydrology. On the right side, soil

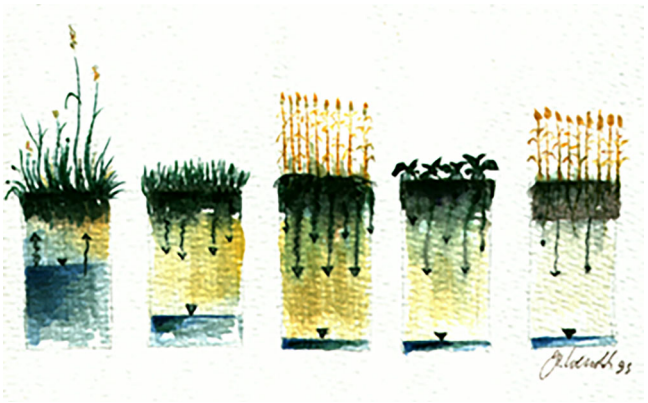

FIGURE 4 Effects of groundwater lowering on soil organic matter (SOM) mineralization, water, and nitrate transport to the groundwater—Gerd Wessolek's watercolor painting from 1995 featured as the cover page of a research report financed by the German Research Foundation (DFG).

mapping as well as soil classification criteria are depicted. Both components of the image underscore the fundamental necessity of mapping to translate the intricate nature of soil into tangible soil physical and hydrological units. The artwork on the right depicts two fundamental soil hydraulic functions: water retention and hydraulic conductivity. However, soil physics encounters difficulties in integrating soil structure and aggregation criteria. Both artworks pay homage to Rien van Genuchten, recognized for his contributions in modernizing soil physics as an environmental discipline. They also stand as examples of a science-art methodology that could be called SSA. The artworks convey that both soil mapping and soil physics serve as formal instruments for comprehending soil, yet they remain somewhat removed from the actuality of the soil. Just as with all natural phenomena, neither science nor art can fully elucidate it. Consequently, the lingering question posed by the image is: How can we reconcile these diverse perspectives?

Similarly, the coauthor's (Alexandra Toland) interests in the vadose zone also began as a PhD student at the Technical University Berlin (TUB). With formal training in the humanities, visual arts, and landscape planning, she pursued her doctoral research on soil and art in the DFG-funded graduate research cluster for urban ecology. In 2015, she used street dust collected from sealed areas in Berlin to create a wall map of soil sealing in Wedding, Berlin, a district with decreased green space and higher rates of air and soil pollution. Envisioning streets and sidewalks as an infrastructural grind mill in which urban surfaces are subject to the same forces of weathering as mountains and seashores, the author placed soil-sealing maps on the soles of shoes and welcomed visitors to the Art Laboratory Berlin to explore their own neighborhoods and imagine less asphalt. The goal of the work was to explore topics of soil sealing as they affect the environment and human well-being: How does "imperviosity" affect individuals and communities? How do humans overcome concrete barriers to reconnect with soils?

Over the past two decades, the vadose zone has also featured prominently in university teaching at the TUB. In courses and seminars such as "Urban Ecology" and "Soil Functions," artistic approaches were integrated alongside scientific topics like soil sealing, water retention in cities, sponge city design concepts, and the planning and evaluation of ecosystem services provided by street trees. These endeavors included (i) collaborations with artists, (ii) seminars focused on the creation of soil-related movies, which can be accessed on YouTube under the channel "MediaSoil" (https://www.youtube.com/@MediaSoil), and (iii) providing opportunities for students to engage in creative soil-art projects and field exercises. One of the student-produced films featured a whimsical depiction of the urban water cycle, narrating the tale of two raindrops, Willy and Wilma, as they descend onto the urban terrain of Berlin. Along their hydrological journey, they fall in love, lose track of each other, traverse distinct urban paths, and ultimately reunite as they evaporate. The above-mentioned creative field exercises were conducted, among others, in an overgrown urban lot adjacent to the TUB campus. Students specializing in landscape planning and environmental engineering were encouraged to not only paint their impressions but also to integrate artifacts discovered within the soils into their artwork (Figure 6). At the conclusion of the seminar, discussions extended beyond the artworks themselves, delving into the significance of urban discoveries in relation to contamination risks and methods for decontaminating and repurposing the soil, considering its potential uses on the site. This kind of teaching enables the development of new criteria for seeing, teaching, mapping, and evaluating soils and landscapes, effectively—and attractively highlighting soil-related aspects.

Figure 7 (left) displays familiar soil esthetic criteria, while the painting on the right illustrates a designated soil alphabet. Each letter symbolizes a soil-related topic, representing both scientific and artistic narratives.

4 | THE IMPORTANCE OF DIALOGUE

In 2018, Toland, Noller, and Wessolek published "Field to Palette: Dialogues on Soil and Art in the Anthropocene," which is a dialogic investigation of the cultural meanings, representations, and values of soil in a time of planetary change. The book offers critical reflections on some of the most challenging environmental problems of our time, including land take, groundwater pollution, desertification, and biodiversity loss, as seen through the perspectives of different soil practitioners. At the same time, the book celebrates diverse forms of resilience in the face of such challenges, beginning

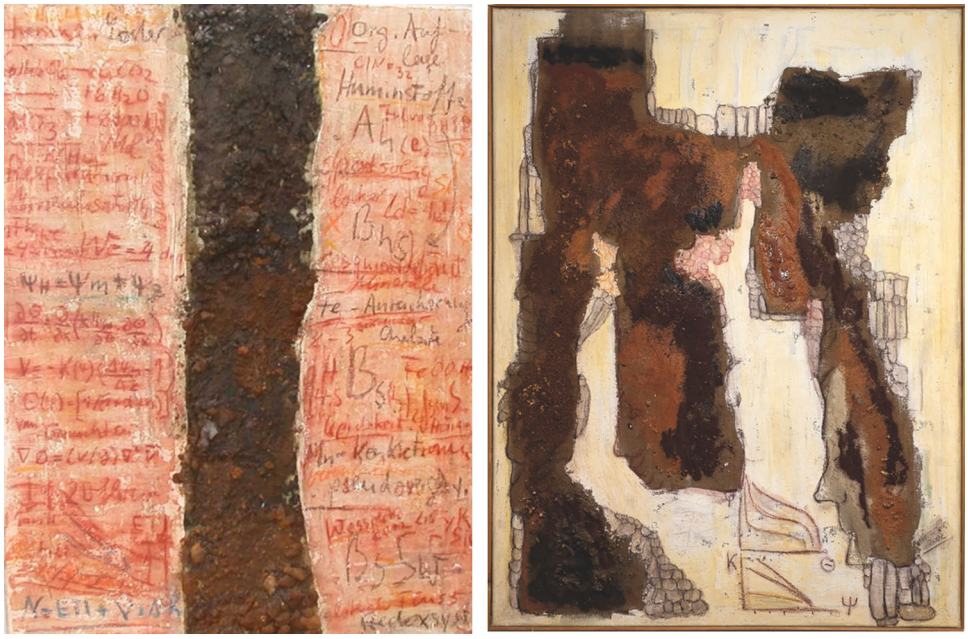

FIGURE 5 Left: "soil physics meets soil classification"; right: "soil structure enters soil physics." Both tribute to Rien van Genuchten and his input in soil physics, painted by Gerd Wessolek in 2002.

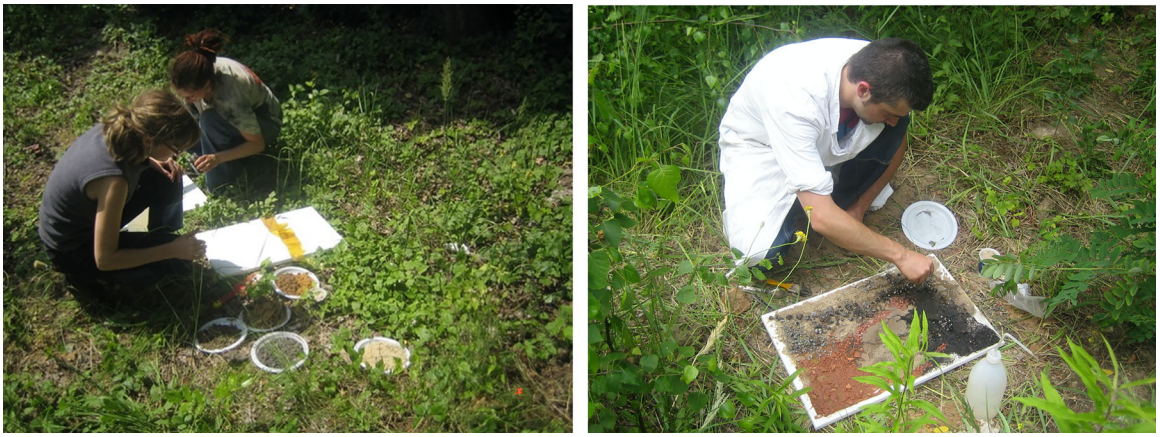

FIGURE 6 Field exercises with students fixing soil and artifacts on canvas (photos by Wessolek).

with its title as a way of honoring locally controlled food production methods championed by "field to plate" movements worldwide. By focusing on concepts of soil functionality, the book weaves together different disciplinary perspectives in a collection of dialogue texts between artists and scientists, interviews by the editors and invited curators, essays and poems by earth scientists and humanities scholars, soil recipes, maps, and do-it-yourself experiments. With contributions from over 100 internationally renowned researchers and practitioners, "Field to Palette" presents a set of artistic methodologies and worldviews that expand our understanding of soil and encourage readers to develop their own interpretations of the ground beneath our feet. More than anything, the book aims to facilitate dialogue about soil and encourage exchange across and beyond disciplines.

Expanding on this dialogic work, we look back on two of our own long-term transdisciplinary projects that have been central to our understanding of the vadose zone. The first, more recent project is the WindNODE research collaboration from the years 2018–2021, funded by Federal Ministry of Education and Research. The partnership was established between (i) energy companies, (ii) soil scientists, and (iii) artists and designers. The research project "WindNODE" (https://www.windnode.de/en) focused on the energy transformation to renewable sources (wind parks) in Germany and their little-known effects on soil resources. On a

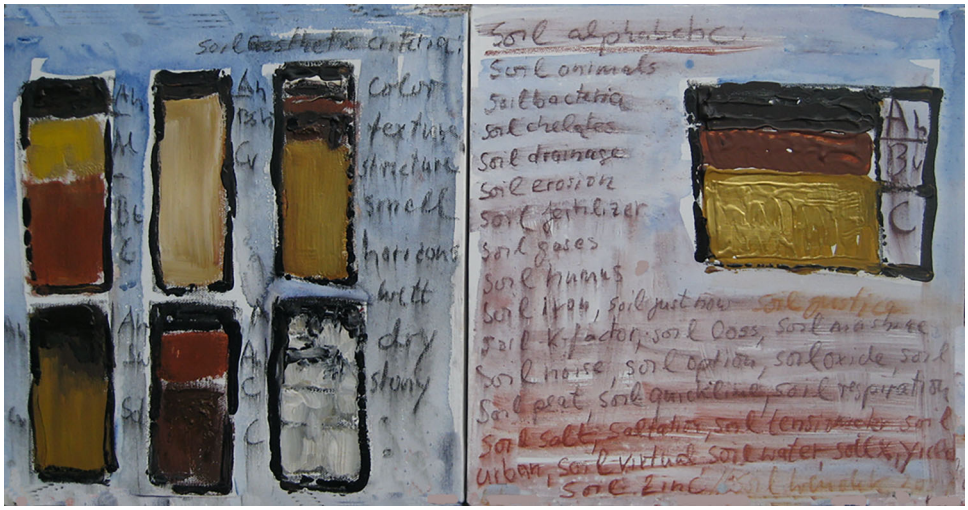

FIGURE 7 Left: soil esthetic criteria; right: soil alphabetic topics, both painted by Wessolek in the context of a soil-art teaching exercise, 2007.

4000-km-long high-voltage energy terrace, a 360 kV cable line was installed in the soil for transferring electric power from the northern, windy part of Germany to the south with a high energy demand. In a teaching collaboration in 2017, Toland and Wessolek teamed up with Professor of Elemental Design, Myriel Milicevic, from the FHP Potsdam, and research assistant Dr. Björn Kluge for the interdisciplinary "Electric Avenue" project. Environmental engineering and landscape planning students and design students collected data on energy uses, leaks, and potentials in energy diaries, visited sites in Berlin and Brandenburg and worked together to develop project ideas that addressed the soil-energy nexus. Results of this "Energy meets Art" project were published by Wessolek and Kluge (2020). Artist Betty Beier was part of this interdisciplinary research project. Betty Beier has spent over 20 years documenting soils found on contested sites of major infrastructural projects around the world. Concerned with the rising yearly loss of soil due to urban and industrial development, Beier explores the loss of landscape in the series "Erdschollen Archive" (Earth Print Archive). Within this context, she prepared an "earth print" (1 m × 1 m) of the soil surface to preserve a square meter of soil as it was before the digging started (Figure 8, left).

Because of implanting cable liner, soil properties and functions are impacted as shown in Figure 9. Before the intervention, soil formation development of soil structure and nutrient translocation has been visible (Figure 9a). After installing the cable liners, however, only a uniform topsoil horizon and subsoil with cables remain (Figure 9b). Thus, not only the historical profile of the soil changed but also its functions from a pure agricultural land to an energy transport media. The main soil function is now hosting the cables safely and transferring cable-induced heat from the voltage transport to the soil environment to prevent high cable temperatures. Among others, a central question arose as to how to predict soil thermal conductivity using theoretical and empirical approaches. A cable cross-section and some basic heat transport equations are illustrated in Figure 9c on a canvas by Wessolek (2019), and scientifically discussed in an article by Wessolek et al. (2023). Through our own artistic practice and insightful discussions with Betty Beier, we try to reflect on the science behind monitoring the environmental impacts of large infrastructure projects that form the literal backbone of the energy transition in Germany. As with Beier's other earth prints, artistic archival shows that no major infrastructure project can leave the soil intact. Scientific monitoring and artistic recordkeeping bear witness to anthropogenic change.

The strength of the WindNODE project was that it placed research on the vadose zone within larger public debates on energy transition, energy security, and the politics of large infrastructure projects. The question remains as to how this work can influence public policy and legal frameworks. In working on the "Field to Palette" (2018) volume, we similarly invited authors to reflect on the sociopolitical concerns of soil study, from addressing industrial agriculture to soil pollution and waste management, to indigenous land use practices and rights. Through this work, we aimed to make visible the historical and political aspects that have influenced soil and art activities.

The second vadose zone example picks up a human-made environmental pollution topic, namely, the long-term leaching of sulfate coming from huge rubble deposits of World War 2 (WW2) in Berlin, leading to problems in groundwater quality. The research projects on this topic were financed by (i) the DFG and (ii) the Berlin Government in cooperation with the Berlin Water Works from 2010–2014.

About 30 years after ending the "cold war" in 1990, the topic of war-effected soils came back while preparing this article; two significant conflicts erupted that have direct and long-lasting effects on not only world peace but the future of soils: the ongoing war between Russia and Ukraine, and the 75-year conflict between Palestine and Israel. In the

FIGURE 8 Energy long-distance transport by cable liner (left) Betty Beier preparing (middle) a "footprint" artwork (right) of the soil as part of her "soil archive" (photos by Wessolek).

FIGURE 9 Soil profile before (left) and after cable laying (middle) and a picture of heat transport aspects (right), painted by Wessolek in 2019.

words of former president of the International Union of Soil Science, Lal (2022, p. 43) has argued that "soil degradation and climate change are mutually reinforcing stressors, which strongly interact and undermine peace." While sustainable soil management and regenerative agriculture are vital for world peace, social equity, and human and more-than-human livelihood, military activities have extreme impacts on the soil through compaction from heavy vehicles, introduction of anthropogenic substrates from wartime debris and rubble, and long-term pollution through the leakage of chemicals both associated with weaponry and the destruction of infrastructure.

The consequences of these conflicts for people, their perspectives on life, and the impact on soils and the environment are vividly apparent in all areas affected by war. Scientists and artists in the city of Berlin, Germany, have long been grappling with the aftereffects of war on the environment. For anyone interested in soils, these effects are exemplified by massive rubble heaps such as the "Teufelsberg" (Devil's Mountain), an artificial hill constructed from building debris from WW2, which has been the focus of several research projects in the department of soil protection at the Technical University Berlin for over 20 years. About 30% of all buildings in Berlin were destroyed during WW2. A portion

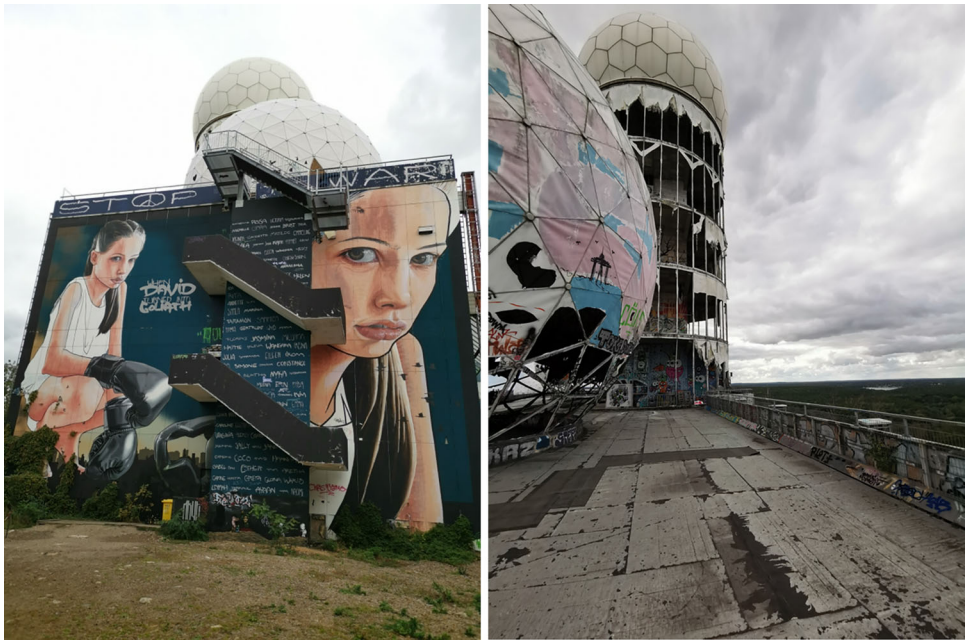

FIGURE 10 Impressions of the former Central Intelligence Agency (CIA) buildings on the Devil's Mountain (left), and the roof platform (right), both utilized for large size graffiti art, photos by Wessolek in 2023.

of the 26 million m^3 of rubble was deposited from 1950 to 1972 in a pyramidal shape according to plans by the renowned architect Hans Scharoun, who also created the Berlin Philharmonic. Additional components in the rubble include coal, ash, slag, and gypsum from former brick and mortar buildings. Mineralogical, chemical, and numerical analyses lead to the prognosis that sulfate leaching will continue for a duration of over 3000 years. Thus, percolating water and groundwater exhibit significantly elevated sulfate concentrations of >750 mg L^{-1}, leading to long-term challenges in pumping and purifying groundwater to meet drinking water quality standards. What a stark contrast: Hitler aimed to establish a 1000-year Reich called Germania, which, however, lasted only 12 years and sank into ruins, but the environmental problems his regime created will persist for the next 3000 years, that is, 100 generations. Devastation to landscapes and built infrastructure in Ukraine, Syria, Palestine, Afghanistan, Iraq, Yemen, the Democratic Republic of Congo, and Dafur will similarly lead to the slow violence of groundwater contamination and soil degradation for generations to come.

Currently, the reforested "Teufelsberg" is used as a recreational area for sports, and the former Central Intelligence Agency (CIA) budlings, which were erected during the "cold war," are now used unofficially as a place for street art and temporary cultural interventions, as illustrated by Figure 10.

The history of the Teufelsberg and its underground legacy have been recognized by artists, who have addressed the profound human suffering and the loss of homes. For example, Philip Topolovac's project "Soil Samples" (Bodenproben, 2005–2010) is an archive of hundreds of twisted jewels of emerald and amber-colored glass that were collected in rubble soils in Berlin and serve as a material memory of loss. Notably, Dr. Lukasz Kosela, a Polish artist, has tackled this issue by portraying individuals who lost everything during the war with portraits printed on bricks sourced from rubble heaps.

Figure 11 gives impressions of the devastation in Berlin in 1945 and a view of Devil's Mountain, which includes the former secretive CIA station of the United States. In the figure, a typical rubble soil profile is displayed along with Kosela's artwork from 2002. More information on Devil's Mountain, long-term sulfate leaching, and artistic approaches are given by Abel et al. (2015), Wessolek et al. (2011), and 2014. The problem of addressing soil memory and cultural heritage of war-affected soils in the context of cultural ecosystem services is dealt with in Wessolek and Toland (2017). In the interest of soil health and human well-being, we agree with Rattan Lal's proposal for a "soil-peace" nexus and see the potential of art–science collaborations in not only addressing past conflicts and healing cultural and environmental memory, but in working together to cultivate and restore healthy soils for the sake of a common future.

5 | SUMMARY AND OUTLOOK

Because cities boast a concentration of cultural and artistic activity as well as acclaimed research and academic institutions, urban soils can be considered a productive starting point for interdisciplinary collaboration. This is reflected in

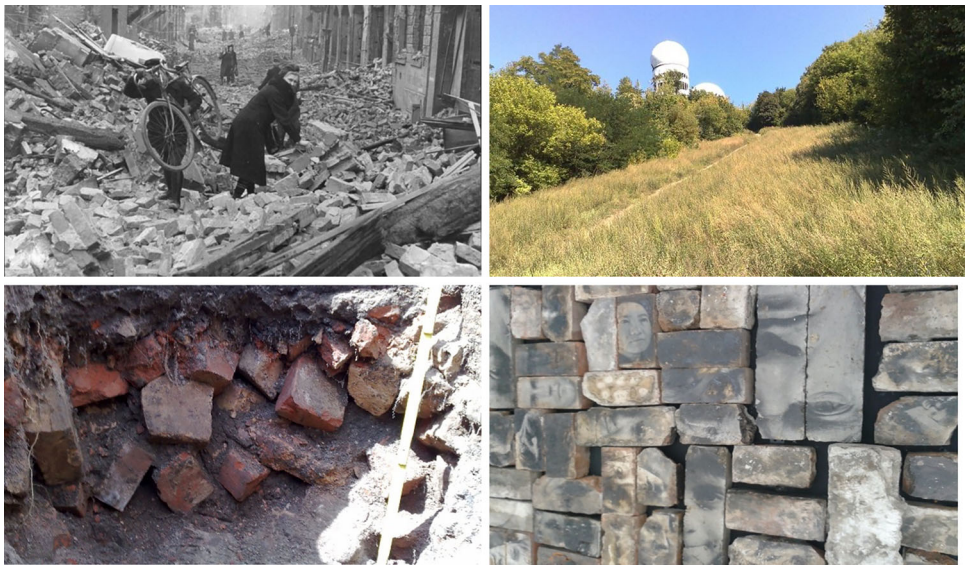

FIGURE 11 Devil's Mountain narrative. At the top: Berlin in ruins at the end of World War 2 (WW2) and the current view of the Devil's Mountain, featuring the former Central Intelligence Agency (CIA) station of the United States. Below: A typical rubble soil profile and Lukasz Kosela's artwork (2002) displaying photos of WW2 victims on bricks.

the selection of artworks above, many of which were created in urban and industrial areas. While the field of soil science has traditionally focused on optimizing soil as a resource to produce food, fuel, and fiber, city soils have historically been evaluated on different terms, that is, as medium for buildings and infrastructure and place of water retention. An increase in urban ecological research has led to new forms of perception and environmental protection objectives in cities. For example, urban soils offer a unique perspective into history. An archive of war, peace, cultural, and environmental change is preserved beneath our backyards and sidewalks. Urban agriculture and on-site rainwater harvesting have also become important topics for subsistence farmers in developing nations as well as slow food movements in industrialized nations. Open soils are also an important habitat for myriad animals, insects, plants, and microbial life in cities. The diversity, dynamics, and vulnerability of urban soils demand a need for awareness, acceptance, and education and thus provide creative stimulus for artistic involvement.

While artists can play a crucial role in sparking interest in soil protection, Stephen Wilson (2010) suggests that "artists can help researchers become aware of previously unrecognized perspectives and cognitive frameworks, while establishing connections with audiences beyond the research community." The question that remains is whether scientific collaborators genuinely embrace new perspectives and alternative cognitive frameworks when collaborating with artists. How do scientists incorporate creative insights into their research, and can this integration be influenced by interdisciplinary or cross-disciplinary collaborations? Lastly, do such collaborations typically arise from individual personalities seeking specific skills or from institutional structures and funding opportunities for interdisciplinary research? To enhance collaboration between soil scientists and artists, it is imperative to revamp our traditional research funding programs and educational institutions. Otherwise, soil protection will become increasingly one-sided and challenging to achieve as soil science sub-disciplines delve into highly specialized topics that are not easily comprehensible or relevant to the public. It is true; scientists are not inherently trained in the realm of communication, but they could be through a more wholistic education that included units on soil esthetics, history, politics, and culture. In the context of contemporary integration of art and science, we must consistently explore the parallels that emerge between an ever-converging critical art world and a culturally literate scientific community. To engage in constructive dialogue, both domains must remain open and informed about each other's methods of observing and understanding the world. Deliberate cross-referencing and regular engagement are essential. This is not just an observation but a call to action. Professional artists, cultural theorists, historians, poets, and social scientists should be more frequently invited to soil science conferences, laboratories, and journals to contribute to engineering more actively, agricultural, and ecological discourse. Conversely, soil scientists have much to offer at environmental art symposiums, exhibitions, and seminars. And both have a responsibility to address policymakers and stakeholders, using their skilled expertise to make appeals for groundbreaking soil protection legislation.

In lieu of a conclusion, the authors would like to draw attention to the following points addressed to the soil science and vadose zone community:

- *Need for interdisciplinary models*: The vadose zone is undeniably a complex and dynamic system that plays a pivotal role in groundwater protection. To gain a deeper understanding for effective management, it is imperative to consider the development of interdisciplinary models that integrate different insights and sources of knowledge. Collaborative research spanning these fields can provide a more holistic comprehension of vadose zone behavior.
- *Need for transdisciplinary lectures*: Let us develop new transdisciplinary and innovative teaching concepts to inspire students and members of the public for the topic of soil and vadose zone.
- *Challenges in applying knowledge*: Despite significant strides in vadose zone science, there can be a disconnect between scientific knowledge and practical implementation. Efforts should be made to bridge this gap by actively engaging with stakeholders, policymakers, and local communities. This ensures that research findings are effectively applied to real-world scenarios. The author's experiences in teaching and engaging with the public show how interdisciplinary cooperation can help bridging theory and practice for a better understanding of real-world problems.
- *Breaking away from formulaic thinking*: Conventional and formulaic approaches to vadose zone management and research should be challenged. Encourage innovative thinking and the development of novel models that can address the unique challenges posed by human activities and climate change in the Anthropocene.
- *Diverse data collection, analysis, and presentation*: Incorporate diverse data sources and analysis and presentation techniques. This may involve leveraging remote sensing, geospatial data, sensor networks, and machine learning algorithms to enhance our understanding of vadose zone processes. The fields of information design, media arts, and visual communications can help make vadose zone data more esthetic and more accessible.
- *Improved communication and accessibility*: Address limitations in communicating research findings. Explore communication strategies to make scientific knowledge more accessible to the wider community through clear and engaging communication, public outreach, and open-access publications. This facilitates better community engagement and informed decision-making.
- *Water supply and memory*: Investigate the relationship between water and memory within the vadose zone. How does the vadose zone store and release water, and what implications does this have for water, that is, groundwater quality and management in future? Develop models that capture this intricate interplay.
- *Humor and collaboration*: Utilize humor and collaboration to foster interdisciplinary discussions. Sometimes, humor can break down barriers and encourage creative thinking. Collaboration among scientists from different fields can lead to fresh insights.
- *Financing research*: We must reevaluate our research policies and programs. Instead of exclusively financing pure soil science projects, such as vadose zone research, let us actively cooperate with cultural agents, artists, designers, and science communicators. This collaboration could foster innovation and represent a new form of research, helping our community to bring soil-related topics and messages to the people.

AUTHOR CONTRIBUTIONS

Gerd Wessolek: Conceptualization; data curation; funding acquisition; investigation; project administration; resources; supervision; validation; visualization; writing—original draft. **Alexandra R. Toland**: Conceptualization; data curation; formal analysis; methodology; software; supervision; visualization; writing—original draft; writing—review and editing.

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