***Mitwelten*. Towards Relational Worlding with Environmental Media**

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Chapter 1 Introduction

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1.1 Environmental media for support of urban biodiversity

We live in a time of an accelerating biodiversity crisis (IPBES 2025). The increase in the extent and intensity of land uses and global industrialization processes are leading to an acceleration of the loss of species and degradation of ecosystems across the planet. This process is driven primarily by human activities such as habitat destruction, overexploitation of natural resources and biodiversity, pollution, climate change, and the spread of diseases and other invasive species. Scientists estimate that species are now going extinct at rates tens to hundreds of times higher than the natural background rate, with millions of species currently at risk. This crisis not only threatens individual species but also undermines ecosystem stability, reducing resilience to environmental changes and eroding the ecological foundations on which all life depends, including human societies (IPBES 2025).

The current biodiversity crisis forces nature conservation practitioners to adapt their strategies and solutions. Mainstream conservation efforts have until recently mainly focused on protecting vulnerable areas and species from negative anthropogenic impacts. Such traditional strategies to protect nature from human influences have become illusionary and have always been only partly adequate because for centuries much biodiversity coexisted with human land uses. It is increasingly recognized that biodiversity is an issue of relevance to all human practices and places, including amongst others urban areas, and therefore the biodiversity crisis is meanwhile recognized and addressed by disciplines and professionals well beyond nature conservation, which opens space for new inter- and transdisciplinary collaborations (IPBES 2025). This book illustrates how collaborations between media theory, design, IT engineering and ecology can foster innovation and lead to directly implementable solutions.

The publication "*Mitwelten*, Towards Relational Worlding with Environmental Media" is based on the *Mitwelten* research project (Swiss National Science Foundation, 2020-2024), which explored how media technologies can support more-than-human, relational approaches to biodiversity conservation and foster richer human-nature relationships that transgress outdated dualistic understandings of nature conservation. The project focused on urban and peri-urban environments, and on low-tech, Do-It-Yourself (DIY) uses of environmental media. The hardware required for this was developed on the basis of simple, inexpensive components and documented for replication with instructions on the Github[1] platform. The software developed is open source and has also been documented on Github. However, a certain level of technical understanding and a basic technological infrastructure are required for setup and handling.

The book aims to facilitate collaborations between media designers and biodiversity conservationists, and especially by inspiring DIY sensing initiatives and public participation in environmental monitoring projects. It aims to contribute to experiments on how easy-to-implement media technologies can be effectively used to support more-than-human coexistence in populated urban areas. In the fields of media, design, the arts, as well as cultural studies such as environmental humanities or science-and-technology studies (STS), ecology and biodiversity have become important topics of concern. For them, the *Mitwelten* project illustrates how to integrate relational and

[1] https://github.com/mitwelten

more-than-human perspectives into their curricula, artistic practices and research. Citizen science (CS) initiatives and grassroots activists gain hands-on information on how to use DIY environmental media to monitor biodiversity, challenge environmental injustices, engage communities in conservation efforts, and strengthen human-nature relationships. Finally, we engaged with practitioners, policy makers and urban planners from horticulture, nature conservation and urbanism in our three case studies and demonstrated how the rapidly growing availability of Internet-of-Things (IoT) technologies can help their daily work.

Such emerging inter- and transdisciplinary collaborations ask for new concepts that recognize the hybrid socioecological realities of biodiversity embedded in human systems. The *Mitwelten* project proposes a new approach to the design and use of environmental media. We use the term *Mitwelten* – translated as "co-worldings" or "worlding-with" – to indicate the aim of this approach as fostering relational and more-than-human coexistence in postnatural landscapes. The term *Mitwelten* draws on feminist and posthumanist writing by scholars like Donna Haraway, who emphasize that worlding is always a shared, entangled process – it is always "worlding-with" or "in company". *Mitwelten* became our framing of relational worlding that resists anthropocentrism and acknowledges the co-constitutive entanglements of humans, nonhumans, and technologies. Drawing from media studies, feminist science and technology studies (STS), and environmental humanities, the project proposes a critical yet practical approach to using environmental media that emphasizes that technologies and practices of their design and use should be approached with attentiveness, material accountability, and acknowledgment of the situatedness of knowledge.

The project focused on peri-urban and urban areas where challenges and opportunities of conservation approaches become particularly complex. Indeed, in recent years, urban biodiversity has become an important focus of ecology and biophilic design. There is a growing recognition that urban spaces, previously often dismissed as ecologically barren, can function as critical habitats for a variety of species, and urban ecosystem services are an essential backbone of sustainable and liveable cities. Urban areas, often marked by post-industrial remnants and infrastructural interdependencies, are examples of nature-culture entanglements – what we call "postnatural" landscapes – and present both challenges and opportunities for conservation efforts that aim to move beyond traditional, anthropocentric models (Kueffer 2020).

The *Mitwelten* project was led by a media theory lab that enabled the interweaving of the different disciplinary perspectives on human-nature relationships, technologies and media. It understands environmental media as having agency, or capacity for worlding, and therefore contributing to shaping shared realities of postnatural landscapes. In particular, the *Mitwelten* project explores, critically and creatively, "technoecological entanglements," the intricate interactions between digital infrastructures and ecological systems. In the context of environmental management, these technologies contribute to co-creating new forms of worlding – generating multispecies interactions, reconfiguring habitats, and influencing how humans and non-humans alike engage with and perceive their environments.

Today, technologies that digitally represent and simulate many of the planet's processes – circulating as data visualizations of phenomena ranging from rising global temperatures to deforestation trends – create a compelling but misleading sense of ecological comprehensibility. These representations create an illusion that ecosystems can be fully captured, known, and managed through the use of sensing technologies. The information generated by sensors is inevitably partial. This partiality stems not only from the inherent limitations of what can be 'rendered technically' – what can be measured, quantified, and transmitted – but also from the epistemic choices made by scientists and technologists. Decisions about which aspects of ecosystems are deemed significant or measurable invariably shape what remains excluded.

As technological tools – such as environmental monitoring systems, remote sensing, and genetic analysis – are increasingly employed to support conservation efforts, their designs are inevitably informed by the dominant perspectives. Environmental sensors, remote monitoring systems, and data analytics platforms are typically designed to capture information that is deemed relevant to human aims, such as optimizing resource use, enhancing productivity, or mitigating climate impacts. This approach often prioritizes data that aligns with economic and policy objectives. Even when the goal is explicitly nature conservation, with technology employed to, for example, enable more precise tracking of biodiversity and ecological health, the assumptions embedded in the existing tools and practices can invisibly reinforce anthropogenic ideas of what ecologies should look like, and what sensing technologies can capture.

Sensor data and other environmental media therefore do not simply reflect ecological realities; they actively participate in constructing them. These devices exert agency both materially and semiotically, a capacity called "performativity", shaping how ecological phenomena are understood and managed, and how their "health," and relation to human well-being, are determined. By generating specific kinds of data and privileging certain ways of knowing, technologies represent and contribute to materializing particular realities. While such representations can be powerful tools for governance and decision-making, they risk naturalizing the exclusions and simplifications embedded in the technologies and practices of their use. As critical media thinkers remind us, these exclusions are not neutral; they reflect value-laden assumptions about what matters and who gets to define ecological priorities. Developing new approaches to designing and using environmental media requires therefore first an interrogation of the ways each of these technologies renders ecological phenomena. What aspects of the ecosystem are made visible or invisible? Whose perspectives are amplified or silenced?

By acknowledging that environmental media do not only represent ecological processes but actively shape them through their performativities and entanglements, the *Mitwelten* project asks how these tools can foster more ethical and attentive forms of coexistence, and what can be gained from rethinking environmental media through the lens of more-than-human theory and approach of care.

This book documents the project's experimental interventions, theoretical underpinnings, and practical insights, providing a roadmap for reimagining environmental media as tools not of representation, control, or extraction but of relational care and multispecies attentiveness.

1.2 Our approaches

The *Mitwelten* project was implemented in three **Field Study Sites** distributed along a gradient of different types of urban green and open spaces in and around Basel (Switzerland): a urban park (Merian gardens), a post-industrial development site (Dreispitz) and a peri-urban nature reserve and recreational area (Reinacher Heide). The three sites can be understood as three comparative realworld laboratories that allow for experimentation with the **Mitwelten Media** and **Design Interventions** developed by a transdisciplinary team.

New conservation: beyond the human-centric and technology-centric approaches

In the past centuries, and more rapidly since World War II, intensive human land uses have expanded across the planet and replaced most wilderness areas and transformed most traditional cultural landscapes. The term ‘Anthropocene’ – or alternative terms such as ‘Capitalocene’, ‘Plantationocene’ or ‘Chthulucene ’ – stands for such a domination of the Earth’s landscapes by neoliberal monocultural systems for agriculture, forestry, fishery and tourism, amongst others (A. L. Tsing 2017; D. Haraway 2016; Moore 2016). Biodiversity conservation’s traditional strategy to protect nature from human influences has become illusionary in the Anthropocene and has always been only partly adequate because for centuries much biodiversity coexisted with human land uses. Increasingly, the contributions of ecosystems to human well-being, and especially also in human-dominated landscapes, have been recognized as central to conservation (Mace 2014). In the late 20th century, the concept of “ecosystem services" emerged as a first important framework to acknowledge nature’s manifold and immense contributions to people in modern landscapes. Initially the focus was on the economical value of nature’s utility to humans in providing such benefits as clean air and water, pollination, climate regulation, but also cultural or recreational value. A major emphasis was on monetizing nature’s contributions to people as “natural capital”. Meanwhile, the understanding of the relationships of humans and nature has been expanded and critically reflected. Nature conservations, including through international agreements such as the Convention on Biological Diversity (CBD) and international expert panels such as the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), talk about mutualistic and reciprocal human-nature relationships, labelled as “Nature and People”, that includes beyond economic dimensions also social, cultural, religious, psychological dimensions embedded in diverse cultures and personal biographies. Such truly relational understandings are enriched through indigenous cultures and emerging novel perspectives from cultural sciences, including ecofeminism, STS, environmental humanities or post-humanism. In short, nature conservation is in a phase of paradigm shift transgressing an outdated dualistic thinking that separates human and natural spaces and species.

Such a shift of perspectives in biodiversity conservation has important implications for practices and strategies, and ultimately also for how environmental media are used to monitor and communicate ecological processes and patterns. Foremost, anthropogenic land is nowadays considered critical for nature conservation and ecological research, including especially agricultural landscapes and urban areas. As a consequence it is acknowledged that much biodiversity is co-produced through biodiversity-friendly land use practices, and to promote nature-based solutions and ecological restoration strategies within diverse economic and societal sectors has become a main strategy of conservation – sometimes called ‘mainstreaming biodiversity’ (Kueffer et al. 2023; WBGU 2020). Agroecology and urban ecology have moved from marginalized applied subfields of ecology to the core of fundamental research in the discipline. The valuation of nature expanded beyond a focus on intrinsic values – each species and ecosystem has a value of its own – and utilitarian values, i.e. the use-values of nature. It encompasses diverse social, cultural and personal relationships with nature, i.e. relational values, and thematics such as health benefits of nature or multicultural and indigenous concepts of nature and nonhuman living beings have become self-evident dimensions of biodiversity (Chan et al. 2016). Complementary, for many humans that increasingly live a life far from nature and everyday nature experiences the challenge is to recreate and reimagine interactions with nonhuman beings in postnatural landscapes. This requires innovating new cultural practices, stories, imaginations, and forms of multisensorial nature experience and foremost education about the very basic knowledge of the species in a location and the ecological processes that maintain well-functioning ecosystems.

The emerging novel ecosystems are often non-analog to prehuman ones, and the concept of 'pristine' ecosystem cannot serve anymore in a straightforward way as a reference point for ecological management and valuation (Hobbs, Higgs, and Hall 2013). They are composed of mixtures of native and nonnative species and are typically recently assembled without a long history of coevolution and ecological sorting. It is thus difficult to straightforwardly transfer knowledge from already well-studied analog wild ecosystems to understand their functioning. They are also typically highly disturbed, environmental and biotic conditions are in flux and constantly changing, and they are therefore highly dynamic. In short, their behaviour is difficult to understand and predict, and therefore intervening in them or living with them requires continuous observation and interpretation of these observations and continuous adaptation of management interventions, i.e. adaptive management. The high human population density in principle provides with a high capacity for nature observation and resulting data, however only if people are knowledgeable about and interested in their surrounding nature. Environmental media can strengthen these observational capabilities both by collecting data and educating citizens.

Focus on urban biodiversity

Urban systems are at the centre of an anthropogenic transformation of local to global ecologies. Although they still make up a relatively small proportion of the Earth's surface – that is however growing rapidly through recent urbanisation rates–, it is in urban areas where the majority of humanity lives, consumes resources and takes decisions on how to exploit the planet. Urban areas and their globalized hinterlands are thus ecologically, economically and socially closely interlinked and form together a globally distributed and interconnected socioecology. Consequently, biodiversity in urban areas has become a main focus of nature conservation (Kueffer 2020). Foremost, successful global biodiversity conservation policies depend on transforming resource use in cities, amongst others resulting from the building industry and consumerism. But also within urbanised spaces the great importance of local biodiversity, long neglected both by conservationists and urban planners, is meanwhile recognized. It is here where most humans are exposed to their everyday nature experiences and form diverse human-nature relationships embedded in their diverse social, cultural, religious and economic lives. The services of urban nature are crucial to maintain and restore sustainable and liveable cities, amongst others for climate adaptation and human health (Kowarik, Bartz, and Brenck 2016). Last but not least, urban areas can be refugia for many species, including rare and special ones, and urban biodiversity can be seen as a model system for nature conservation strategies in the Anthropocene (Kueffer 2020).

While some urban biodiversity survives in fragments of pre-urban habitats engulfed by urbanized landscapes, many species have adapted to or even depend on designed urban greenspaces, horticulture and artificial infrastructures – for instance buildings as nesting sites analogous to cliff and rock habitat. Anthropogenic urban landscapes can be characterized by a high diversity of different habitat types, ranging from urban parks and rivers to horticultural plantings and green roofs, which can foster species diversity. However, this should not give the wrong impression that urban spaces are particularly wildlife-friendly; in many ways they are hostile to nature: a high proportion of soils are sealed or otherwise disturbed or destructed, pollution, artificial light and noise levels are high, human activities are intensive, and the landscape is highly fragmented with often unpassable barriers such as roads are railways. As a consequence most urban species are generalists that are able to adapt to a wide range of habitat conditions, disturbances and biotic interactions, and the proportion of nonnative species is typically high.

Urban biodiversity brings with it particular challenges and opportunities for biodiversity conservation, i.e. for how we perceive, observe, monitor and based on these perceptions interact with urban species and ecosystems. Thus, the use of environmental media in urban areas and with a focus on biodiversity poses specific questions. In urban ecosystems human-nature relationships and nature experiences are particularly important, with the challenge that urbanites increasingly lose their knowledge about nature and increasingly spend less time outdoors. Environmental media can help to restore awareness of and interest in local nature and coexisting species and encourage outdoor and nature-related activities. However, this is a double-edged sword. By using media to mediate nature experience there is also the risk that a technology-based way of perception and an institutional ecosystem supporting the media technologies, involving often indoors jobs and knowledge systems estranged from nature, is fostered further contributing to a shifting baseline of lost nature experiences and knowledge.

Urban ecosystems are characterised by particularly tight feedbacks between human actions and ecological processes often mediated through diverse infrastructures and technologies. An urban ecology is thus in essence always a network of human and non-human living beings as well as artificial actors that influence each other's actions mutually. The conscious use of environmental media can help to reshape such networks and guide them towards a more sustainable and biodiversity-friendly media ecosystems. In this sense urban nature can be seen as a paradigmatic example of technoecologies that increasingly dominate the planet in the Anthropocene.

Experimentation as a key approach of critical design and media research

For our societies to develop more sustainable approaches to environmental management and urban planning, there is a need not only for traditional expertise in biology, design, engineering, and construction but also for experimental innovation and design strategies and attitudes rooted in care and attentiveness to the serendipitous connections that arise within more-than-human environments. Supporting and fostering new forms of coexistence requires management practices that recognize the agency of non-human actors, allow for the emergence of interdependencies, and leave space for the unpredictability inherent in ecological systems.

Design has traditionally been associated with solution-oriented practices aimed at creating useful artifacts to meet human needs. However, its alignment with economic imperatives, technological optimization, and industrial efficiency has been increasingly questioned in recent decades. This critique has led to the emergence of alternative framings within the design discipline, such as 'critical design' and 'design for debate' (Dunne and Raby 2013), which seek to approach design as a practice for societal engagement and environmental sustainability.

Drawing on feminist STS insights, the *Mitwelten* project reconceives "design" as a practice of worlding that must account for the agency of non-human actors. Incorporating practices of "speculative fabulating" and "modest interventions" of experimental tinkering (Haraway 2016), these approaches resist traditional control-oriented paradigms. Instead, they prioritize co-creation, collective responsiveness, and engagement with the complex, entangled processes that shape shared environments.

The climate and biodiversity crises demand new theoretical and practical approaches. In the *Mitwelten* project the team has explored the potential of practice-based, interdisciplinary design research (Mareis 2018) to approach the challenge of biodiversity loss. Design research allows a relatively open approach to a topic and to respond to developments and serendipity as they occur. The experiments were not predefined in detail in advance, as is standard in other disciplines. The design methodology within the *Mitwelten* project aligns with feminist frameworks of care that shift away from solutions focused on optimization and control, and towards fostering responsive and adaptive interactions with nonhumans. This approach incorporates experimental interventions that aim to evolve through feedback, adapting to the needs and agencies of the diverse actors involved. Concepting, prototyping, outdoor testing and improving also allow to include slower ecological processes in iterative, cyclical development steps. Practice-based design research becomes, in this context, an iterative exploration of the ways technologies co-create worlds in more-than-human contexts. By paying close attention to the perceptual lifeworlds of plants, animals, and microorganisms, this approach challenges the dominant, human-centric uses of technology. This approach invites researchers to consider how technologies like sensors and AI contribute to co-shaping, disrupting or sustaining these lifeworlds, with insights that can inform conservation practices to support genuine multispecies flourishing.

A core aspect of the project's approach is the commitment to interdisciplinary collaboration. The project has been developed by an interdisciplinary team of contributors who are respectively trained in the disciplines of ecology, design, systems engineering, and cultural studies, and who worked together to envision the interventions that foreground the values of multispecies cohabitation. Interdisciplinary work, however, requires to look beyond one's own horizons and to question and reshape established disciplinary methods. Merging standards and value systems is challenging and jointly gained insights sometimes have to be formulated separately again for the different disciplines and their publication formats. By developing prototypes and media installations that engage the public as citizen science (CS) initiatives, the project also aims to foster public participation and knowledge-sharing, bridging the gap between scientific expertise and community engagement.

Environmental media: IoT technologies for sensing and communicating used for environmental monitoring

Media, computation, and IoT (Internet of Things) technologies are increasingly integrated in urban planning (e.g. smart city designs), agriculture (precision farming) or in sensor-based monitoring in environmental management and nature conservation. By capturing environmental metrics, these systems enable real-time decision-making and automated responses, allowing for rapid action in situations such as drought, fire outbreaks, poaching incidents, or high visitor density. Embedded within environments, these technologies add a layer of automated “agency”, giving ecosystems the capacity to “respond” according to pre-programmed parameters. These technical developments and tools offer a wide range of applications but they also introduce complex ethical and practical questions. For example, they have an increasingly large environmental footprint, can be used for surveillance of humans and nonhumans alike, or lead to a social alienation from nature. They can oversimplify complex ecological interactions and reinforce human-centered priorities, potentially sidelining the diverse agencies and interdependencies that characterize living systems. They raise the questions about whose values shape which ecologies are studied, monitored or protected, and at what environmental and social costs. Each decision regarding value attribution and data prioritization is underpinned by unarticulated conceptual frameworks which often favor Western, human-centric paradigms.

In response to these tensions, the *Mitwelten* project engages with post-humanist and more-than-human critiques, aiming to approach environmental technologies as connected, situated actors within multispecies worlds. By developing its own technoecological experiments, the project invites a critical examination of how environmental monitoring can lead to considerations of ethics in conservation practices that value forms of life as co-constitutive agents, rather than objects of technological observation or control, and that examine environmental media as material-semiotic agents within those ecologies.

For the *Mitwelten* design experiments, the team has developed an IoT Toolkit and applied machine learning (ML) to measure, record and identify different types of living beings in their habitats. Additionally, in teaching initiatives, the team has discussed and experimented with what it would mean to involve non-humans as active participants in the design process, and not treat them solely as objects of scientific investigations. The project documentation and findings are made publicly accessible following the guidelines for 'open science' and 'open source' publications. The team has developed Media Applications and Participative Installations to make the research results accessible in different formats. The project has also investigated how the public could be engaged as citizen scientists (CS) and what institutional infrastructures would be required for CS to work independently.

1.3 Who we are

The research project *Mitwelten* was initiated by the Basel Academy of Art and Design FHNW and realized in collaboration with the FHNW School of Engineering, Institute for Mobile and Distributed Systems (IMVS).

The full *Mitwelten* research project team (affiliations, project role, contributions to this publication) is presented in the Appendix A.

This publication is a collection of chapters and subchapters written by authors coming from different fields of expertise. To introduce the author team and provide an insight into the interdisciplinary collaboration processes, the main contributors introduce themselves, present their background, their relation to the topic and their contribution to the *Mitwelten* project and the publication.

Karolina Sobecka

I came to explore environmental media topics from a background in media art and experimental design, with a long-standing interest in the ways humans conceptualize and interact with nature. My work has long explored how emerging technologies shape environmental perception, how they structure knowledge, and how they become sites where broader cultural, political, and ecological tensions play out. My art practice has been rooted in open-source and DIY communities that develop, misuse, or reconfigure tools and technologies—an ethos of early media art or "net art" that Brian Holmes describes as "using [the emerging internet's] languages and its technical tools and focusing on its characteristic objects, with the goal of influencing or even of directly shaping its development". In this sense, my early work operated within the technological frontier as a space for intervention: shaking up dominant narratives, interrogating power structures, and re-staging them within art and cultural critique.

My focus has always been on the intersections of technology and the environment, particularly in relation to climate change and ecology. Over time, this led me deeper into critiques of technology and Western scientific knowledge, drawing from feminist science and technology studies (STS) and posthumanities. These fields opened up new ways of thinking about technology—as infrastructures entangled in world-making processes, actively shaping what is perceptible, governable, and possible.

My PhD research, completed in 2023 at the Kunstuniversität Linz and the Institute for Experimental Design and Media at HGK Basel, explored how imaginaries of carbon and heat shape atmospheric futures. Alongside my academic work, I have developed artistic research projects and participatory interventions that examine ecological governance, post-natural landscapes, and the epistemic legacies of ecosystem ecology. I have written on art, design research, and climate imaginaries in publications such as *Routledge Handbook of Art, Science, and Technology Studies (2021)* or *Climate, Science, and Society: A Primer (2024)*.

I joined the Mitwelten project in its final year, after the practical experiments had already been completed. My role was to contribute to the reflective framing of the book, which serves as both a project report and a reflection on the potential to reimagine environmental media. I also organized workshops that brought together scholars, practitioners, and artists to discuss and articulate questions around relational worlding, multispecies cohabitation, and the design of environmental media. These workshops were not about arriving at definitive conclusions but about developing strategies, posing new questions, and foregrounding the tensions and possibilities inherent in this field.

My hope is that this book will be useful to practitioners, educators, and researchers looking to develop more nuanced, situated, and care-oriented approaches to environmental sensing, representation, and intervention.

Jan Torpus

Since 2003, I have been a design and art researcher at the Basel Academy of Art and Design FHNW, today working at the Critical Media Lab Basel. I have backgrounds in interior design (Massana- Art and Design College, Barcelona, 1989-93), audio-visual arts (HGK FHNW, 1996-99), interaction design (Hyperstudio, 1998-99), and an MA degree in art and design research (Masterstudio Design HGK FHNW, 2010). I have collaborated on development of several interdisciplinary practice-oriented research projects and published mainly in the context of design research and HCI. In collaborative teams, we investigated future and alternative techno-social living environments and ways of thinking. Based on technologies such as augmented reality and the Internet of Things, we built physical interactive research installations that we examined with test persons in order to draw conclusions about experience, perception, behavior and sense-making.

It was only with the *Mitwelten* project that I started to apply these methodological approaches to ecology and biodiversity promotion. The tremendous threats of our time have prompted me to make a small contribution to mitigating them, using the means at my disposal. As I grew up in the countryside in the Basel region of Switzerland and have had a close relationship with nature since childhood, it was a natural step to build bridges between art and design on ecological topics. As a nature enthusiast and citizen scientist, I am interested in ornithology, botany and ecosystems in general and am active in bird surveys and an environmental protection commission. But my relationship with nature is not only scientific. When I am out walking, I also experiment with self-dissolving integration into the environment, for example by walking very slowly and attentively or by sitting down for a long time with camouflage clothing and merging with the ground, shedding human shape and presence and becoming less perceptible to the animal world. Knowing the bird calls and mammal voices and, e.g., where the badger family lives, and at which pond the young grass snakes grow up, allows me to immerse and become part of the local environment. In this sense, knowledge about nature is not only valuable for statistical surveys from which measures for nature conservation can be derived, but also makes the hidden parallel worlds of non-human creatures more accessible on different scales, creates empathy and promotes mindfulness. The *Mitwelten* project is precisely about this interconnection between scientific knowledge and experiential inclusion, the development of formats for knowledge transfer and thus falls within the scope of design and art research. This interconnection is also achieved from a technological point of view: the collected and analyzed scientific data is stored on a central database and dynamically accessed through communication media to raise public awareness.

I developed the *Mitwelten* project together with Felix Gerloff, a researcher in cultural studies, with the support of Thomas Amberg, a Professor of computer science, and Christoph Küffer, a Professor of ecology. I managed the project, was involved in developing and conducting the field studies and teaching units, and provided concepts and design inputs for the media applications and outdoor interventions. Karolina Sobecka, Cedric Spindler and I are the main authors of this book.

Cedric Spindler

With an MA in Composition and Music Theory (Audio Design) and a diverse background that bridges the worlds of sound arts and computer science, I joined the *Mitwelten* project in its second year. It sparked my interest as it aligns closely with my passion for the interdisciplinary application of media technologies and the discourse surrounding a fundamental subject of my work: the intersection of artistic practice, technology, and science.

In my artistic practice, I work in recording arts, electroacoustic music, and interactive installations, to create interdisciplinary engaging experiences. My research focuses on the intersection of human-computer interaction and creative practice, examining how technologies can mediate our understanding of and relationship with our surroundings – be it society, nature, or machines. My teaching activities extend these explorations, encouraging students to critically examine the role of sound arts and technology in the development of artistic expression, personal creative identity, and the ability to develop ideas effectively. Through courses on creative coding, interactive sound, and critical listening exercises exploring the aesthetics and perception of sound, I aim to inspire the next generation of artists and researchers to create innovative and impactful work that bridges the gap between technology and human experience.

During my work for the *Mitwelten* project, I have contributed to the development of open-source tools and platforms for environmental monitoring, data analysis, and visualisation. While designing and maintaining the project's infrastructure I have advocated the development of a holistic ecosystem of data management and disemination. Beyond software and infrastructure development, I was actively involved as an artist in the design, creation, and production of media applications and participatory installations. With my research I have contributed to several publications on this project.

Christoph Kueffer

By training an environmental scientist and plant ecologist, Christoph Kueffer works for about 25 years in the field of the ecology of the Anthropocene in basic, applied and transdisciplinary research and consultancy. One primary interest is to understand how the reshuffling of species communities and biogeographies locally and globally affects ecological functioning and biodiversity patterns and what that means for nature conservation. He has for many years contributed to invasion biology, or more generally invasive species research,by building on an interdisciplinary, socioecological perspective rooted in environmental sciences, environmental humanities and Science & Technology Studies (STS). At an ecosystem level this entailed innovating ecosystem management and restoration strategies for novel ecosystems, e.g. on oceanic islands. In recent years, his research focus has primarily shifted to urban ecology. He is the head of the "ecology and planting design" research group at the Swiss landscape architecture school in Rapperswil (Switzerland), and he teaches and collaborates with architects, planners, social and cultural scientists, designers and artists at different universities including ETH Zurich.

Felix Gerloff

I am a research associate at the Critical Media Lab (FHNW Academy of Art and Design, Basel, Switzerland) and graduated in 2013 as Magister Artium (M.A.) at the Humboldt-University's Institut für Kulturwissenschaft (Institute for Cultural History & Theory). I strive to understand the ways in which media, epistemic practices, and the formation of culture constitute each other, specializing in sound studies and media ecology. I wrote the *Mitwelten* project proposal together with Jan Torpus and was involved in developing and conducting the field studies and teaching units, and provided concepts and design inputs for the media applications and outdoor interventions. I contributed to the early stages of this project book.

Olivia Höhener

Olivia Höhener studied History, English and Media Studies in Basel and completed a CAS in Research Management. She worked for the Mercator Foundation Switzerland for eleven years, where she was responsible for science communication, dialogue between science and society, participatory research and international exchange. She joined the team of what is now called Citizen Science Zürich in March 2021 and has been Managing Director since January 2023. She is committed to science with and for society and wants to contribute to the emergence of new forms and formats of collaboration that benefit both sides.

The *Mitwelten* approach to collaborative knowledge production

The *Mitwelten* project embraces a deliberately transdisciplinary approach, recognizing that the liveliness of knowledge thrives when disciplinary boundaries are not rigid but permeable. While the researchers involved in the project may have foundational training in specific fields, their practices often extend into and blend with other methods and frameworks. This reflects a recognition that established disciplines, while valuable, often fail to fully capture the complexity and multiplicity of experiences in post-natural environments. By valuing transgression, dialogue, and creative intersections, *Mitwelten* fosters innovative methods and practices that acknowledge and respond to the entangled nature of multispecies coexistence.

Ecology: grounding in the biological and ecological sciences

In *Mitwelten*, urban ecology served as a foundation for studying interactions between organisms and their environments, particularly within human-modified landscapes such as cities and peri-urban areas. Ecologists conducted biological assessments to evaluate ecological conditions, identify key topics, and formulate research questions. Their work informed the development of Ecosystem Studies, which provided systematic observations and data collection on ecological processes. These efforts were not isolated but entwined with the design and implementation of the project's interventions, ensuring that ecological knowledge informed media and technological applications.

Engineering: building the infrastructure of digital connectivity

Engineering in the *Mitwelten* project extended beyond conventional technological development to include the creation of responsive infrastructures for ecological and media applications. This involved organizing storage capacities, implementing IoT toolkits for outdoor environments, and developing software environments for setup, monitoring, and data collection. Engineers worked closely with designers and ecologists to ensure that the interventions met both technological and ecological requirements. Public-facing participatory installations and educational media applications emerged from this collaborative work, which facilitated shared engagement with environmental media.

Design: translating ecological principles into action

Design in *Mitwelten* was key in developing the process facilitation, communication strategies, and experimental installations. Designers collaborated with ecologists, engineers, and humanities researchers to translate ecological understanding of the sites into actionable design interventions, crafting participatory and educational experiences that made ecological processes tangible. Through iterative prototyping and field research, design became a medium for fostering new relational practices, encouraging not just functional solutions but also speculative and creative engagements with multispecies environments.

Post-humanities: understanding more-than-human relations

Drawing on cultural and media studies, the post-humanities researchers in *Mitwelten* focused on understanding the cultural, social, and material dimensions of multispecies entanglements. This included analyzing how IoT installations and participatory media can mediate relationships between humans and nonhumans. Additionally, post-humanities scholars documented the interdisciplinary collaboration processes, reflecting critically on how knowledge was produced, shared, and contested within the project. By emphasizing relationality and care, they contributed a nuanced perspective on how technologies and practices could support more-than-human coexistence.

These intersections were not without their challenges. Differences in methodological approaches – quantitative for ecology and engineering, qualitative or mixed for design and post-humanities – required ongoing negotiation. Through bi-weekly meetings, technical workshops, and collaborative fieldwork, the team developed experimental setups that allowed for learning across disciplinary lines. Tasks were co-designed to determine which could be carried out by citizen scientists and which required professional expertise, highlighting the collaborative and iterative nature of the work.

1.4 Field work implementation overview

Most studies and interventions were based on the *Mitwelten* project's **Mitwelten Media**. An appropriate database structure had to be created for data storage and processing power (Infrastructure Backend). A modular sensor-actuator system (IoT Toolkit), which can be adapted to a variety of situations and issues, was developed for measuring and recording the environment. The toolkit was made of inexpensive electronic components and was set up in workshops with participants from different backgrounds. Different components from the IoT Toolkit were combined for Field Sensor Systems for the three Citizen Science based Ecosystem Studies. While the sensors functioned as measuring devices, the actuators served to display the recorded data sets and processed findings in physical form, which was implemented in various forms: by sound (e.g. *Sensing with Trees*), as animated image sequences (e.g. *WildCam TV*) or physical movement (e.g. Guidance System). To use the IoT Toolkit in the field, different software applications had to be developed, as a group of applications we called Software Environment. Deploy was developed to integrate the sensor nodes placed in the field into the database. Monitor was developed to monitor the sensor function online and, for example, the charging status of the sensor nodes in the field. The data was analyzed using statistical methods or machine learning Infrastructure Backend, validated with the help of Label Studio (existing open software), processed with Explore and visualized for analysis.

The Citizen Science based Ecosystem Studies included the three investigations Bird Diversity, Pollinator Diversity and Human Presence, carried out by professionals and citizen scientists (CS). Some were also related to ethnological surveys such as questionnaires and interviews. To present the data sets and results to the public and raise awareness of biodiversity issues, we developed several Media Applications that serve as interactive online platforms or were presented in public spaces and could thus be experienced in the local context. On the computer screen, the perspectives of non-human actors can be taken in an interactive environment *(Panorama*) or information can be called up based on a map and customized with filter functions (*Discover*). The *WalkApp* is location-sensitive (GPS) and designed for cell phones. It allows a walk to be extended medially by creating direct links between the data collected and the places physically visited. *WildCam TV* allows recorded wildlife photos to be selected according to various parameters and compiled into film sequences.

In our workshops and classes, the participants and students developed design interventions as Interspecies Platforms in the form of Interspecies Outdoor Furniture that also met the needs of more-than-human neighbors at the Campus of the School for Engineering. On the campus of the Basel Academy of Art and Design FHNW we Reconfigured Infrastructures to improve the habitat for neighboring plants and animals and prototyped modular Stepping Stone Habitats to help connect remaining ecologically important habitats in heavily sealed peri-urban areas. We also developed Participatory Installations by creating a management tool for the installation of sensors and actuators in a terrain to guide humans by pointing out or distracting from ecological features (Guidance System). Another participative approach intended to contribute to an improvement of biodiversity by sounding environmental conditions and thus making passers-by aware of soil conditions of non-human neighbors (*Sensing with Trees*).

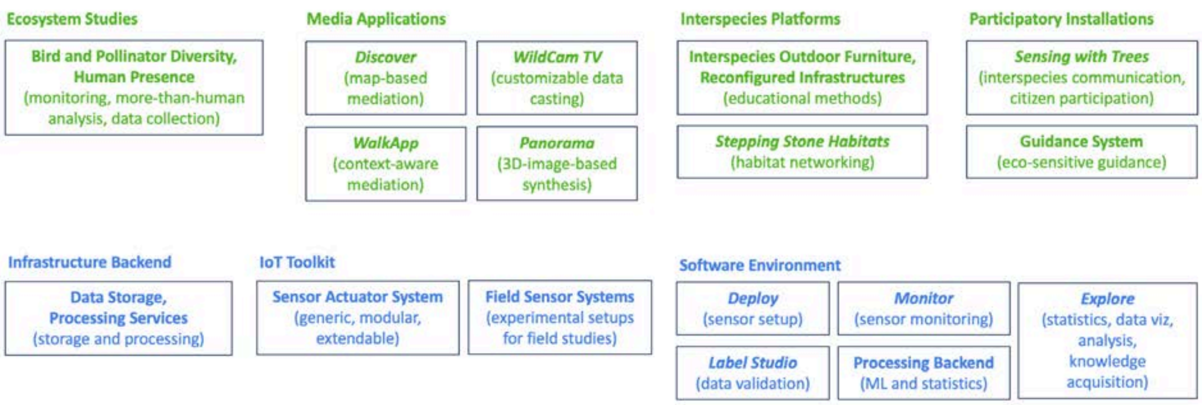


Fig 1: Infographic on the technical and design media developed in the *Mitwelten* project.

1.5 Monograph structure

This publication presents a collection of experimental design interventions and environmental media applications developed through *Mitwelten*'s practice-based interdisciplinary efforts. It calls for thoughtful and careful further experimentation that acknowledges the entangled socio-ecological and material realities we inhabit. It brings together the perspectives of design, ecology, technology and theoretical reflection and makes visible a plurality of different voices, as they were exchanged in the interdisciplinary project. The names of the corresponding authors are therefore listed under the main chapters and their backgrounds and affiliations are presented under 1.3 Who we are.

Since the publication covers a large number of technological developments and design experiments, we have developed a map and color coding to help the reader navigate through the material (see Fig. 1). The open access publication is organized as a hypertext that allows readers to access the text according to their interests. The following types of links are integrated in the text flow by different colors:

- Green LINK to empirical work: eco-design studies, experiments, educational examples, site specific information, …
- Blue LINK to technical specifications: HW and SW developments, infrastructure, installation descriptions, …

The publication is subdivided into the following chapters and contents:

Chapter 1 Introduction starts with the project overview, discusses Our approaches (1.2) to exploring the topic, and introduces team members, their backgrounds and contributions in the section Who we are. The Field work implementation (1.3) and Monograph structure (1.4) explain how the publication is structured and how it can be read.

Chapter 2 *Mitwelten* Glossary forms the conceptual frame of reference that guides the design research experiments. Central concepts and the underlying theory are introduced.

Chapter 3 *Mitwelten* Field Studies presents the three Field Study Sites (3.1) based in and around Basel, Switzerland: the botanical garden and recreational area Merian Gardens (3.1.1), the mixed-use post-industrial urban area Dreispitz (3.1.2), and the recreational area and nature reserve Reinacher Heide (3.1.3). Finally, the Development Process that was carried out in the tree field studies is presented (3.2).

Chapter 4 Can a device create a world? is an essay based on the workshop “Civic Sensing” carried out during the *Mitwelten* project.

Chapter 5 *Mitwelten* Media is technology-focused and gives an overview of the structure and components of the IoT Toolik (5.2) developed during the research project as an open sensor-actuator system. It further presents the associated Software Environment (5.3) used for the data collection, field setup and analysis. Finally, the underlying Infrastructure Backend (5.4) is described and the Field Sensor Systems (5.5) and the Field Sensor Systems that were used to carry out the Citizen science (CS) based ecosystem studies. The chapter is extended by a documentation on the Github developer platform for professionals and CS users.

Chapter 6 Learning with the post-natural land is an essay based on the workshop “Land as Pedagogy” carried out during the *Mitwelten* project.

Chapters 7 *Mitwelten* Design Interventions is the most extensive chapter, framing and describing the experiments and interventions that were implemented and offers findings for practitioners aiming to integrate environmental media into their initiatives. The section CS based ecosystem studies (7.2) starts with an introduction to expert-layperson collaboration processes and presents the three field studies: Bird Diversity (7.2.1), Pollinator Diversity (7.2.2), and Human Presence (7.2.3). The section Media Applications (7.3) presents four different media formats for communicating collected data sets and findings to the general public and to sensitize them to locally existing ecosystems: the map-based information retrieval platform *Discover* (7.3.1), the public exhibit *WildCam TV* (7.3.2), the location-sensitive *WalkApp* (7.3.3), and the 3D-image-based immersive *Panorama* (7.3.4). The section Interspecies Platforms (7.4) starts with an introduction of settlement and open space design tools and presents design experiments and student works that were intended to lead to Interspecies Outdoor Furniture (7.4.1), Reconfigured Infrastructures (7.4.2) and Stepping Stone Habitats (7.4.3). The section Participative Installations (7.5) describes interventions that follow media art concepts with ambient information systems and are based on the IoT Toolkit. Integrated in the outdoor environment, interactive installations invite the visitors of ecologically fragile environments to participate and take responsibility: Sensing with Trees (7.5.1) and Guidance System (7.5.2).

Chapter 8 Responsibility in Postnatural Environments is an essay based on the workshop "Responsibility in Postnatural Environments" carried out during the *Mitwelten* project.

Chapter 9 *Mitwelten* - Reflections and Propositions is introduced by the section Designing for Relational Worlding (9.1) findings and conclusions of Where design succeeds and fails (9.2) and closes with an Outlook (9.3).

Technical specifications make the studies accessible to the developer community by providing instructions for replicating the developed technologies. All technical developments are Open-Access, Open-Software & Open Hardware and are documented in an online service for software development (Github). In order to generate an interactive experience and to stimulate critical discussion, we supplemented the publication with media extensions that include research data, design prototypes, and tools via external web-based content: https://www.mitwelten.org, https://explore.mitwelten.org, https://discover.mitwelten.org, https://pano.mitwelten.org, (https://tv.mitwelten.org, https://walk.mitwelten.org)

Chapter 2 *Mitwelten* Glossary

Karolina Sobecka

2.1 Glossary introduction

The following glossary entries summarize key concepts that inform the book, drawing from feminist science and technology studies (STS), posthumanist thought, environmental humanities, and media theory. These concepts shape the book's exploration of how environmental media—such as sensing technologies, digital platforms, and participatory installations—can foster multispecies coexistence and relational ways of knowing and engaging with ecologies.

The glossary is not intended as a comprehensive theoretical framework but rather as a collection of touchpoints that frame the book's methodologies. Each entry offers a condensed discussion of ideas that have shaped the *Mitwelten* project's approach, emphasizing the relational, material, and performative dimensions of environmental media. The book engages with existing definitions and perspectives, reflecting on how these concepts can be mobilized to rethink design practices and conservation strategies.

Among the entries, *Mitwelten* is a term developed within this project. Translating to "co-worldings" or "worlding-with," it draws from Donna Haraway's (2016) notion that worlding is always a shared, entangled process—worlding is always in company. *Mitwelten* serves as a conceptual reframing for the book's approach to environmental media, emphasizing that media technologies do not merely represent ecological processes but actively shape them, co-creating shared realities with both human and nonhuman actors.

Other entries—such as *Post-Nature, More-than-Human, Environmental Media*, and *Care*—are terms with established scholarly genealogies that the project references. The Post-Nature entry addresses the shift away from a nature-culture binary, instead recognizing the co-constitutive entanglements of humans, nonhumans, and technologies in shaping contemporary landscapes. The More-than-Human entry articulates the necessity of moving beyond anthropocentric frameworks, foregrounding multispecies agency and interdependence. Environmental Media examines the performative role of digital technologies in conservation, while Care draws from feminist ethics and STS to explore alternative approaches to responsibility in environmental design and management.

Together, these entries provide a foundation for the book's exploration of environmental media as tools for relational worlding. They frame the discussions of the *Mitwelten* project's experiments, interventions, and theoretical insights, offering readers conceptual tools to rethink their own engagements with biodiversity, conservation, and media design.

Post-nature

The term "post-nature" signals a move beyond the idea of nature as a pure, timeless realm devoid of human influence. It reflects the recognition that the nature-culture divide is a social construct rooted in human exceptionalism. The critique of this dualist thinking, by scholars from Bruno Latour (1993) and Timothy Morton (2009), to feminist science studies writers like Donna Haraway (2004; 2008) and Anna Tsing (2015), as well as post-humanist thinkers in STS and geography (Whatmore 2002; Lorimer 2015; Pritchard 2013; Wakefield 2020) has been developed under the label 'post-nature,' or connoted by related concepts such as 'socio-natures' (Swyngedouw 1996) and 'naturecultures' (Donna Haraway 2004). We chose to use the term post-nature in this project because, beyond challenging the nature-culture binary, it evokes a historical moment of rupture and transformation. In this moment, climate change, biodiversity loss, and pollution have culminated in catastrophic environmental disruption, demanding a radical rethinking of the imaginary that underpins human-nature relations at the root of these crises.

The current environmental upheaval is the result of Earth's physical systems being destabilized by human-driven disruptions in material and energy cycles. These disruptions stem from extractive economies shaped by colonial and capitalist logics. The resulting condition, the so-called Anthropocene, is an emergent quality arising from the interplay of many agents and circumstances—including geophysical forces, biological dynamics, and anthropogenic technologies and practices driven by cultural narratives and imaginaries. This moment has been described as "an unintended muddle of multispecies relationships that emerge from contaminated landscapes, postwar rubble, and garbage heaps" (Tsing et al. 2017). The speed of this "muddling" now exceeds the capacity of ecosystems to adapt, but this should not be mistaken for the "end of nature." The liveliness of matter persists in the new assemblages and forms of existence emerging from these entanglements.

The three study sites in the *Mitwelten* project exemplify the histories and accelerated processes of mixing, sorting, and muddling that characterize post-nature: Merian Gardens, a botanical garden cultivating and studying hundreds of plant species from around the world; Dreispitz, a former farmland turned materials storage site and international freight hub; and Reinacher Heide, a nature reserve where the biodiverse floodplain is maintained through engineering efforts that mimic the now-regulated river Biers' past natural dynamics. Intensively maintained, these sites may not resemble "capitalist ruins" - as Anna Tsing calls landscapes that manifest the precarity of our world (2015), but they are part of the same web of relations that lead to devastating natural disasters, displace species, or spur rogue geoengineering trials. These entangled dynamics make it clear that repair does not involve returning to some pre-contaminated, purely "natural" state, but rather begins with recognizing that these environments have always been co-produced by a variety of material-semiotic agents.

The post-nature is characterized not only by material mixing and entanglements, but also by accommodation of rival imaginaries of the humans and nature. While modernist dualisms persist, alternative conceptual frameworks and cosmologies have begun to gain recognition. One predominant vision that emerged in the second half of the 20th century is understanding of nature as a series of ecosystems, which integrated organisms, environments, and human society into a single interconnected system using the lens of material and energy cycles. The new science of ecosystem ecology became a new holistic perspective, emphasizing the constitutive importance of relations, the value of diversity, and the effects of emergence.

The science of ecology formed in dialogue with the concurrent development of chaos theory, complexity theory, computation, and cybernetics. These fields left a significant influence on two aspects of the ecosystem imaginary that are particularly relevant to this project: its technocratic tendencies and the speculative practices of worlding that it inspired. As Erich Hörl notes, the entanglements of the science of ecology with early computational sciences carry into contemporary thinking the paradigms of technological and algorithmic forms of control (2013). Ecologies started to be increasingly “cyberneticized”– portrayed as resilient, adaptive, self-organizing systems that stabilize themselves through feedback and communication. In turn, the methods associated with ecosystems thinking became essential to governance of a decentralized, networked society comprised of self-regulating elements and levels of organization that are managed through an array of incentives, nudges and rewards.

The second critical element of the ecosystem imaginary is the notion of nature's plasticity and the speculative world-making practices that arose from it. Through an influence of chaos and complexity theories, nature started to no longer be viewed as a fixed, unchangeable order, but rather as an indeterminate system, shaped by a history of disruptions and adaptations. This realization led to profoundly new practices of systems governance, reaching far into all disciplines concerned with management, anticipation and prediction. The technique of speculative envisioning of specific futures as a way of bringing them into being became an important part of taking advantage of uncertainty in systems. As Melinda Cooper notes, such “performative” or “prospective” method “recognized that degrees of wishfulness (belief, confidence, and trust) play a formative role in the realization of futures” (2010). Speculation, as a technique of world-making was adopted across institutional and ideological spectrum, from the fossil fuel corporation Shell, to IMF and IPCC, to feminist STS writers such as Donna Haraway who proposes the worlding practice of “speculative fabulations:” “a storytelling and fact telling; it is the patterning of possible worlds and possible times, material-semiotic worlds, gone, here, and yet to come" (2016). As intentional practices of worlding are taken up as critical interventions in post-nature, they become the new face of old debates. Contemporary eco-modernists embrace them to reinforce the portrayal of humans as decoupled from nature: in this view, understanding of nature as “constitutively fluid entity” leads to seeing it as “a product of deliberate intervention, a locus of artificiality, an object produced by humans” (GIBBON and NOVAS 2008; Pellizzoni 2011). Feminist thinkers on the other hand, insists that worlding needs to depart from situated, embodied perspectives that pay attention to the materialities and that respect the agencies and affordances of non-human actors and forces. This practice invites us to center the relational possibilities within the post-natural condition, embracing uncertainty and emergence as central to environmental transformation.

More-Than-Human

The *more-than-human* conceptual framework seeks to displace the human from its historically perceived centrality, acknowledging the deep entanglements of the human within ecological and material interdependencies. Insights from feminist science and technology studies (STS), environmental humanities, new materialism, actor-network theory, multispecies ethnography, and human geography demonstrate that humans are always “more-than-human,” enmeshed with other forms of existence, forces, and elements. Unlike related terms such as post-human, "more-than-human" emphasizes not what comes after the human, but what includes and exceeds the human, underscoring the ongoing relationality of humans with non-human entities, pushing against anthropocentrism and expanding our understanding of what it means to be entangled in the world. From the microbes that inhabit our bodies to the technologies that reshape our lives and the landscapes that evolve in relation to human activity, humans are intricately embedded in an interwoven web of existence. Rather than positioning these relations as secondary to human action, the more-than-human perspective foregrounds them as central to the processes that shape lifeworlds.

Feminist STS scholars like Donna Haraway have played a crucial role in deepening the more-than-human framework. Haraway’s concept of *becoming-with* highlights the co-constitutive relationships between humans and non-humans, particularly animals, technologies, and ecologies. Her discussion of *companion species* opened up possibilities for understanding how humans and non-humans shape each other's lives in continuous processes of becoming. This approach pushes back against simplistic narratives of domination or exploitation, instead exploring how more-than-human entanglements can be sites of care, responsibility, and ethical relations.

A central feature of the more-than-human approach is the re-conceptualization of agency, challenging the understanding of agency through the prioritization of intentionality or willpower, foregrounding instead material and affective agency of non-human entities, materials, and forces. The more-than-human perspective distributes agency across a wide range of material, animate, and inanimate entities, asserting that agency does not belong exclusively to humans but is dispersed across material bodies, landscapes, infrastructures, and ecologies. Entities as diverse as soil microbes, rivers, technologies, and atmospheric systems all exert their own kinds of influence, shifting our understanding of how the world operates. Agency, in this sense, is no longer about mastery or control but about the capacity of various entities to affect the worlds around them—often in unpredictable, contingent, and emergent ways.

The shift away from the rational mind as the primary site of agency has brought increased attention to the performative, affective, and embodied dimensions of entanglements. This reorientation redistributes agency to the body, emphasizing movement, intensity, visceral processes, and affective atmospheres. As a result, the subject is reconceptualized primarily as a sensing, feeling body immersed in the world. The more-than-human perspective also opens space for considering the nonhuman subjectivities of other animals, of plants, and even of ecological aggregations like microbiomes, soil, or forests. Matter is recognized not simply as inert substance, but as possessing the capacity to affect and be affected. As a critique not only of human-nature binary but all other deeply ingrained dualisms including the separation of living non-living, more-than-human perspective posits that all entities are "lively"—are forms of *matter-in-relation*. This approach reveals the ways in which all matter is always in the process of becoming, and enabling or foreclosing possibilities for life. Feminist scholars, like Karen Barad, emphasize that matter is not just something acted upon, but is itself active and relational. Barad notes that entities do not pre-exist their relations but come into being through these very entanglements. This reframing shifts the focus from subjects and objects to processes of becoming and relationality.

The concept of a "more-than-human world" was first coined by David Abram's in his book *The Spell of the Sensuous* (1997). In the *Mitwelten* project, Abram's eco-phenomenological perspective is particularly relevant as it emphasizes the importance of sensory and embodied forms of knowing, and of attending to the diversity of perceptual capacities and experiences among non-human beings and materials. The notion of multiplicity of realities that exist beyond human perception and understanding invites us to consider how various entities engage with and experience their environments.

Technologies and human-made infrastructures and their agencies are also considered through the more-than-human framework. Bruno Latour's *actor-network theory* has been foundational in understanding how technological assemblages shape the world. Latour's interest in scientific technologies was followed by other scholars' explorations of anthropogenic assemblages, including media ecologies, algorithmic decision-making, and ubiquitous surveillance technologies that sense, trace, and anticipate the actions of humans and non-humans alike. Acting as agents in their own right, they produce semiotic-material effects and structure the ways social life is ordered.

In the context of environmental management, urban design, and ecological restoration, the more-than-human approach challenges anthropocentric practices that position humans as separate from and superior to nature. Instead, it advocates for an ethic of coexistence, where humans are understood as one species among many, all engaged in the ongoing making and remaking of worlds. This ethic calls for attentiveness to the contingent, emergent relations that shape life, urging a rethinking of management practices that acknowledge the agency of non-human entities and the unpredictable nature of ecological systems. It moves beyond a simplistic stewardship model toward one of participatory entanglement, recognizing that we are not in control but rather are co-participants in a shared world of more-than-human relations.

Technoecologies

The term "feminist technoecologies" refers to the complex interplay between digital technologies and ecological systems, where human-designed media and natural systems converge, shaping contemporary environmental management, urban planning, and citizen engagement. The term, coined by Dagmar Lorenz-Meyer (Lorenz-Meyer, Treusch, and Liu 2021), captures how digital infrastructures and ecological processes interweave, creating novel configurations that reshape environmental sensing, monitoring, and governance practices.

Scholars have highlighted various facets of technoecologies. For instance, Turnbull et al. use the term "digital entanglement" to analyze the intertwined relationships of humans and nonhumans in digitally mediated environments. Jennifer Gabrys explores how environmental sensing technologies activate new forms of citizenship, illustrating how these tools encourage individuals and communities to engage actively with environmental data and the ecosystems around them. Scholars further discuss how smart technologies are envisioned as promising increased integration with natural systems, particularly in urban environments, to aim for what is sometimes termed "ecosystem intelligence". In such techno-optimistic visions, the communicative processes of plants and other organisms are portrayed as folding into digital circuits to create more intelligent, resilient, and adaptable urban ecosystems. These technoecologies aim to enhance the perceived mitigating and balancing functions of vegetation in urban environments, sometimes even employing plants and other organisms as sensors or actuators within smart systems. Experiments with such "bioindicators" that can reveal the quality of the environment have been basis for exploring ideas about "more-than-human collaborators" and the possibilities of creating more reciprocal relations with plants. Projects such as the *Internet of Trees*, where plant data is collected and processed by digital technologies, reference the notion of Internet of Things, while generating new forms of environmental monitoring and urban governance.

However, these technologies also raise significant concerns, including regarding the influence of Western-scientific and anthropocentric bias on how ecologies are represented and sorted through the technological systems: which organisms and environments "count" and are counted, which are intelligent or valuable. Moreover, digital representation and proliferations of on-screen nature encounters has produced new types of relationships that pose unique and complex questions. These digital encounters have been critiqued for engendering disengagement with ecology and "extinction of experience" (Pyle 1993), simultaneously spectacularizing, exoticizing, or aestheticizing nature. These representations find also extensions in models and simulations that built on large amounts of remotely sensed data, transforming modes of environmental governance, and raising questions around who controls the design and deployment of these technologies and how they impact decision-making. Furthermore, such systems have their own environmental and social costs, as they require vast quantities of material resources and energy, and are mired in extractive and often exploitative processes of resource mining and waste disposal that disproportionally impact marginalized populations that are not the primary users of these technologies.

Another aspect of scholarship on technoecologies considers how practices of environmental sensing produce not just data but also social and more-than-human relationships, shaped by political obstacles and organizational structures, and by the process of negotiating partnerships with community groups, navigating disciplinary differences on academic teams, or interpreting sensor data in relation to existing regulatory standards. DIY environmental monitoring, participatory sensing, and citizen sensing initiatives exemplify attempts to democratize ecological data gathering, encouraging individuals to participate actively in addressing environmental issues. By taking up low-cost and DIY technologies, users are meant to realize newfound abilities to engage with environmental problems, and acquire new capacities for acting on those problems. However, these platforms sometimes implicitly assume a consensus-driven approach to environmental monitoring, sidestepping the inherent political and conflict-laden nature of environmental issues.

Technoecological systems thus present complex modes of environmental engagement that carry both substantial risks and promise. As Turnbull et al write, they can, under certain circumstances, potentially cultivate environmentally progressive communities, convivial human–nonhuman encounters, and just forms of environmental governance, generating “meaningful modes of care and concern outside capitalist relations” (2023). It is environmental media’s participation in the broader practices of maintenance and care that is of primary interest in the *Mitwelten* project, while it remains analytical and critical of how it also can reinforce the tendencies that lead to environmental degradation. The *Mitwelten* project draws on insights from environmental media studies as framework for analyzing how media systems—ranging from digital and networked technologies to analog infrastructures—are intertwined with the planetary ecosystem. Environmental media approach, by following the wires and metals beyond the screen and beyond the data, emphasizes how the global media networks are entangled with fragile ecological systems, and extractive economic demands. It aims to examine intricate entanglement of media technologies and environmental processes, engaging with the material infrastructures, computational systems, and elemental forces that intersect with ecological networks. Further, environmental media is concerned with the agentive and political dimensions of technologies, focusing on how they shape ecological and social realities. Through more-than-human approaches, scholars in this field start to challenge anthropocentric perspectives and offers critical framework for understanding the environmental impact of digital technologies and the infrastructures that support them.

Design as a matter of care

The climate crisis and environmental degradation have made it clear that adopting non-anthropocentric ethics is crucial for worlding that would bring more just and sustainable futures into being. Design, as one of the most fundamental worlding practices—a semiotic-material way of actively shaping the future—is central to this urgently needed transformation. Yet, in the context of design, more-than human perspective introduces a fundamental tension. Design, which emerged as a solution-oriented practice, aimed at shaping objects, environments, and systems to fit human needs, and had long reinforced anthropocentric perspectives. The discipline has been closely aligned with economic imperatives, technological optimization, and industrial efficiency and viewed as a tool for mastery—of materials, users, and environments.

As these central tenets of design have been increasingly questioned, over the recent decades different directions in design have emerged, seeking to critically approach and reposition it as a practice for societal responsibility and environmental sustainability (Barab et al. 2004; Dunne 2008; Bardzell and Bardzell 2013; Dunne and Raby 2024). These new approaches aim to transform the norms and values embedded in design—including technology design and nature conservation practices. Among those developments, scholars and practitioners who have called for rethinking design from more-than-human perspective, propose recasting design as a practice of care.

The concept of "care" has long been central within feminist thought including feminist STS. Care ethics emphasizes relationality, interconnectedness, and the situated, ongoing work of tending to the needs of others. Scholars such as Donna Haraway and María Puig de la Bellacasa have expanded this understanding to include more-than-human relationships, bringing attention to the processes of co-constitution and the ethical implications of material-semiotic relationships in which humans and non-humans participate. The ethos of care requires attentiveness, situated knowledge, and responsiveness to the vulnerabilities and dependencies of diverse beings and systems, and involves an ongoing, messy work of maintaining, sustaining, and co-creating. As such, it fundamentally troubles the historically human-centered and control-oriented design approaches.

The resulting tensions produce dilemmas around which the new practices emerge through experimental, adaptive and “bumpy” processes. One of the primary tensions lies between recognizing that non-human actors are implicated in ecological entanglements and not being able to know or trace their concerns. Attempts to make these silent voices heard without speaking for them and risking appropriation or anthropomorphizing point to a related tension between visibility and privacy: discovering traces of ecological actors is often only done at the cost of their surveillance and disruption. Another tension emerges from the development of tracing technologies, which promise to be integrated into ecosystems to enhance their resilience, yet introduce their own material impacts and ingrained bias. Challenging normative assumptions about who or what is deserving of care raises questions about the scope of caring relations and the distribution of caring obligations. Perhaps a most fundamental tensions arises between the situated and universal knowledges and thus between the multiplicity of worlds of subjective experience and the single world rendered by western science.

Puig de la Bellacasa's notion of "speculative ethics" (2017) offers a way of navigating these tensions by emphasizing the experimental, improvisational nature of care that opens possibilities for new configurations, even as it attends to the demands of the present. Puig de la Bellacasa sees ethical obligations of care only emerging from situational constraints, making speculative ethics a hands-on, ongoing process of sustaining ‘as well as possible’ relations. This speculative dimension of care resists the linearity and predictability often associated with traditional design practices. Experimental "tinkering," as Donna Haraway describes it, not only in the practice of design but with modes of thinking, perceiving and feeling, becomes a key methodology, allowing designers to make small, situated interventions that adapt and sustain systems rather than impose control.

In practice, design as care might involve "performative prototypes," for example experiments to design “with” plants or animals, aiming to use digital technologies to develop new forms of communication and collaboration between species. It may involve rethinking the way data is collected and interpreted, for instance by developing more iterative, situated processes that allow designers to engage with the experiential qualities of experimental sites and more-than-human subjects. The lack of a common language between human and non-human actors opens exploration of modes of communication based on movement and behavior. Researchers in human-computer interaction (HCI) have explored disrupting the idea of the human as the central "user" in design, instead proposing that non-humans can be co-designers, collaborators, and participants in care relations. In attempts at “interspecies architecture,” biologists teaming up with designers build ecological structures to offer marine fish a space for reproduction and interspecies encounters. Shifting toward a responsive, situated practice that attends to the ongoing needs of systems and communities often can only proceed through small, experimental acts of intervention that seek to adapt and sustain, rather than disrupt or optimize.

Mitwelten

The concept of “Umwelt,” developed by early 20th-century Estonian biologist Jakob von Uexküll, refers to an organism’s perceptual lifeworld. It describes the subjective world each organism inhabits, shaped by the specific sensory and perceptual capacities through which it interprets its surroundings.

Today, scholars are building on Uexküll’s insights, arguing for understanding ecologies as multiplicity of worlds—coexisting realities constituted through particular ways of knowing and mattering which are constantly in the making. This view of plurality of the actually-existing realities is often positioned as a countering of a single-world view implied by the modernist universalist science that essentializes and totalizes - a hegemonic vision linked to assumptions of universal knowledge, universal man, and universal path of progress. Although producing concepts useful for governing climate and biodiversity, this kind of knowledge obscures and erases geographical, cultural, and experiential difference, and is implicated in colonial and discriminatory violence.

Yet, while critiquing the universalist science, scholars today must grapple with the need for making and governing of the kinds of knowledge that is produced and required by the planetary-scale problems such as climate change (Hulme 2010), as well as by the practices of collectivity—of making a common world. Anthropologist Annemarie Mol borrowed the notion of “more than one and less than many” from Marilyn Strathern (1991) to navigate this tension between one and many worlds. In her book, “The Body Multiple” (2003), Mol describes how atherosclerosis is both a disease for doctors and an *experience* for patients, and outlines practices through which multiple worlds of experience hold together as a single thing—in this case, the disease of atherosclerosis. Following Mol, other anthropologists showed “that many ordinary phenomena fracture when one examines the multiplicity of practices through which they are made” (Swanson, Bubandt, and Tsing 2015). Today, this tension has prompted scholars today to develop conceptual frameworks for what Zapatistas call “a world in which many worlds fit” (Subcomandante 1996), such as Martin Savransky’s concept of “planetarity” which is “speculatively situated in the ‘and’ that connects ‘one’ and ‘many’ through divergence, holding the many connecting frictions in generative tension” (2021). Initiatives such as the Center for Emerging Worlds at UC Santa Cruz deepen this thinking, exploring the cultural heterogeneity and diversity created through world-making practices, and elaborating on points where these worlds meet: “border cultures, contact zones and middle grounds in which communication and social relations work through difference but do not get rid of it”[2].

Donna Haraway goes further, showing that different worlds not only connect through border zones, but are entirely co-constituted by the entangled entities that emerge through co-evolution. Embracing a term coined by Lynn Margulis—“sympoiesis,” Haraway writes that worlding is always “worlding with, in company”—to indicate relational and symbiotic process of embodied perception. Haraway writes: “Critters do not precede their relatings; they make each other through semiotic

[2] https://emergingworlds.ucsc.edu/about/index.html

material involution, out of the beings of previous such entanglements. Lynn Margulis (1981) knew a great deal about “the intimacy of strangers,” a phrase she proposed to describe the most fundamental practices of critters becoming-with each other at every node of intra-action in earth history”.

In the *Mitwelten* project, the term “mitwelten” was chosen to refer to the process of postnatural worlding-with that includes entanglements with environmental media technologies. These entanglements produce new modes of co-shaping of worlds through novel material-semiotic capacities and relations. The term “mitwelten” modifies Uexküll’s “umwelt” (“mit” meaning “with” in German), and adapts Haraway’s description of “worlding-with,” to specifically focus on technoecological world-making and co-shaping. Further, it is proposed as an approach that employs more-than-human lens and care ethics to guide designs and practices of environmental monitoring systems, based on case studies on supporting biodiversity in peri-urban settings in Switzerland.

The one-and-many-worlds tension is especially pronounced in relation to planetary-scale phenomena, such as climate disruption or biodiversity loss, which are visible only through deeply technological practices of representation that render Earth as a single totality. While contemporary environmental research aims to be increasingly more integrative, inclusive of different scales and methods, disciplines and stakeholders, producing a picture of a multifaceted and complex world, it continues to face the problems linked to universalist knowledge approach internalized in design methods and media technologies.

One of the exaples of postnatural worlding-with Haraway describes is in the figure of an orchid that looks like the erotic organs of a now-extinct bee. Citing an illustration by aritst xkcd, Haraway writes: “The flower collects up the presence of the bee aslant, in desire and mortality. The shape of the flower is ‘an idea of what the female bee looked like to the male bee . . . as interpreted by a plant.’” This example comes to life in a reconfigured more-than-human form in one of the study sites of the *Mitwelten* project. Nature reserve Reinacher Heide is protected as a habitat of an endangered species of the same bee orchid. However, today, the conditions that support orchid’s survival have to be artificially recreated. The flooding dynamics of the now-regulated river Birs are mimicked through continuous engineering of its banks. In this case, just as the extinct bee is present in the ongoing performance of its memory by an orchid, the flooding pattern of the river is present in the continuous engineering the floodplain for species that are only able to survive in these conditions. Monitoring technology employed into this environment introduces additional considerations and profound questions about practices of environmental conservation.

Engaging with this complexity, the *Mitwelten* project adapts speculative approach, building on feminist STS care ethics, where the ethical obligations emerge from situational constraints. Conflicting ideas are not treated as simply oppositions—instead the tension between them is used to think through them more productively in committed dialogues. Such commitment to “staying with the trouble” proceeds through non-idealized vision of care and knowledge-making—one where the existing conflict, difference, and incommensurability are not omitted, but put center-stage. The *Mitwelten* project aims to create an ongoing, open, and collective conversation that pursues transformation through engagement and reworking, rather than through avoidance or utopian idealization.

Chapter 3 *Mitwelten* Field Study Sites

Jan Torpus, Felix Gerloff

3.1 Field study sites

The *Mitwelten* field study sites have characteristics typical of Switzerland. They represent **urban and peri-urban settlement, recreation and nature conservation areas**, with varying levels of human presence and infrastructure. In the selected study areas, the needs of people and nature conservation must be reconciled in consultation with the relevant authorities and municipalities. The choice of local everyday contexts helped to integrate the settled communities and to gradually adapt and verify technological and pedagogical interventions. Where possible, grassrooted existing social networks and infrastructure were therefore involved and the knowledge of local processes accessed. The following three neighboring areas of the city of Basel were chosen:

- **The Merian Gardens**, a peri-urban botanical garden and recreation area, Münchenstein
- **The Dreispitz Areal**, (post-)industrial, residential and cultural urban quarter, Basel-Münchenstein
- **The Reinacher Heide**, city agglomeration, recreation and nature conservation area, Reinach

3.1.1 Field study site "Merian Gardens"

Situation

The Merian Gardens is a spacious **botanical garden** on the outskirts of Basel and is located in the millennia-old landscape of the river Birs. Over the centuries, various personalities have left their mark on the site, including the owner Christoph Merian, who was born into a wealthy and influential family. In the 19th century, the wild river landscape was transformed into an important agricultural site and later was gradually transformed into a garden complex.

The history of botanical gardens in Europe is inseparably linked to **colonialism**. The colonies had to supply plant-based food and raw materials for the advancing industrialization. Crops were systematically imported and advertisements were placed in greenhouses to promote the supposedly indispensable "protectorates". Ornamental plants were marketed by commercial nurseries and presented to the public in botanical gardens. However, it was only after the end of the colonial era that the University of Basel laid out the Merian Gardens in 1968 as an extension of its botanical garden. Scientific collections of historical plant families have been donated over the years by important collectors and housed in various locations throughout the territory. Today, the Merian Gardens are administered by the charitable **Christoph Merian Foundation** and combine these plant collections, nature conservation areas of national importance, horticulture, and biological non-profit agriculture with farm animals. They are aimed at a culturally and scientifically interested public and are a recreational area for the local population.

Fig. 2: Photo (2023) of historical buildings designed by the architect Melchior Berri (1801-1854), transformed into a restaurant (left), and used as an agricultural building (right). In the foreground a pond and the historic iris plant collection are located.

Fig. 3: Photo (2022) of the farm garden, which was one of the sensory study sites. 19th century buildings, including the mill and the Villa Merian (right) are in the background.

As the artificially created and cultivated plantations in the Merian Gardens border on nature reserves, certain contradictions become apparent. Plants and animals that are unintentionally and undesirably introduced into Switzerland as a result of the increasing international interconnectedness of trade routes are combated as **neophytes and neozoa**. Since they often have no natural predators in existing ecosystems, they can spread rapidly and affect local flora and fauna. In botanical gardens, however, they were introduced as crops or curiosities of colonial exploration, and today they are also cared for and nurtured as part of conservation programs. This juxtaposition highlights power-critical approaches that arise from the hierarchization of other species by humans (speciesism), which are, for example, based on attractivity, rarity or curiosity.

Characteristics and research focus

We chose the field study of the Merian Gardens because it offers a broad field of investigation with a variety of **perspectives, needs, services, and correlations of the involved stakeholders**. Negotiation processes between education and entertainment, people and nature, farm animals and wild animals as well as cultivated and wild plants. On paths, along canals, in greenhouses and on animal trails or in the vicinity of their buildings, a complex interplay of the actors and habitat types can be observed. How does the specific species community function in relation to the inanimate elements of the

Merian Gardens? Superimpositions of various uses of space lead to emergent effects and helped to better understand specific relationships between the types of actors.

The field study was carried out in close **cooperation with the Merian Gardens**. They were interested in using our technologies to learn more about the non-human inhabitants that populate the Merian Gardens. The biologist and Head of Science & Documentation, Dr. Lisa Eggenschwiler, supervised the research and established contacts with the various people working in the Merian Gardens, from the management to the gardening and agriculture departments and to the mediation team. In this field study the focus was on investigating the relationship between nature, culture and technology, and the inclusion of sensor-based survey methods and multimedia presentation formats for analyzing biodiversity and ecological knowledge production. The field study research question was: ***"What scope for action arises from the media-ecological determination of the behaviors, needs, achievements and mutual relationships of different actors in a hybrid ecosystem?"***

Experiments

For the first field study the necessary technological infrastructures were developed: the Infrastructure Backend and the IoT Toolkit and the associated Software Environment were set up for sensing, monitoring, and analyzing. The Citizen Science based Ecosystem Studies (Bird Diversity, Pollinator Diversity, and Human Presence) were initiated and continued in the consecutive two field studies during the following two years. We decided to do these investigations because **birds and insects are good indicators of habitat quality** and we wanted to take into account the presence of humans, their personal perception of and potential impact on the environment. Although the consecutive field studies were carried out in different years and the technology constantly improved, it allowed comparisons of the different terrain and habitat types of the three field studies using our *Explore* software. The quantitatively collected and analyzed data was supplemented and correlated with ethnological, qualitative data. Interviews with managers, gardeners and conservationists of the Merian Gardens helped to understand the operational structures and a potential integration of our developments into the system: joint experimental setups, discussion of findings, and evaluation of practical benefits. For the data presentation the map-based publication format *Discover* and the 3D image-based publication format *Panorama* were developed.

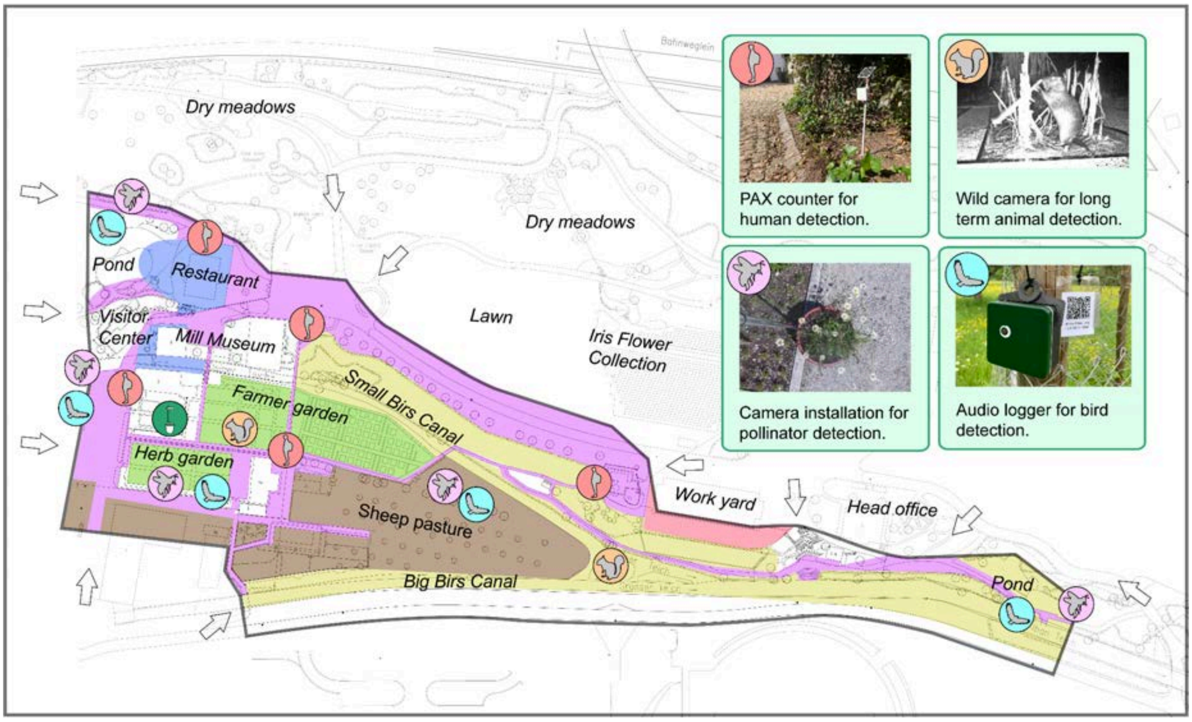


Fig. 4: Map of the Merian Gardens: investigation perimeter and positions of sensor installations.

3.1.2 Field study site "Dreispitz"

Situation

The second field study was conducted in a **post-industrial area** on the outskirts of Basel, including the campus of the FHNW Academy of Art and Design and in its vicinity.

At the end of the 19th century, the agricultural area became a Swiss Federal Railways (SBB) materials storage area due to the inadequate freight depots at Basel Central Station and the convenient transport links. A **private railway line connected the area with the SBB network and the Rhine ports**, making it attractive for logistics companies, a duty-free port, trade and industry, which settled here over the course of the century. The network also meant that foreign plants and animals were introduced unintentionally with the railway wagons and the stored goods, or that the railway tracks were **used as corridors by animals or allowed plant seeds to be dispersed**. Plant species such as the rare spotted knapweed (Centaurea stoebe) indicate this, as they originate from the Upper Rhine Plain. Since the end of the 20th century, the Dreispitz has been undergoing a gradual process of transformation moving away from industrial production and the primacy of transportation towards more mixed forms of use with residential areas, gastronomy, and sport centers. The recent architectural enhancement and the promotion of creative industries, as well as the expansion of public educational and cultural institutions, are intended to appeal to higher-income segments of the population. However, large parts of the approximately 50-hectare site are still dominated by industrial and retail businesses.

Fig. 5: The *Mitwelten* team and guests during an outdoor workshop inspecting the disused railroad lines that serve as connecting corridors for wildlife.

Fig. 6: View of the completely sealed Campus square with some buildings of the Basel Academy of Art and Design FHNW.

Characteristics and research focus

The field study area exhibits characteristics and challenges typical of current transformation processes in Western European societies and is accordingly suitable as an object of study for the prevailing model of urban development and open space design. Specific local, historical, administrative, and urban social conditions, however, also have an impact on the research process. The **Christoph Merian Foundation (CMS)**, for example, owns and manages large parts of the site and, as a single stakeholder, has considerable material resources at its disposal. Institutions such as the University of Basel and the **Basel Academy of Art and Design FHNW**, which moved into its new campus on Freilager-Platz back in 2014, are partially involved in the development of the site. As part of CMS's overarching master plan, scope for design is being developed with sustainable and diverse approaches. The transformation process involves major ecological challenges: the whole area is geared towards commercial profit and human requirements and the surfaces are largely sealed. Only small but biologically valuable ruderal areas remain and should be connected to each other and to neighboring natural areas to create corridors for wildlife to move safely and to optimize genetic diversity. The Dreispitz quarter therefore has a great need for ecological upgrading and offers scope for landscape architecture and media-ecological design in collaboration with the local authorities and in the context of the Basel Academy of Art and Design FHNW.

In this field study, the guiding research mode shifted from ecological analysis to design and intervention. It focused on the development of adaptive, Interspecies Platforms with multifunctional furniture in order to design the limited space available in such a way that it allows animals and plants more development and protection, and to coordinate the various forms of use. Places and infrastructures were (re)designed where different living beings can meet, get to know and respect each other and create new forms of coexistence and ecological cooperation. The field study research question was: ***"What forms of cross-species coexistence can be stimulated in urban settlement areas through the design of interspecies infrastructures?"***

Experiments

Current discourses and design tools from landscape architecture and open space design such as Animal-Aided Design, Habitectures and a Swiss federal value system for Ecosystem Services were partially adapted and used as a starting point for the analysis of the field study area and for the design process. As part of various study programs of the Basel Academy of Art and Design FHNW, we have investigated the potential of design for promoting biodiversity and developed Interspecies Platforms. The IoT Toolkit developed in the first case study was expanded in the second to include different actuators to develop the Participatory Installations on campus and the exhibit *WildCam TV*.

3.1.3 Field study site “Reinacher Heide”

Situation

The former farming and wine-growing villages of the Birs Valley are now part of the Basel agglomeration, with all the associated problems of traffic congestion, noise, urban pressure and a lack of recreational space. Reinach is a village in this **agglomeration** and is fighting with various means against the pressure exerted on the Reinacher Heide **nature reserve** by the growing population. They employ professional rangers to patrol the area and inform people about the local nature. They have also created an ‘adventure pond’ to sensitize visitors to the nature reserve and its natural treasures. Right next to it, a **recreation area** with a river pool has been created so that residents can enjoy their leisure time in nature and to relieve the pressure on the adjacent nature reserve. The Reinacher Heide nature reserve is located in the municipality of Reinach at the Birs river. It was designated a ‘nature reserve of national importance’ by the federal government in 1994 and is characterized by three main types of vegetation: gravel surfaces, dry meadow and alluvial forest.

The Reinacher Heide looks like a natural romantic river landscape, but it has been and continues to be significantly influenced by human intervention. At the beginning of the 19th century, the Reinacher Heide belonged to the approximately 500-meter-wide floodplain landscape of the Birs. During floods, the entire floodplain was affected, which led to the removal of deposited humus and the relocation of watercourses. Since the gravel and pebble surfaces were constantly changing, only specialized plants and animals were able to settle. The dangerous unpredictability of the river's course and the desire to use the land for human purposes led to the decision to correct the course of the Birs. The channeling took place between 1847 and 1855 and completely changed the previous erosion and sedimentation regime. The narrowed riverbed deepened by several meters, which in turn caused the groundwater level in the area to drop. The former gravel deposits of the Birs with a hygrophilous flora were transformed into dry meadows with a xerophilous flora. Over time, pioneer plants were replaced by grasses, perennials and shrubs and eventually, a forest developed. To stop this process and to create areas that correspond to the original habitat of the Birs landscape, **gravel areas were artificially restored**. In this way, humans take on the role of the river and imitate the mechanical removal of humus and nutrients. The substrate and the past use of the area are crucial for the development of a dry meadow. The subsoil of the Birs gravel means that rainwater only stays on the surface for a short time and seeps away very quickly, which means that only a limited amount of it can be absorbed by the vegetation – a dry meadow develops. In addition, the area was grazed by sheep after the municipality of Reinach had extracted gravel and sand. Grazing prevents the development of scrub, which contributes significantly to the development of dry vegetation. Through these interventions, humans have a decisive influence on the landscape, and in order to maintain it, the areas must be maintained according to a precise annual plan.

Alluvial forests are found along rivers and are characterized by periodic water level fluctuations. The floodplain forest can be divided into different vegetation zones, depending on the distance to the riverbank: right on the bank is the drift line with pioneer plants, followed inland by willow bushes that can withstand the mechanical forces of flooding. After this comes the softwood floodplain, which is regularly flooded, followed by the rarely flooded hardwood floodplain. This complex system of diverse landscapes was destroyed by the canalization of the Birs. Only the renaturation measures at the end of the 1990s made it possible for a floodplain landscape to develop again to some extent.

Fig. 7: Orthophoto (2024) of the Birs river and the Reinacher Heide dry meadows, surrounded by agglomeration settlements and industry.

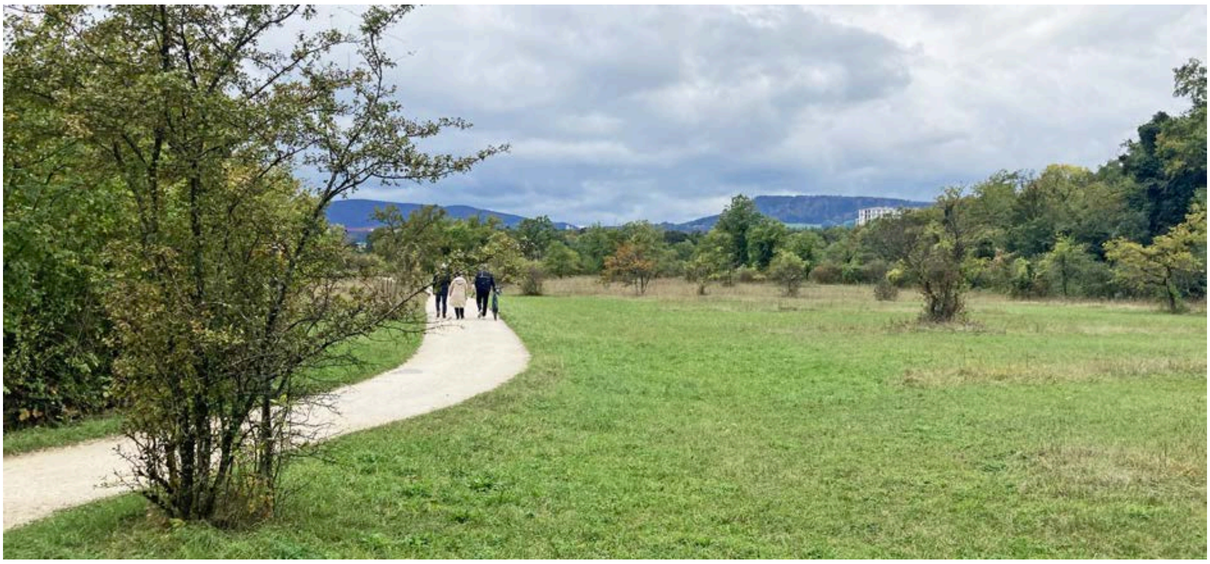


Fig. 8: Photo of the main path through the Reinacher Heide in early autumn 2024.

Characteristics and research focus

In collaboration with the municipality of Reinach (Marc Bayard, biologist), the Reinacher Heide Supervisory Commission (Prof. em. Dr. Andreas Erhardt, biologist) and the Rangers (Yannick Bucher, geographer), we developed the research questions and methods. The field study partners were interested in our bird and insect diversity studies and to learn more about the different human visitor types and their behaviors: e.g. age group, interests, favorite locations, activities. They wanted to find out if the new bath and recreation area relieves the nature reserve, whether their visitor guidance can be extended by media interventions, and if the 'adventure pond' was a good measure to improve visitor information. The field study research question therefore was: ***"How can media-ecological infrastructures and communication formats help to promote a more responsible approach to nature and cultivate a new value system?"***

Experiments

In the third field study the developed technological infrastructures were used to continue the Citizen Science based Ecosystem Studies. In addition to the empirical field studies, we also conducted surveys to learn about personal opinions and to find out whether the existing communication concepts worked and how they could be improved by media tools. For the public data presentation the location-sensitive *WalkApp* was developed and the potential of an IoT Guidance System for Reinacher Heide visitors was initiated.

3.2 Development process

We approached the three urban sites, each characterized by unique ecological, cultural and infrastructural interdependencies, following the same three-step procedure: 1. Situational Analysis, 2. Design Interventions, and 3. Publications as Public Interventions.

Situational analysis

The process started with a situational analysis of the urban sites. This phase combined ecological and cultural methodologies to understand the specific dynamics of the environments. For the analysis of biological diversity, we determined the occurring bird and insect species and human presence in all three field studies (Citizen Science based Ecosystem Studies) by applying our Field Senor Systems.

They couldn't cover the entire range of biodiversity, but as comparable indicators they allowed us to make statements about the ecological state of the field study areas. The examination of social and cultural forms of human interaction with infrastructures and media systems was also evaluated because it plays a role for the design interventions. For example, the educational programs in the Merian Gärten were examined, the reactions to prototypical media installations in the Dreispitz and user interactions with the mobile app in the Reinacher Heide were observed.

The field study site "Dreispitz", for **example**, is separated from the neighboring green spaces by massive traffic axes, which, together with the rising temperatures caused by climate change, poses key challenges for ecological upgrading. The goal of the master plan developed by the Dreispitz owner Christoph Merian Foundation (CMS) is to create more green spaces and to improve ecological connectivity amongst them. The flow of traffic and goods is oriented north-south and presents structural barriers for small mammals and pedestrians who want to cross the area on the east-west axis. Accordingly, this problem also affects the social and cultural dimension, as living space has been created in the district and cultural institutions have found a new home. Instead of creating additional green spaces through selective interventions, the large-scale creation of new connecting corridors opens up better socio-cultural and ecological networking, which can lead to an increase in biodiversity. Such objectives were developed in the 'Plan Guide and Biotopverbundkonzept der Stadtgärtnerei Basel' (Reisner and Farrèr 2016), which defines the needs and potentials of various habitat types and species groups.

The situational analysis aimed to capture the relational dimensions of postnatural human-environment interactions. The gained insights laid the groundwork for the design interventions that followed, emphasizing the need to attune to both the existing material realities and the emergent possibilities of each site.

Design interventions

Building on the insights from the situational analysis, in the second step, the Mitwelten project developed **design interventions which combined creative design and technological innovation guided by ecological principles** to generate new forms of relational engagement. Methods such as an extended Animal-Aided Design approach were used to translate the socio-ecological findings into design applications. They led to a series of Design Interventions, which are explained in detail in Chapter 7. The developed Media Applications make data collected by the Field Sensor Systems publicly accessible by interactive online media interfaces. For the development of the Interspecies Platforms, the focus was on expanding settlement areas and their infrastructures to meet the **needs of non-human cohabitants**. To engage the public with Participatory Installations, the IoT Toolkit was used to transform collected ecological data into tangible information.

Stepping Stone Habitats offers a good **example** of how a design intervention can seamlessly integrate ecological protection measures into the existing infrastructure that takes on the function of regulating local ecological conditions. Following the ecological concept of connectivity, they allow certain species to develop transit routes through barely habitable terrain. At the city management level, they make a concrete proposal for standardized components of future infrastructures creating an additional networked habitat layer for flying insects and birds. Another **example** of an ecological concept being the basis for a design strategy are the Interspecies Contact Zones studied in Merian Gardens, leading to the Media Application *Panorama*. In the botanical Merian Gardens hotspots and key actors were identified as potential application points for interventions and infrastructural upgrades. The immersive 3D image-based Panorama viewer provides a designerly, playful tool that allows the users to put themselves in the shoes of other non-human actors and to identify the needs and possible services of all actors. It combines the ecological situation analysis of the network with creative solutions that promote empathy. The topological conditions of the landscape, the infrastructures and the established activity patterns of the living creatures are also manifested in the existing furniture. For the hotspots with a high density of diverse use, the question of post-anthropocentric forms of organization arises and the range of diverse needs and services of the cohabiting life-forms define the requirement profile for the design process.

Publications as public interventions

The third step in the *Mitwelten* process was evaluation and publication of the impact and results of the experiments conducted in step two. The *Mitwelten* project's **publications spann a variety of formats, including scholarly articles, reports for practitioners, and public-facing presentations**. These outputs target diverse audiences, from the DIY citizen science community and environmental educators to urban planners and policymakers. The evaluation and dissemination phases of the *Mitwelten* project can be understood not only as reflective or summative processes but as interventions in the broader spaces where public engagement, conservation practices, and urban planning intersect. The approach aims to actively shape dialogues within specific communities of practice.

For the **DIY citizen science** community, for instance, publications serve to legitimize and validate grassroots practices. By sharing the methods, findings, and lessons learned from *Mitwelten*'s interventions, these outputs provide actionable knowledge that others can adapt and replicate, empowering communities to integrate environmental media into their own biodiversity projects. Similarly, publications targeting **urban planning stakeholders and policymakers** operate as a form of advocacy, foregrounding the potential of participatory design and more-than-human approaches to transform urban spaces into sites of multispecies coexistence. By embedding ecological knowledge within frameworks accessible to urban planners, the *Mitwelten* publications aims to shift the terms of debate, emphasizing relational accountability and the inclusion of nonhuman agencies in decision-making.

These outputs function as tools for 'making things public,' in the dual sense proposed by Bruno Latour and adapted in this project: they bring hidden processes, exclusions, and relational complexities to light, while simultaneously inviting contestation and dialogue. By **bridging disciplinary divides and engaging diverse audiences**, the dissemination phase extends the project's ethos of worlding-with into the very spaces where future environmental practices are negotiated and enacted.

Chapter 4 Can a device create a world?

Karolina Sobecka

"Can a device create a world?" Brian Holmes asked in his essay “After Chimerica: Bioregionalism for the City of Ashes”[3]. The device he referenced—a container lock—serves as a component of a larger socio-technical apparatus, which, as Holmes describes, was integral to the logistics systems that enabled global commodity circulation, linking production and consumption across continents. The container lock thus played a key role in the emergence of the neoliberal world order, where localized forms of production and exchange were dismantled in favor of globalized flows of goods and resources. Invisibly underpinning modern globalism, the machinery of logistics was instrumental not only in erasing a multiplicity of local worlds but in generating today’s post-nature characterized by an accelerated mixing and redistribution of materials and biological entities. Restructuring the planet’s material circulations, powered by fossil fuels, it reshapes ecological processes, introducing species into foreign ecologies and facilitating new patterns of co-adaptation, conflict, or disruption.

Holmes’ essay underscores that to grasp the specific world-making of a device, one must situate it within the broader historical and socio-technical systems it operates within. Devices are embedded in networks of practices, policies, and infrastructures that mediate and shape knowledge, governance, and materialities. Such process of world-making operates not just technically and materially but also through the visibilities and imaginaries, shaping how societies perceive, value and related to their environments. This is what Donna Haraway refers to as a material-semiotic knot.

Transparency of mediation

Sensing and media technologies possess particularly potent world-making capacities. They don’t just passively record or reflect the world—they actively shape it. This is because knowledge and representation are performative, meaning they don’t simply describe reality but help bring certain realities into being. The ways we interpret and represent the world shape what becomes materially possible, and in turn, material conditions influence how we come to understand the world. Media technologies play a role in this by structuring perception—what gets sensed, recorded, and visualized determines what we recognize as significant, what problems we define, and what solutions we pursue. At the same time, these technologies don’t engage with environments only through dis-embodied representation; they physically interact with and alter the environments they render. Environmental sensors that track biodiversity enable and restrict which aspects of environments are visible which contributes to shaping conservation priorities, influencing policies, and may even altering habitats by requiring infrastructure for power and data transmission.

Sensing technologies contribute to constructing what Donna Haraway critiques as the “god trick”—a disembodied and seemingly neutral perspective that purports to deliver objective truths while erasing the situatedness of those claims. These technologies—scientific instruments, remote sensing or vision systems, and media platforms—often present themselves as transparent conduits for reality, obscuring the complex socio-technical processes and power relations involved in their operation. As Haraway writes, this erasure operates through “an ideology of direct, devouring, generative, and unrestricted vision, whose technological mediations are simultaneously celebrated and presented as utterly transparent” (1988).

[3] https://www.boundary2.org/2020/07/brian-holmes-after-chimerica-bioregionalism-for-the-city-of-ashes/

This operation is central to the social construction of scientific objectivity, which science and technology studies (STS) scholars have critically examined. Far from being neutral, all knowledge claims—especially scientific ones—are situated within specific cultural, economic, and institutional contexts. Sensing instruments and media technologies mediate these claims, framing reality through layers of socio-technical assumptions. By rendering themselves invisible, they produce what appears to be unmediated access to the material world. However, the purported neutrality of these tools often masks the regimes of value and control they enact, shaping not only what is known but also how that knowledge is used and by whom.

The rise of the global logistics industry and the interweaving of ecological and technical systems that make it possible, exemplifies effects of such mediation. The logistical systems that sustain global supply chains depend on construction of a “one-world knowledge”—a universalized perspective that portrays the world as a single, manageable entity. A container lock might be a device that symbolically enables the process of making entities standardized and fungible, commensurable across global exchanges. The logistics infrastructures are grounded in mediation practices that claim universality and objectivity, while they obscure and erase alternative ways of knowing and engaging with the world. They enable the disembodied logic of efficiency, scalability, and standardization, while rendering difference invisible and often materially displacing it through practices such as monoculture farming.

The modern globalization was possible not only through these epistemological foundations, but also due to a rise in global informational infrastructure largely developed through the postwar sciences of computation, cybernetics, and meteorology. One might trace the beginnings of the “information globalism” to the first project which aimed to continuously sense and represent the planet as a single entity. Called the World Weather Watch, and initiated in the 1960, it was a network for automatic collection, processing, and distribution of weather and climate information (Edwards 2006). It required a functioning planetary information infrastructure, and an international institution that could coordinate standards and data: this role was taken by the World Meteorological Organization or WMO. The World Weather Watch “actively produced shared understanding of the world as a whole” (ibid). This global vision, supported by sensing and computational technologies, established a framework for how societies perceive, manage, and intervene in planetary systems.

Today, weather and climate models represent some of the most extensive data-processing operations on Earth, drawing on a dense global network of meteorological sensors that capture conditions from ocean surfaces to the upper atmosphere. Living in Western societies, we have come to internalize a sense that we can “zoom out” from our local point of embeddedness on the planet to a total-picture-view, rendered through the technologies of constant mapping, modeling, and simulating planetary processes, to see anything from traffic conditions in our vicinity, to the encroaching rain clouds which are not on the horizon yet, to air quality in a city on another continent. Jennifer Gabrys describes this condition as the “becoming computational” of the planet (2016a)—a state where planetary-scale processes and phenomena are continuously measured, modeled, and rendered intelligible through digital infrastructures. They produce planetary-scale data that reinforce our understanding of the Earth as a singular, known, and computationally rendered entity.

One set of technologies behind the development of the planet becoming computational are the remote sensing tools associated with "big science" projects, such as climate models, GPS mapping systems, or global meteorological infrastructures. But while these large-scale systems depend on top-down funding, coordination, and governance, and require vast resources to build and maintain, they also rely on small, networked, inexpensive sensors embedded in environments. The development of this technology has been further shaped by the once-aspirational vision of ubiquitous computing and the Internet of Things (IoT). This vision of pervasively integrated computing embedded in our living and working environments, invisibly mediating our life, was first described in 1991 by Mark Weiser, working at Xerox Parc (1991). Weiser envisioned seamless integration of computing into daily life, with the digital systems invisible within our homes, workplaces, and environments.

These extensive assemblages of environmental media promise potential benefits for nature conservation efforts. The expanded knowledge they offer can foster a deeper understanding of ecological interdependencies, informing more nuanced conservation strategies. For instance, acoustic sensors can detect the presence of elusive species, and soil sensors can monitor subtle changes in habitat conditions, providing data critical for protecting biodiversity. Additionally, efforts to recognize the temporalities and spatialities that shape animal life can lead to new understandings of the relationships between organisms and their perceptual spacetimes.

However, environmental sensing technologies also require careful critical consideration of the risks inherent in their use. One of those risk is reinforcement of universalizing narratives. Sensing technologies can reinforce the universalizing logics by integrating data into totalizing frameworks that overlook local specificities. For example, the deployment of sensors to monitor the so-called invasive species might yield valuable data, but without understanding "invasiveness" not as a biological property but one that arises from entangled anthropogenic, historical, cultural, and ecological factors, such efforts risk perpetuating reductive solutions.

Another risk is the overemphasis on technological solutions. There's a danger in viewing technology as a panacea for conservation challenges. This technological determinism can lead to underestimating the importance of socio-cultural factors, traditional ecological knowledge, and the need for systemic changes in human behavior and policies. Further, large-scale data platforms often prioritize metrics that align with global economic or political agendas, sidelining the nuanced, situated insights that sensors can provide. This can result in an oversimplified understanding of biodiversity, reducing ecosystems to a set of quantifiable variables while ignoring their relational complexity and distinctiveness. Similarly, it's worth remembering that sensing technologies cannot capture all aspects of environments—only those aspects that can be "rendered technical" become visible to those representational systems, and thereby obscure the "the milieus, inventions, and becomings that might remain off the computational map, no matter how many more data points we add" (Gabrys 2022).

Equally, there is the risk of misinterpretation and misuse of sensor data, detached from its ecological and cultural context. Without a nuanced understanding, data may lead to inappropriate actions that inadvertently harm biodiversity, for example be co-opted to serve interests that conflict with conservation goals, such as commercial exploitation or political agendas. While the approach of "sensing nature in order to save it" focuses on generating every more data, this data can function as a resource exploited through digital capitalism (Ritts and Bakker 2021).

The use of environmental media raises also ethical questions. Those are in particular raised around surveillance (of both human and nonhuman subjects), and around questions of equity in the access to these technologies. Disparities in technological literacy and resources can limit who is involved in designing and using environmental sensors, potentially exacerbating the existing invisibility of the most vulnerable or most locally-situated perspectives.

Finally, the widespread use of sensor networks raises questions about the environmental costs of manufacturing and powering these devices, which often rely on extractive industries.

The invisibility of the mediation of digital technologies have the effect of concealing also their environmental impacts. Along with those, obscured are also the unarticulated assumptions and biases embedded in software and hardware and how they reflect and reproduce the values and priorities of the societies that deploy them.

Given the invisibility of these risks, and the powerful modes of world-making that these mediations enable, media technologies should be approached with critical scrutiny. Who determines what is measured, represented, and acted upon? What assumptions about the world are built into these devices and infrastructures? And how do these systems shape the ways societies perceive and value ecological and social relations?

Perspectives from more-than-human theory and feminist STS helps us approach the use of environmental sensing technologies as not passive instruments but active participants in the co-creation of knowledge, imaginaries, and materialities. These theoretical perspective also point to the opportunities to reshape and rethink designs of environmental media and practices around them.

A closer engagement with environmental media offers an opportunity for countering the "god-trick-thinking", and foregrounding the partiality of every perspective—the situatedness and embodiment of every knowledge claim. This also goes for knowledge produced by devices. As Jennifer Gabrys (2016a) observes, environmental sensing data - even if used for construction of the totalizing perspectives of global models - are "creaturely" - in a sense that they are not universal but rather occasioned by particular ways of perceiving and acting. This observation is a reminder that the sensing technologies are also (as every perceiving entity) only capable of partial perspective. Acting on Haraway's suggestion to foreground situatedness of knowledge is to account for how the technological and media systems work, technically, socially, and through imagination; to examine the elaborate specificity and difference that they are built in response to, and to be especially observant of the processes that coordinate and integrate these inputs into the totalizing perspective.

A closer look at the historical development of meteorology might be instructive here. Meteorology, a world-making science par-excellence that straddles the global and the local is a case in point. In the 1800s new instruments for recording weather conditions (such as thermometers and barometers) made it possible for individuals to make first standardized weather observations. However, to scale these individual observations to a new global framework of knowledge required an emergence of practices and devices —including a data table—which were precursors to processes and infrastructures of the distributed knowledge operations today. This coordinating process was underpinned by a belief that weather - and all physical phenomena - was governed by universal laws applicable everywhere.

Yet, the same meteorological observations were the basis for the naturalists and physicians of the time to argue for the distinctiveness of knowledges arising in different ecologies. They observed that the climatic distinctiveness of different geographical areas shaped the flourishing of distinct diseases that demanded environment-specific treatments (Valencius 2004). These practitioners "helped to cultivate regional medicines that were different from the universal systems of medicine invented by Europeans" (Skydsgaard 2010). Today, the recognition of the multiplicity of co-existing worlds allows to approach such situatedness without lapsing into the forms of environmental determinism. Instead of trying to find the "general laws" (a thinking that had lent itself to attempts to naturalize forms of social difference), we can recognize that situated entanglements and co-dependencies shape what Jane Bennett (2010) calls "emergent causality"—the unfolding of events as a process of co-worlding of entangled elements that produce difference and ecological distinctiveness.

This moment from early history of meteorology invites speculation: what if the scientific imaginary evolved since the 1800s not towards universalizing claims but towards foregrounding the relationality and situatedness of knowledge? What kind of technologies of sensing and representation might have been invented in such a society? Can we rethink today how the sensors and environmental monitoring technologies can be used to both critically assess the way they might be reinforcing the singular epistemic framework, and to understand how they can instead be used in support of multiplicity of knowledges?

The challenge lies in cultivating the "ability to partially translate knowledges among very different—and power-differentiated—communities," as Haraway observed (1988).

Distributed nature of computational globalism means that environmental media can also be used by grassroots practitioners to collect locally relevant data. Availability of the low-cost sensors can potentially empower communities to engage directly in conservation efforts, fostering participatory practices that can enhance locally-specific and culturally appropriate biodiversity protection. Community-led monitoring can for example identify biodiversity hotspots, track the success of restoration projects, and detect threats such as poaching or pollution, at the same time developing and strengthens community building initiatives and practices.

The agency of devices

Holmes' example of a container lock, as well as Gabrys' examples of environmental sensing technologies, show that every device inherently has a capacity to transform the material and social arrangements it participates in, and this agency introduces a certain amount of unpredictability. While designers might have a particular use in mind for their invention, its real world adaptation might depart from that vision or have unforeseen consequences even if used in the way it was intended. Every device presents a potential possibility of a pivot, of an unanticipated shift of the trajectory, an opening to a different world. The availability of the inexpensive sensor technology to individuals, grassroots initiatives and DIY projects further offers a mode of techno-ecological engagement that builds on this capacity. For instance, sensors designed for corporate resource management might be repurposed by communities to monitor pollution or track species reintroduction efforts, enabling counter-narratives and new forms of environmental advocacy. As examples of communities tracking environmental pollution show, the decentralized and participatory use of sensors can shift power dynamics, enabling communities to assert their own priorities and perspectives in conservation practices.

The example of the historical trajectory of meteorology shows how the pursuit of universal laws can overshadow the distinctiveness of regional ecologies and knowledge systems.

Similarly, as Dagmar Lorenz-Meyer describes (Lorenz-Meyer, Treusch, and Liu 2021), the present technoecologies build on foundations of universalizing sciences, resulting in climate models, GPS systems, and environmental monitoring devices which can easily contribute to sustaining the infrastructures of global capitalism such as the logistics systems, while contributing to the epistemological frameworks that perpetuate the imaginary of a global singular world.

But drawing on the speculative question of how scientific imaginaries might have evolved differently—foregrounding relationality and situatedness rather than universalizing laws—we can try to envision sensors as tools that support the recognition of ecological distinctiveness and emergent causality, understanding biodiversity as shaped by co-adaptive processes among humans, nonhumans, and environments. In order to do that we need to become familiar with these devices' specific world-making capacities, with how they work.

Beyond visuality

One type of the sensors used in the Mitwelten project are acoustic sensors. Building on the insight that the most radical potential of sensing technologies lies in their ability to enable new modes of worlding—beyond the dominant visuality, how can we understand what the acoustic sensors contribute to world-making?

Haraway's critique of the bias of visuality in science prompts a broader inquiry: what other sensory capacities might we cultivate through technological mediation, and how might these alternative modes of sensing potentially avoid the invisibilization of mediation itself? Ecoacoustics, as a field that amplifies and extends human auditory capacities, offers a site for exploring these questions. What do these devices allow us to hear, and how do they shape the socio-technical arrangements and ecological imaginaries in which they operate?

Building on the long-standing field of bioacoustics, ecoacoustics has emerged as a key area within biodiversity conservation, fueled by advances in computational power and digital recording technologies. The transition from analog to digital devices significantly broadened the range of "audible natures" that could be detected, recorded, and analyzed.

Yet, while more of the acoustic realities are revealed to us, they also hint that their full extend is far from being captured, and what we have access to is still rather like the top of the iceberg. If the infrasonic rumble of an earthworm, or of elephant communications can now be analyzed, if now we know that flowers emit sounds to communicate (Khait et al. 2023) and respond to the sound of pollinators by making their nectar sweeter (Veits et al. 2019), there are still multitudes of uncaptured acoustic signals and signatures that travel through the earthly spheres.

In the Mitwelten project, AudioMoth devices used in the Reinacher Heide captured soundscapes that were used to identify bird species and highlight some of the ecological dynamics in different habitats, such as dry grasslands, forest edges, and floodplain zones.

These loggers revealed the presence of rare species as well as impacts of human activity, such as human presence or noise pollution, on bird behavior. Such information allows for the landscape to potentially become what Jennifer Gabrys (2019) describes as not only a "senseable" but "actionable" reality, turning data into computationally legible forms that can inform conservation strategies. In the Mitwelten case studies, it was the data from pax sensors that was proving as "actionable"—it was very much of interest to the park rangers, who saw it as a tool that could help them enforce protection of the area. In fact, the rangers were so motivated to extend the use of the sensors that the Mitwelten project members led additional workshops for them to enable them to continue using the sensors and develop their own infrastructure to support it after the project was finalized.

Here the experimental nature of the project proves effective: it provides results that were entirely not anticipated. Another such unanticipated lesson can be found in the practices that had to be developed to use the sensors effectively. While AudioMoth devices were designed to capture data for quantitative ecological assessments (namely detecting particular bird species which function as biological indicators), this aim was challenging to accomplish. However, the sensors also in a way revealed more than anticipated. The acoustic sensors captured the complex interplay of sounds in the landscape—birdsong, anthropogenic sound, and wind patterns—offering an opportunity to experience the site as a post-natural multispecies soundscape.

While the data analysis faced challenges, including misidentifications caused by overlapping sounds and background noise, these difficulties unexpectedly had the effect of enriching engagement with the site. The process of cleaning, validation and interpreting the data required periods of active listening, which can encourage one to become attuned to the landscape in new ways. This embodied practice of listening shows that the act of sensing becomes a transformative encounter with more-than-human relations in assemblages of technological, material, social and attentional. Failures in sensor accuracy thus can become valuable opportunities for participants to reflect on the limits of technology and the need for embodied, situated knowledge to complement digital sensing. By attending to the interplay of sounds rather than isolating species, one can begin to see the landscape as a dynamic and interconnected system.

Listening, at its core, is an act of attention. It requires more than the physiological capacity to perceive sound—it is a practice of orienting oneself toward another, of making space for voices, presences, and expressions that might otherwise go unnoticed. Philosopher Jean-Luc Nancy (2007) describes listening as existing between two senses of “sense”: as data, the sensory input of sound waves and vibrations, and as world-making, the interpretive act of assigning meaning and significance to what is heard. This duality underscores that listening is never passive; it is an active process of engagement, one that involves tuning in, interpreting, and, ultimately, responding.

Attention, as Simone Weil (Weil 1997; Petriceks 2023) suggests, is one of the most profound forms of care. To attend to something fully is to make oneself available to it, suspending one’s own preconceptions in order to encounter it on its own terms. Listening, in this sense, is an ethical practice. It is not merely about detecting signals but about allowing oneself to be affected—by another’s voice, by the rhythms of an environment, by the silences and absences that punctuate sound. Listening, in this expanded sense, entails an attentiveness that creates space for relationships of care, requiring us to reflect on what is heard, how it is heard, and what remains unheard.

Acoustic sensing devices perform much of the listening on our behalf, capturing auditory data that is then interpreted through computational models and human analysis. In this context, listening becomes distributed across human and nonhuman entities, transforming across more-than-human body. The displacement or augmentation of direct sensory experience by automated listening technologies raises important questions: What forms of attentiveness do these devices cultivate? What relationships do they foster or foreclose? Working with acoustic sensing technologies thus necessitates a critical engagement with the ways they influence our own listening practices—how they train us to recognize patterns, to become attuned to specific ecological dynamics, and to interpret multispecies soundscapes through computational and scientific frameworks.

This engagement also presents an opportunity. If listening is a relational and interpretive act, then acoustic sensing technologies could be designed not only to extract data but to cultivate new forms of attentiveness.

Towards worlding-with

We know that digital encounters with environments can potentially generate economic value, and insights into nonhuman worlds, but can they foster more sustainable and caring ways of coexisting? As active participants in ecologies, they must be approached not just as a technical tool but as a situated practice of world-making. By enabling new sensory experiences, these technologies can generate alternative ecological imaginaries, moving beyond the reductive frameworks of data commodification and market-driven conservation.

Realizing this potential requires careful attention to the socio-technical arrangements that underpin practices of the use of these devices. Who designs these systems, and for what purposes? How are data collected, shared, and acted upon? And how might we ensure that these technologies serve as tools for care and cohabitation rather than extraction and control? By critically engaging with its possibilities and limitations, we can begin to imagine how these technologies might support just multispecies futures—where the act of listening becomes a form of care, and the soundscapes of biodiversity are preserved not as resources but as vital expressions of life itself.

To this end I'd like to end this essay with a speculative exercise that might broaden how we think about how working these technologies can reorient our own capacities for attentiveness, making us more sensitive to the voices and presences that constitute the living ecologies we seek to understand.

The AudioMoth devices listen for us. They are shaped not only by our perceptual capacities but our knowledge and values. They listen for birdsong that is meaningful to humans as a biological indicator of a state of the local ecology. But birdsong carries a lot of other meanings decodable as information or an affective impression, to many different ecological partners. Birds themselves would probably develop very different technology to record their songs. Birds, as studies show, encode meaning in aspects of their songs - like temporal fine structure - that our ears can't pick out and our brains don't pay attention to. "Our electronics couldn't handle the fine detail that the birds are capable of discriminating," explained biologist Rober Dooling (Yong 2022), describing a study which showed that a zebra finch's "fast ear" can hear complexities that are imperceptibly fast to humans. The birds also disregarded the sequence of notes in the songs, being interested only in "what's inside individual notes"—something that is, again, imperceptible to humans (ibid). Further studies showed that not only do humans experience bird songs in a different way than birds, but birds can also experience their own songs in different ways, depending on their sex and the season. Building recording technologies to serve the birds auditory and meaning-making capacities is one of those ideas fit for an art project and not useful application. Yet, I would argue we would learn a lot about our world, and about practices of listening, knowledge which could be transformative for humans as well.

Computational planet is not a static entity but a dynamic, contested terrain where the forces of globalisation, post-nature, and technoecological systems intersect. The same infrastructures that support extractive economies and the homogenization of local worlds also harbor the seeds of alternative futures. By reconfiguring the relationships between technology, ecology, and society, these systems hold the potential to disrupt entrenched logics and foster new modes of cohabitation and care within the complex, entangled realities of post-nature.

Chapter 5 *Mitwelten* Media

Cedric Spindler

5.1 Introduction

Chapter 5: *Mitwelten* Media explores the development and implementation of accessible technologies for citizen science-based biodiversity research in urban environments. It showcases the creation of a modular Internet of Things (IoT) Toolkit, a comprehensive Software Environment, and a robust Infrastructure Backend, all designed with a focus on open-source hardware, software, and data. Together, these elements served as the media-technological underpinnings of the ecosystem studies, experiments and design interventions of the *Mitwelten* project. This chapter elaborates their application in three key areas:

Data collection: Utilising the Field Sensor Systems based on the IoT Toolkit, data was collected through observation of habitats and indicator species during the three Citizen Science-based Ecosystem Studies.

Data analysis and knowledge production: Collected data was analysed to draw conclusions about the ecological quality and biodiversity of different habitats.

Presentation of research results: The actuators of the IoT Toolkit, along with various Media Applications, public displays, and Participatory Installations, were used to present research results in tangible formats, making them more accessible to the general public.

The chapter particularly highlights the collaborative process, involving citizen scientists in various stages of the project, from technical assembly and field installation to data collection and validation. This participatory approach, combined with the project's commitment to open development, aims to democratise technology, foster ecological awareness, and promote a deeper understanding of emerging technologies in environmental research.

In the spirit of our commitment to open science, our developments have been made publicly available. This approach is consistent with our goal of sharing knowledge, fostering collaboration, and enabling scientific research that adheres to principles of reproducibility. Central to this approach is the decision to license our software under open-source licenses (MIT and Apache 2.0), ensuring that others can freely access, modify, and build upon it. This commitment reflects our belief in the importance of transparency and innovation, while encouraging contributions from the broader community.

An integral part of our work involves hardware. For our own developments we created open hardware designs that are accessible and adaptable. We rely on simple, affordable components that can be assembled by lay people using DIY methods. This approach ensures that the components and systems we create are documented and shared in ways that allow others to replicate, improve, or customise them for their own purposes, resulting in accessibility for a wide range of users, from researchers to practitioners.

In addition to hard- and software, we make datasets from our observations, training data, and other relevant materials publicly available when possible. We share those resources in alignment with principles of transparency and accessibility, but also in accordance with strict rules of data protection and privacy, which limits the sharing of certain datasets. We aim to facilitate further research and development, enabling reproducibility and driving advancements in related fields. These datasets are provided under licenses that permit their use, redistribution, and adaptation, supporting a culture of openness in scientific inquiry.

In the same spirit and in adherence to Open Access requirements, our publications, presentations, and related materials are published under Creative Commons licenses.

IoT Toolkit (5.2) describes the modular, extensible, and versatile IoT Toolkit that was developed for the Mitwelten project. The toolkit contains prototypical nodes fulfilling specific functions, like sensing the environment (record and transmit data) and acting upon input (perform actions like signaling). The chapter provides details on the nodes and their functions, as well as DIY aspects and sustainability considerations.

Software Environment (5.3) explains the applications developed for the IoT Toolkit, from setup and control to maintenance and data analysis, validation and information processing.

Infrastructure Backend (5.4) describes the underlying data management and processing framework developed and set up for the project.

Field Sensor Systems (5.5) describes the specific sensory units used in the three Field Study Sites for the Citizen Science based Ecosystem Studies: Bird Diversity, Pollinator Diversity and Human Presence. The units are assembled from components of the IoT Toolkit according to the situational needs.

Citizen Science (5.6) discusses opportunities for citizen science and limitations that still require expert-led scientific research.

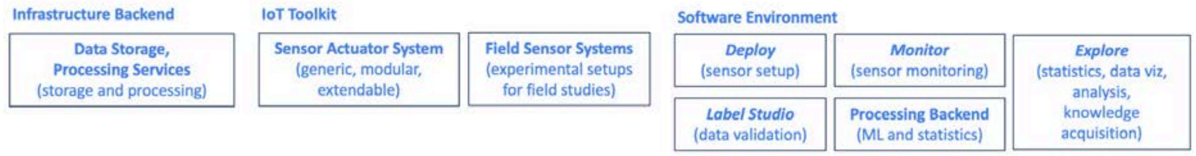


Fig 9: Infographic on the hardware and software developed in the *Mitwelten* project.

5.2 IoT Toolkit

Accessible and affordable open hardware components – such as sensors, actuators, and microcontrollers – have become increasingly available to a growing community of designers over the past 15 years. Supported by open-source software developments from various communities, these components are now integral to both expert-led and citizen science research, particularly advancing scientific applications in wildlife monitoring (Pearce 2012; Hill et al. 2019). The development of an IoT toolkit based on open hardware and software played a key role in the Mitwelten project.

5.2.1 Conceptual foundations of the Mitwelten IoT approach

The **Internet of Things (IoT)** refers to systems that enable the networking of digital computing systems with physical environments via decentralised hardware-software interfaces. These technologies are increasingly utilised in environmental and wildlife monitoring, where sensors measure physical quantities, processors evaluate digital data, and actuators feed this information back into the physical world. Sensor technology plays a crucial role in deriving specific conservation measures, as demonstrated in various studies (Wikelski 2017; Curry 2018; Steenweg et al. 2017; Guo et al. 2015; Van Der Wal and Arts 2015). In the Mitwelten project, sensors were employed for biological monitoring within the Ecosystem Studies, and actuators were pivotal in some of the **Design Interventions** to bring data to life in meaningful ways.

IoT is already well-established in areas like home automation, smart everything, industry 4.0 and consumer innovation. In the Mitwelten project, however, the focus shifts from commercial optimisation to artistic research and exploration. IoT systems have become a significant focus in connected media studies and design research, with contributions from scholars like (Gabrys 2016b; Sprenger 2016; 2019; Ash 2017). These studies highlight the use of IoT systems as tools for understanding and reshaping interactions between humans, media, and environments.

Within the Mitwelten project, those systems, also referred to as **sensor-actuator systems**, are understood as ecosystem actors and were integrated into the environment as well as participatory installations and experimental designs that emphasise creative, ecological storytelling and sensory interaction. Such design interventions promote ecological awareness and engagement by subtly embedding information into the environment (*Sensing with Trees*), presenting media in interactive formats (*WildCam TV*, *Discover*) and guiding human actors in ecologically sensitive areas (Guidance System).

Sensor-actuator systems are known, for example, to turn on the lights in front of a private house when motion sensors detect movement or activate sprinklers in an agricultural irrigation system when humidity sensor values fall below a certain threshold (Knapp et al. 2017). Translating sensor data into physical actuator responses (also referred to as **dynamic mapping**), enables an ecosystem to autonomously respond to detected situations, giving it a certain agency.

5.2.2 Design considerations and implementation details

The IoT Toolkit is composed of sensors, actuators, processors (microcontrollers like Arduino, single-board-computers like Raspberry Pi), power sources, networking appliances and other electronic hardware components.

Some of these components are combined as modular **sensor nodes** to record measurements in the environment. The data those sensor nodes record include temperature, humidity, moisture, the presence of cell phones (PAX count), sound and image.

Other components, such as servo motors, loudspeakers and LED lamps were set up as modular **actuator nodes** and allowed physical actions to be carried out or audiovisual information to be conveyed.

Most of the hardware components making up the nodes of the IoT Toolkit are housed in standard off-the-shelf **weatherproof electrical junction boxes** for which custom parts were developed: 3d printed adapters for mounting the nodes and laser-cut fixtures to keep components in place. The nodes can be used as complete units for follow-up projects or dismantled into their individual components for use in other developments. The electronic components for the prototypical nodes of the IoT toolkit were chosen to meet the requirements at a reasonable price, while preferring open hardware manufacturers in the US (Adafruit) and China (Seeed Studio) to cheaper no-name suppliers with dubious supply chains.

The choice of housing for the nodes not only allows installations outdoors but also disguises them as simple electrical installations, which makes those "Little White Cubes" unattractive to theft and vandalism (see figures 10 and 11).

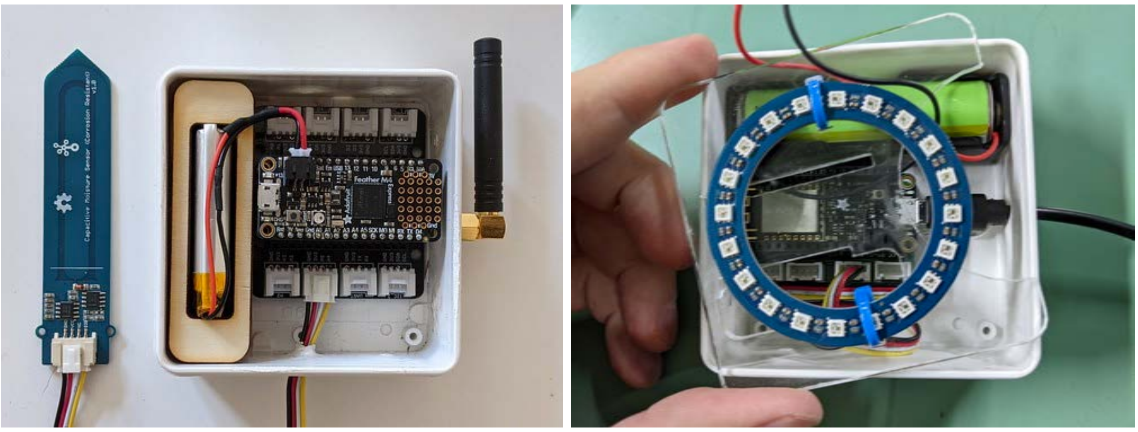


Fig. 10: *Left*: Sensor node example: Grove - Capacitive Soil Moisture Sensor with 2000 mAh Li-Ion battery, Feather M4 Express microcontroller and FeatherWing RFM95W radio module for LoRaWAN network connectivity housed in a off-the-shelf electrical junction box. *Right*: Actuator node example: RGB LED light ring with 3000 mAh Li-Ion battery and Feather HUZZAH32 ESP32 microcontroller, housed in the electrical junction box.

Wireless **data transmission** via new radio communication protocols such as LoRaWAN (Long Range Wide Area Network) enabled wide-area network coverage with low energy requirements at minimal cost. For data streams that require higher bandwidth, standard 3/4/5G mobile networks were used, i.e. for image and audio capture.

As single-board-computers (SBCs), such as the RaspberryPi and similar devices, are advancing in terms of processing power and energy efficiency, this progress enables their deployment as so called edge devices, capable of performing data processing and triggering actions directly within their environment (Sarker et al. 2019). The term **edge computing** emphasises the autonomy and distributed nature of these small, yet powerful, technological devices. **They are no longer mere data collectors but have the potential to become independent actors**, capable of making decisions and initiating actions based on the data they gather and process.

The decentralised approach offers several advantages. Edge computing significantly lowers latency – the delay between data input and system response. Since data processing occurs in close proximity to the source, actions can be triggered almost instantaneously, which is crucial for applications that demand real-time responses, in the case of the Mitwelten project, for example, to trigger a response of the Guidance System or other interactive design interventions to environmental data.

Relying on this concept also contributes to more **sustainability**. By processing data locally, edge computing reduces the need for extensive data transfer through long-distance networks and storage in data centers. This not only reduces energy consumption and carbon emissions but also addresses potential privacy and security concerns associated with transmitting and storing sensitive information. Furthermore, the energy efficiency of SBCs allows those systems themselves to consume less energy, contributing to reduced overall environmental impact.

During the development phase of the project, various configurations of edge computing were evaluated. At first the suitability of an Edge TPU by Coral[4] was tested while developing and training the machine-learning models for the ecosystem study Pollinator Diversity. TPUs (Tensor Processing Unit) are application-specific accelerator devices optimised for machine-learning and inference and allow for significantly increased energy efficiency and performance when compared to CPUs and GPUs. This particular device would enable a Raspberry Pi as an edge computing device, processing image capture data using pre-trained machine learning models in the field. The evaluation was conducted as part of a Master's project[5], and concluded that the accuracy using the Edge TPU was unacceptably low as a result of the devices requirement to quantise the model into a lower resolution (Wullschleger 2022). The same problem was observed when evaluating inference on edge devices using the BirdNET model for audio capture data in the ecosystem study Bird Diversity.

In a more recent study as part of a Master's thesis[6], the inference performance was evaluated on a broader range of devices. In the two years that passed since our first evaluation, significant progress has been made in the field of edge computing. On the one hand, single-board computers have become even more powerful, and on the other hand, state-of-the-art hardware dedicated to machine learning has become more accessible and efficient. These advancements now make it feasible to perform inference directly in the field. For instance, by converting Mitwelten flower and pollinator detection models into CPU-optimised formats such as ONNX or NCNN, the latest Raspberry Pi 5 can handle inference efficiently without requiring additional hardware. Further improvements come from specialised AI accelerators. While a more powerful Edge TPU was part of this evaluation, it was greatly outperformed by Hailo's AI chip featuring Neural Processing Unit (NPU), enabling the processing of larger models with greater speed and energy efficiency. This not only accelerates inference times but also enhances accuracy, making real-time, on-site analysis increasingly practical (Wild 2025).

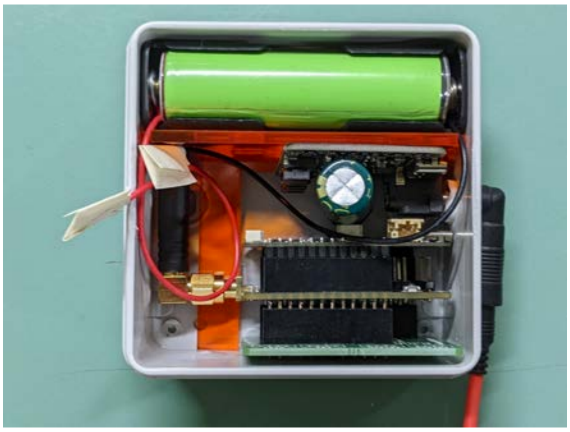
In case of image capture nodes, **as many processing tasks as feasible were offloaded to the edge device**. For instance, the devices were configured to prepare the images by extracting metadata and filtering out unnecessary, corrupted or redundant information before transmission. Furthermore, a load balancing system was developed to operate at lower CPU speeds, not only to reduce heat-stress for components exposed to sunshine but also lowering energy consumption while maintaining functionality.

While processing on edge devices has the potential to significantly reduce data transmission and energy consumption, its full potential is most evident when **managing large datasets**. In contrast, low-energy devices, such as environmental sensors and PAX counters, already operate efficiently. For these cases, the project explored **renewable energy solutions like solar panels** paired with Li-ion buffer batteries to enhance sustainability.

Using the IoT Toolkit, the Mitwelten project explored decentralised approaches to sensor-actuator systems, emphasising **three key aspects: the agency and autonomy of devices, systems, and environments; the close coupling of sensing and actuation; and sustainability through energy-efficient designs.** However, for many of the project's other research questions, data still

[4] https://coral.ai/products/accelerator, accessed 13.01.2025
[5] "Automated Analysis for Urban Biodiversity Monitoring" (Wullschleger 2022)
[6] "Edge ML Camera for Citizen Science" (Wild 2025)

needed to be centrally collected to enable in-depth analysis and comparative studies. Central to the IoT Toolkit is its reliance on a robust data management and processing framework. This framework supports the storage, analysis, and dissemination of large datasets generated by IoT systems, ensuring that both technical and non-technical communities can engage with the data meaningfully. The details of this framework, including its infrastructure and design, are discussed further in: Infrastructure Backend.



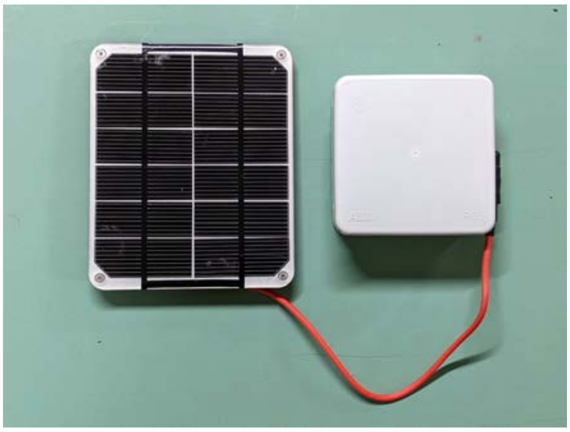


Fig. 11: *Left*: Open Pax Counter Node with 3000 mAh Li-Ion battery. *Right*: Pax Counter Node with 2W solar panel extension.

5.3.2 Components of the IoT Toolkit

In the following section, the components of the *Mitwelten* IoT Toolkit are introduced. All components are further described in detail, including build instructions and bill-of-material in Appendix B and the corresponding repositories.

Sensor Nodes

The **Audio Logger Node** is a specialised device designed for extended acoustic monitoring in ecological research. At its core is the **AudioMoth** platform (Hill et al. 2019), an open hardware device equipped with a sensitive, wide-frequency-range microphone capable of capturing high-quality audio recordings. Data is stored locally on an SD card, enabling the logger to operate independently in remote locations.

To support long recording periods, the device is powered by a large-capacity Li-Ion battery, offering approximately one week of continuous operation before requiring recharging or replacement. Encased in a weatherproof housing, the logger is protected from environmental elements while featuring an acoustically transparent membrane. This design ensures that the device remains functional in diverse outdoor conditions without compromising the clarity of the captured sound.

The Audio Logger has been effectively deployed to record a variety of sounds, including bird and bat vocalisations, as well as ambient noise pollution. Data collection is managed manually, with recordings retrieved and processed using custom software developed as part of the project.

Depending on the target species, different sampling rates were used for recording bird songs (48 kHz) or bat vocalisations (250 kHz). With careful planning of recording periods, sampling rate, battery and SD card capacity it was possible to keep maintenance and data retrieval visits to an interval of approximately one week.

The **Image Capture Node** was developed to facilitate high-resolution photographic monitoring, particularly of flowering plants. Its design evolved through multiple iterations to address practical challenges and improve functionality. Initially, a base model was built using the **Raspberry Pi 3B+**, chosen for its reliability and compatibility with available peripherals. However, due to global shortages of the Raspberry Pi 3B+, an alternative model using the **Raspberry Pi Zero W** was explored. Unfortunately, this version proved to be error-prone and was ultimately abandoned. Subsequent refinements focused on enhancing image quality and usability. Upgrades included higher-resolution image sensors and the integration of autofocus capabilities.

To streamline power management and connectivity, the nodes incorporated Power over Ethernet (PoE) through a PoE HAT adapter. This enabled efficient energy delivery, simplified deployment in field settings and facilitated the transmission of the capture data to the project's infrastructure via a **Field Access Point** (see below), which also provided the power source for PoE.

The **Environmental Sensor Node** is a versatile and energy-efficient platform designed for long-term environmental monitoring. At its core is the Feather HUZZAH32 ESP32 microcontroller, a robust platform capable of accommodating a wide range of sensors. For this project, the node was equipped with DHT22/AM2302 temperature and humidity sensors or capacitive soil moisture sensors, enabling the collection of critical environmental data.

A key feature of this node is its **LoRaWAN radio module** (FeatherWing RFM95W), which facilitates data transmission to a LoRaWAN gateway over long distances exceeding 1 km. This technology enables very energy-efficient communication but imposes considerable bandwidth limitations, i.e. up to 52 bytes at 15 min intervals.

The node is designed for **self-sustaining operation**, utilising a 2W solar panel paired with a 3000 mAh Li-Ion battery to ensure continuous operation while exposed to varying light conditions. This also reduced the need for frequent maintenance and enabled seamless data collection over extended periods. The Environmental Sensor Node exemplifies an integration of modularity, efficiency, and sustainability and was used as a base for the development of other sensor nodes, particularly the Pax Counter.

The **Pax Counter Node**[7] is designed to estimate human presence in an area through innovative use of Bluetooth technology. At its core is the **Feather HUZZAH32 ESP32** microcontroller, which leverages its integrated Bluetooth antenna as a sensory device to detect and count Bluetooth-enabled devices in proximity. The approach implemented here ensures anonymised data collection, preserving privacy while providing valuable insights into human activity levels. Based on the Environmental Sensor Node, the Pax Counter employs the same long-range LoRaWAN method for data transmission as well as a solar-powered energy system.

The Pax Counter Node offers a non-invasive and sustainable solution for studying human presence and its potential ecological impact. Its design exemplifies the adaptability of the IoT Toolkit, extending the functionality of the base platform to address diverse research needs.

The **Camera Trap Node**[8] was developed as a prototype for wildlife monitoring. At its core, the OpenMV Cam H7 Plus module featured a microcontroller, a 5 MP image sensor, and a microSD card

[7] The name and concept is based on the project "ESP32-Paxcounter" by Oliver Brandmueller and Klaus Wilting, https://cyberman54.github.io/ESP32-Paxcounter
[8] https://github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/OpenMV

slot for local data storage. Complementing this was a passive infrared (PIR) motion sensor, enabling the device to detect movement and trigger image capture only when activity occurred, conserving storage and power. Power for the Camera Trap was supplied by a 6600 mAh Li-Ion battery.

Although this prototype was not finalised for field use, it provided valuable insights into the design challenges and requirements for wildlife monitoring systems. Well designed power management is required for extended periods of operation in the field, and turned out to be very tricky to implement: the motion sensor needs to be able to wake the microcontroller, image capture at night requires infrared-red light sources to be switched on in time, etc. As a result, the project transitioned to commercially available, highly optimised devices referred to as **WildCams**, which offered a more practical solution for capturing data in challenging environments. This shift highlighted the importance of balancing custom development with off-the-shelf alternatives to meet the demands of field research effectively.

Actuator Nodes

As the complementary counterpart to sensors, Actuator Nodes are integral to **sensor-actuator systems** within the IoT Toolkit, enabling dynamic interactions with the environment.

The **Color LED Pixel Node** was designed for field signaling, offering a visually intuitive way to convey reactions derived from sensor data. At its heart is a **RGB LED ring**, which illuminates a white, translucent hemisphere with customisable colors. The ring is controlled by the versatile Feather HUZZAH32 ESP32 microcontroller, which also enables wireless communication with other nodes. The node is powered by a 3.7 V Li-Ion battery and encased in a weatherproof housing.

Next to the Color LED Pixel Node a **Direction Indicator Node** was developed for symbolic signaling in the field. The node features a servo motor fitted with a 3D-printed, **colored arrow signal**, allowing it to rotate and point in specific directions as needed. This motion is controlled by a Feather M4 Express microcontroller, which utilises its PWM output capabilities to drive the servo. The node is powered by a 3.7 V Li-Ion battery and includes level-shifting circuitry to enable compatibility with the servo motor. Multiple of these nodes can be deployed and orchestrated to form the Guidance System, reacting to data collected by sensor nodes.

The **Bluetooth Speaker Node** was not developed as a DIY electronics assembly, but instead conceals an off-the-shelf Bluetooth speaker (Hama Pocket 3.0) within an electrical junction box for seamless integration with the other nodes. The Bluetooth connectivity allowed this node-type to be flexibly combined with Environmental Sensor Nodes, specifically outfitted with a soil moisture sensor, and programmed with corresponding software to create an autonomous system for the *Sensing with Trees* study. Installed within the branches of a tree, the speaker vocalised its host's need for water based on real-time soil moisture readings.

For exhibitions and art installations the IoT Toolbox was complemented with off-the-shelf equipment such as screens and computers, allowing for the creation of engaging and presentable formats seamlessly integrated into the sensor-actuator system.

Gateways

The gateways nodes in the IoT Toolkit are essential for connecting sensor and actuator nodes to the wider infrastructure, enabling data transmission, remote management, and integration into the broader system.

The **LoRaWAN Gateway** was initially developed as a cost-effective, DIY solution for enabling long-range connectivity for the sensor nodes using the LoRaWAN protocol. This prototype featured a Raspberry Pi 3B+ SBC paired with LoRaWAN concentrator module (IMST iC880a SPI) and a 3G router for internet connectivity. However, as the node is ideally mounted outdoors, the lack of a weatherproof design led to the adoption of a commercially available, rugged LoRaWAN gateway for field deployment. Additionally, with operators planning to phase out the 3G network, a 4G-capable product was selected. The gateway facilitates the seamless transmission of data collected by the sensor nodes to the project's infrastructure backend via TheThingsNetwork (TTN).

The **Field Access Point**[9] is a high-performance gateway designed to provide seamless internet connectivity and act as a central processing hub for IoT Toolkit components in its vicinity. It houses a suite of hardware within a weatherproof polyethylene barrel and, unlike other nodes, operates on 230V mains power.

At its core is a 4G/WiFi/Ethernet router, connected to a Raspberry Pi 4B encased with a fan for active cooling and a Power over Ethernet (PoE) switch for robust network connection that simultaneously powers the connected Image Capture Nodes nodes. Additionally, a 2TB SSD provides ample storage capacity for data collected and processed locally.

The Field Access Point plays a pivotal role in managing and supporting the IoT Toolkit ecosystems:

- It provides internet connectivity via WiFi and PoE to sensor and actuator nodes in its proximity.
- It collects and processes images captured by the Image Capture Nodes, uploading them to the project’s infrastructure backend for further analysis and storage.
- It serves as a remote management and monitoring entry point, allowing for real-time oversight and control of connected nodes.

Numerous challenges required continuous improvement of the design, with heat being the most critical issue. Deployed in the field, the Field Access Point was exposed to direct **sunlight, leading to overheating** and system instability, sometimes resulting in data loss. The mechanical HDD initially used for storage started to fail due to the extreme temperatures, prompting a switch to a more robust SSD solution. The automatic CPU throttling feature of the Raspberry Pi 4B that initially aimed to prevent overheating was regulating the CPU frequency too aggressively, leading to read timeouts and data corruption when transmitting image data from the Image Capture Nodes. Setting the CPU frequency manually to a fixed low value just enough to ensure stable operation helped to mitigate this issue. Additionally, the barrel housing was covered with a reflective foil to reduce heat absorption.

[9] Inspired by the concept of “Datenklo”, repurposing portable toilet cubicles to provide network connectivity at hacker camps like the Chaos Communication Camp.

Fig. 12: *Left*: Field Access Point in the field, covered in reflective foil. *Right*: Assembly in the Lab.

Together, the sensor, actuator, and gateway nodes form the most important part of a prototypical media-ecological infrastructure, enabling the creation of design interventions that are both responsive to environmental data and embedded within their ecological and social contexts. The IoT Toolkit is intentionally modular, scalable, and adaptable, emphasising a DIY approach and prioritising sustainability and low-cost solutions to ensure accessibility for citizen scientists and diverse communities. By leveraging affordable components and open-source designs, the toolkit also empowers non-specialists to engage in ecological monitoring and contribute to conservation and awareness efforts. This democratisation of technology fosters a sense of ownership and responsibility among participants, promoting a more inclusive and participatory approach to environmental conservation and research.

Over the runtime of the Ecosystem Studies, it became evident that achieving energy-efficient, sustainable designs that can reliably withstand environmental factors is an inherently challenging process. Developing low-power implementations requires not only careful planning but also extensive testing and iterative refinement to ensure stability and longevity in the field. Despite the use of solar power and energy-efficient components, maintaining uninterrupted operation in varying weather conditions and remote locations proved to be a persistent challenge.

During the teardown phase, the substantial collection of **Li-Ion batteries** accumulated from the deployed nodes served as a tangible indicator of the difficulties in designing more efficient and sustainable systems. While the nodes were not overly resource-intensive, the experience highlighted the environmental footprint of such devices, reinforcing the need for continued exploration of more efficient implementations, sustainable power solutions and methods to extend the life cycle of components. These reflections underscore the importance of balancing technological innovation with ecological responsibility, particularly in projects aiming to support conservation and environmental monitoring.

5.3 Software Environment

Over the course of the project, we developed software that spans all operational areas, forming an interconnected and evolving ecosystem. Our approach balances custom development with the integration of established open-source solutions, aiming to ensure both ease of understanding and extensibility for future projects. Central to this effort was our commitment to the citizen science ethos while simultaneously creating robust, accessible tools that meet professional research standards.

This chapter begins with the software supporting the IoT toolkit components deployed in the field, then moves to tools for setup and maintenance of these devices during fieldwork. Next, we discuss applications for research and analysis, where collected data is processed and interpreted, and finally, we explore the media applications implemented as design interventions. The chapter naturally transitions into the following one, which details the backend infrastructure that provides universal access to data, analysis, and resources, supporting the entire software ecosystem.

While this chapter provides an overview of the software environment, it also delves into the design decisions and research processes that informed its development. More detailed descriptions of all components can be found in Appendix C and the corresponding Git repositories.

5.3.1 In the field, IoT Toolkit

IoT software for Sensor- and Actuator Nodes

For the IoT Toolkit the software development initially was based on the FHNW IoT Bricks Project[10]. This framework provides a modular ecosystem for IoT prototyping at room-, building-, and city-scale. It consists of Arduino-based software prototypes that run on field devices, a Java SDK for writing structured glue code to interact with these devices, and a flexible communication stack, allowing seamless switching between LoRa, WiFi, MQTT, and a mock transport layer for virtual prototyping. This allowed different stages of implementation: while some of the experiments were carried out at a conceptual level in a simulated environment, others employed devices in the field, relying on a larger chain of communication infrastructure, further detailed in 5.4 Infrastructure Backend.

Based on the IoT Bricks, a set of set implementations have been developed for the Mitwelten project, finding direct application in the experiments "Sensing Trees" and "Guidance System" as well as setting the foundation for further research and development of sensor and actuator node design of the nodes in the IoT Toolkit.

Mitwelten-specific implementations of IoT Bricks were developed for *Sensing with Trees*, featuring the Movement Sensor, Soil Moisture Sensor, Threshold Fader, Graph Monitor, Sound Player and Bluetooth Speaker prototypes[11], setup for WiFi based communication. For the Guidance System the set features the prototypes Color LED Pixel and Direction Indicator, along with a map based simulator-app for virtual setup and testing.

For the sensor nodes deployed in the field (Pax Counter Node and Environmental Sensor Node), we built on the principles of the IoT Bricks project but adapted the software for centralised data collection. These nodes operate using custom firmware designed for the Arduino-compatible Adafruit

[10] https://github.com/mitwelten/fhnw-iot-bricks
[11] Sensing Tress hard- and software documentation: https://github.com/mitwelten/mitwelten-iot-tree

Feather platform, each featuring a lightweight “Arduino sketch” based on open-source libraries, that reads analog/digital sensor data and transmits compact data packets over LoRaWAN. This approach further exemplifies accessible, open-source software design for IoT applications.

Image Capture Nodes

The **Image Capture Nodes** are built on the Raspberry Pi platform, running a streamlined and customised software stack designed for remote image capture and data transmission. These nodes operated on Raspberry Pi OS Lite, a minimal, headless Linux distribution optimised for embedded applications and efficient resource utilisation.

At the core of the image capture process is a lightweight utility that provides an efficient means of interacting with the camera extension and images, while a server implementation is handling image download requests from the Field Access Point Node. Through various API endpoints it is also possible to monitor the node and dynamically adjust settings such as focus, resolution, and image dimensions, providing flexibility during field work.

To enable smooth deployment and reproducibility, a complete set of setup scripts and documentation[12] was developed, covering installation and configuration for all camera types used in the project. This allowed for seamless integration and straightforward adaptation to different research contexts.

Beyond still image capture, a case study was conducted to assess the feasibility of real-time video streaming. This research, undertaken as the bachelor's project MJPG-Multiplexer[13], explored continuous streaming of image data. However, findings revealed that upload bandwidth was a critical limiting factor, making sustained video transmission impractical with the available infrastructure. Deploying the MJPG-Multiplexer for real-time design interventions would have required a significantly more expensive 4G data plan.

Field Access Point

By far the most complex software stack was developed for the **Field Access Point**, which acts as the gateway between the Image Capture Nodes and the Infrastructure Backend. This node is responsible for managing image capture devices, handling data collection and transmission, and ensuring system stability under resource-constrained, at times challenging environmental conditions.

The software distribution, created for the Raspberry Pi at the core of this node, is made up of several dedicated services[14]: one detects and registers newly connected Image Capture nodes, another component coordinates the retrieval and local storage of images, while a local monitoring and configuration interface allows fine-tuning of the capture schedule and system parameters. Given the low-bandwidth and resource-limited nature of the deployment environment, the uploader process[15] is another critical component of this distribution. It is responsible for extracting the metadata from the images and running integrity checks ensuring data validity before transmission. Since this operation is computationally intensive, it is scheduled to run at night when temperatures are lower, and system resources are not actively needed for data collection. The final upload to the

[12] https://github.com/mitwelten/mitwelten-cam-16mp
[13] https://github.com/mitwelten/mitwelten-fs22-imvs30
[14] https://github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/RaspberryPi/APGateway
[15] https://github.com/mitwelten/mitwelten-ml-backend/tree/main/ingest/uploader

infrastructure backend is managed in an asynchronous manner, with a built-in retry mechanism to handle connectivity disruptions.

To maintain system health and performance, the software stack integrates remote management and custom monitoring tools based on Prometheus exporters[16]. These track host metrics, service status, and upload progress, providing real-time insights into system operations. Over several iterations we managed to balance the system's parameters to ensure that images were collected and uploaded without data-loss or corruption and the uploads were fast enough to not exceed the local storage capacity.

5.3.2 Setup and maintenance

A series of applications have been developed that help handle the increasing number of devices and data, as well as monitoring the operation of infrastructure.

Deploy

The ***Deploy***[17] app supports deployment of the IoT Toolkit in the field, by providing a mobile web platform to create and edit deployment records while installing nodes, assigning metadata such as type, geolocation, deployment period and tags. Those records are used throughout the project to identify the data produced by the associated devices, enabling the aggregation into structured datasets. Further the app serves as an asset management system to keep track of all the nodes built and used during the project.

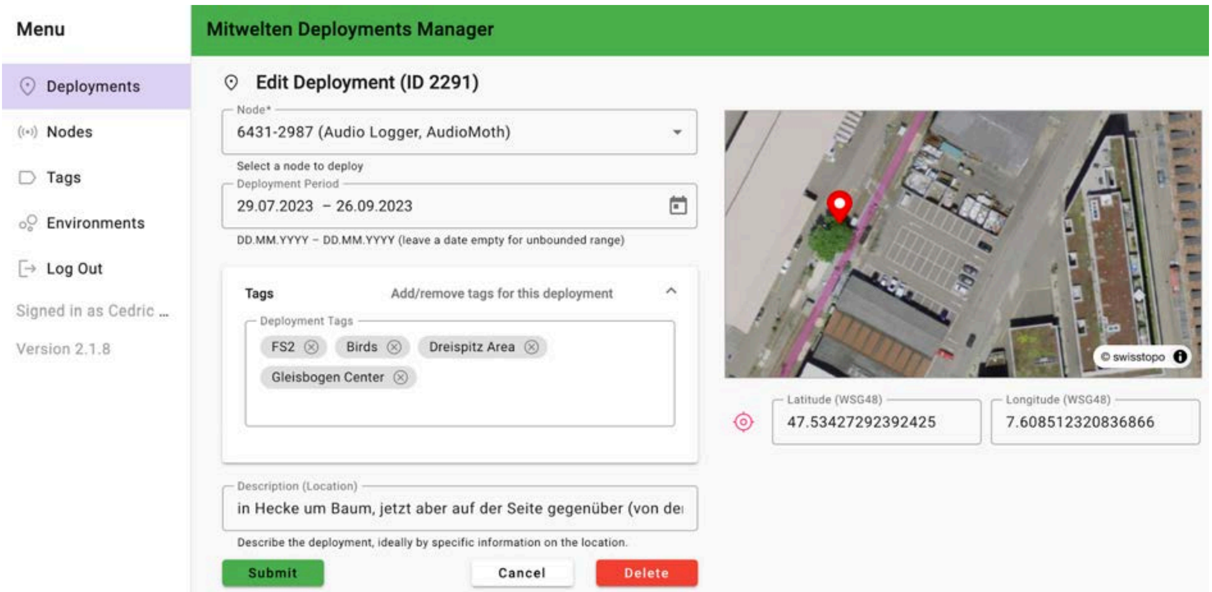


Fig. 13: Editing a deployment record of an AudioMoth Node in the *Deploy* app.

To provide the datasets produced by the experiments with context, the environmental conditions in which the nodes are deployed are registered by adding Environment records in the Deploy app, collecting numerical attributes like Settlement Factor, Sun Exposure, Nesting Opportunity, Plant Diversity, etc. for specific geo-locations.

[16] https://prometheus.io
[17] https://github.com/mitwelten/mitwelten-deployment-manager

Monitor

For real-time data visualisation and system monitoring, we utilise Grafana, a widely used open-source analytics and interactive visualisation platform. Running as a self-hosted instance within our backend infrastructure, Grafana and a set of custom dashboards provide a powerful interface for **exploring** all data stored in our centralised database and metrics collection system.

Grafana plays a crucial role in two key areas of the project. First, it is used to visualise sensor data and machine learning results. Second, it serves as a monitoring and alerting platform for infrastructure components, tracking the status of both field-deployed devices and backend systems.

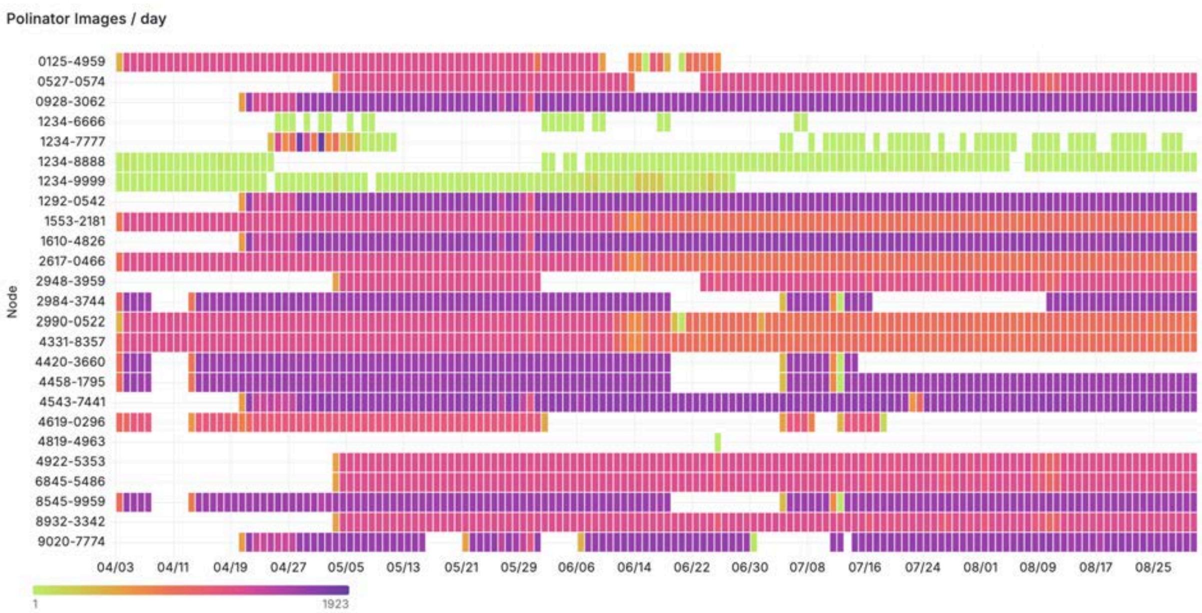


Fig. 14: Grafana dashboard: daily image collection stats per node.

Audio Uploader

A python based desktop app[18] based on the uploader component of the Field Access Point software distribution. Once the SD cards are collected from the devices in the field, members of our team used this app to transfer to the backend infrastructure: metadata imprinted by the AudioMoth firmware (like timestamp, node id, duration, battery level, temperature, etc.) is extracted, the raw audio data is verified, and both are uploaded to the backend infrastructure.

5.3.3 Research and analysis

Label Studio

To validate the inference results produced by the Machine Learning Pipeline, we used the open-source software *Label Studio* (Tkachenko et al. 2020). Citizen scientists and experts used this platform to validate predictions or to record labels for sample data sets of images and audio recordings, subsequently comparing them with the machine-generated labels. Label Studio was integrated into our ecosystem, enabling direct access to the file storage backend. This allowed the software to read audio and image files for display in the labeling interface and to store the resulting evaluation data for subsequent processing.

[18] https://github.com/mitwelten/mitwelten-audio-uploader

We commissioned a bachelors project to integrate a spectrum annotation view for Label Studio. The project successfully developed an interface that renders audio spectra of recordings loaded from the file storage backend, allowing users to label bat vocalisations by specifying time and frequency ranges. Efforts are currently underway to contribute this extension back to the Label Studio project.

Explore

While the Grafana dashboards described in the *Monitor* application proved to be useful for first glances and explorations into sensor data, we developed a more sophisticated platform within the Explore project.

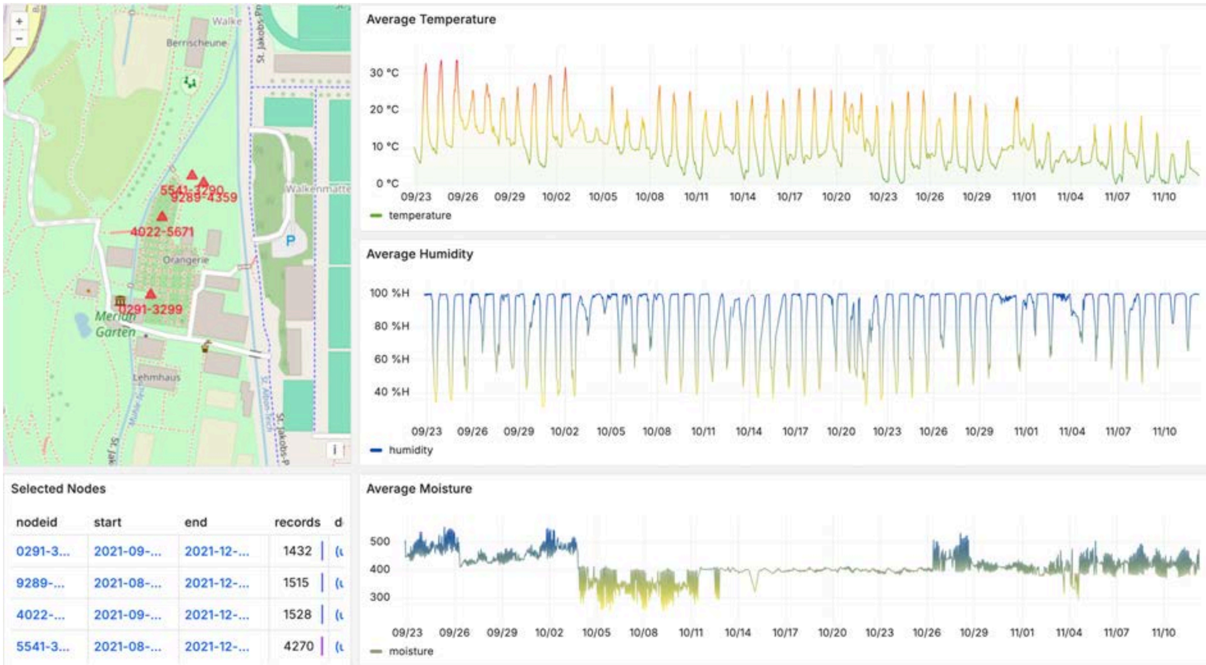


Fig. 15: Grafana dashboard: Sensor data and location of Environmental Sensor Nodes.

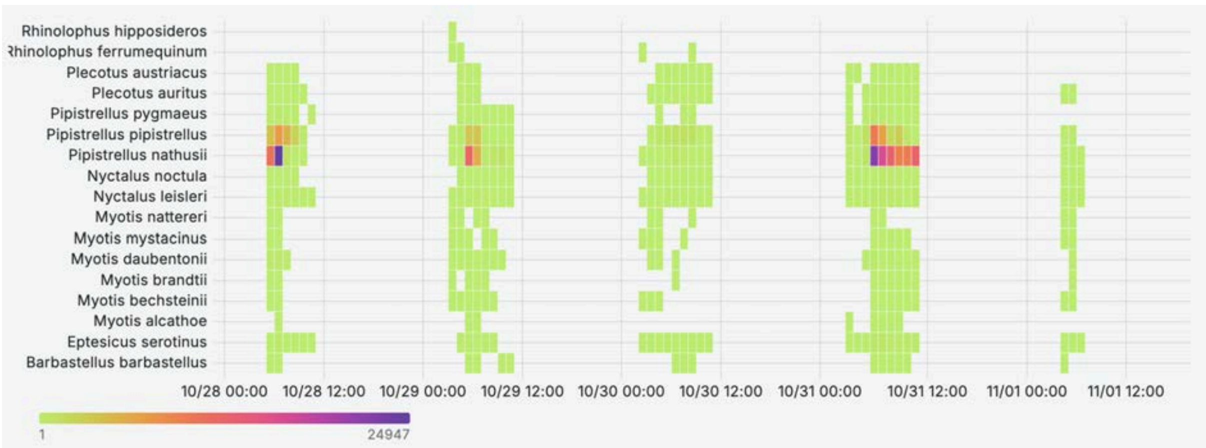


Fig. 16: Grafana dashboard: Machine learning results, inferred concentration of vocalisations of bat species.

For in depth data analysis the ***Explore*** application allows researchers to create custom data sets from all available data in order to analyse, filter, compare and annotate findings (Fig. 17). The software also allows the inclusion and correlation with data from public platforms like GBIF and MeteoSwiss, providing maps, weather data and species observation data posted through citizen science reporting platforms.

In Explore, all the records and datasets are flowing together: Metadata extracted from audio and image data, sensor data, deployment and environment records as well as aforementioned public resources. This turned out to be an invaluable tool for our research, as it provided the means to reflect on the complexity of ecological systems and the potential for mediation and experience. For example, measurements of the occurrence of animals could be combined with those of people and weather data.

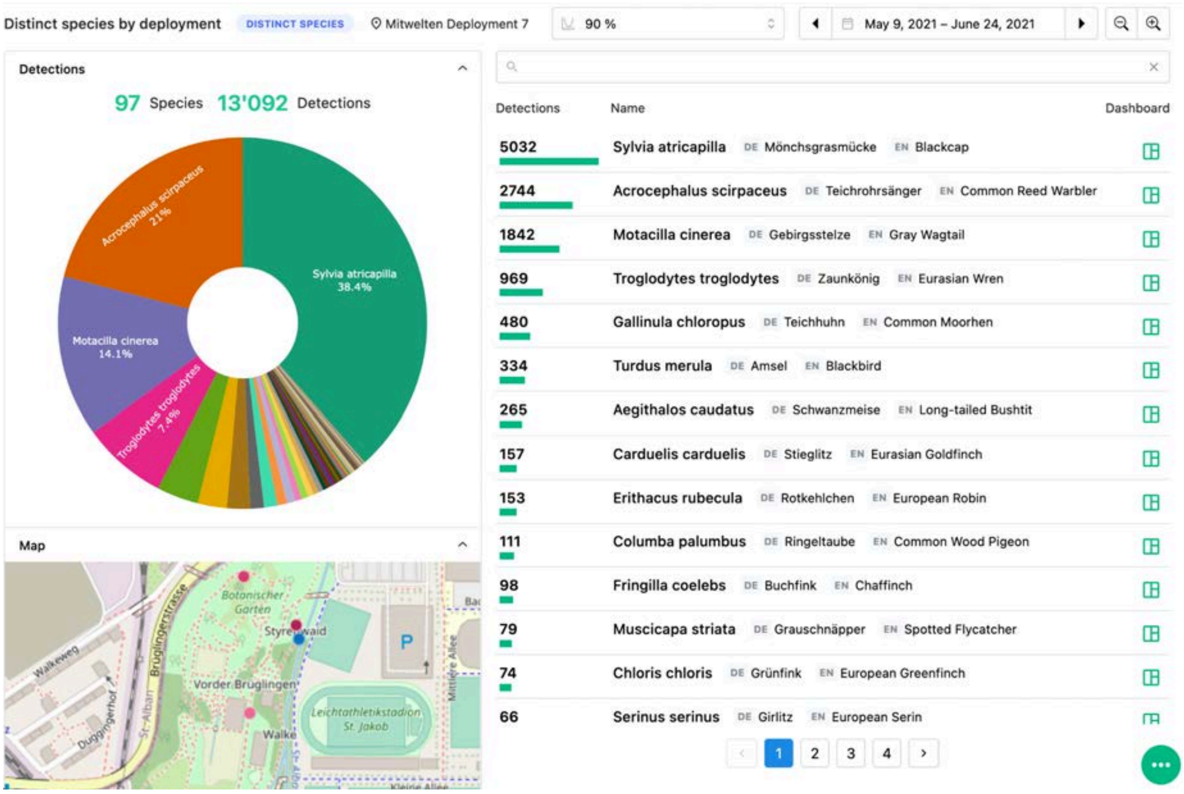


Fig. 17: *Explore* app, visualising inferred bird species (number of identified calls) of an audio-logger located at a pond in the Merian Gardens.

5.3.4 Media applications

In addition to the applications developed for data processing, we have also programmed **Media Applications** for the dissemination of collected information.

Discover App

The map-based ***Discover*** app[19] presents results of the studies in an easily understandable form for the general public, including different types of media such as image and sound. Users can select data of interest by location, time span, sensor and data type.

WildCam TV

With ***WildCam TV***[20] we designed a web app for an exhibition-based format that transforms wildlife image collections into animated sequences in real time. Using data from Image Capture and Camera Trap nodes, it enables visitors to create immersive time-based narratives through an interactive interface.

[19] https://github.com/mitwelten/mitwelten-discover-app
[20] https://github.com/mitwelten/mitwelten-tv-appliance/tree/main/mitwelten-wildcam-tv

Inspired by gamification strategies, the development revolved around design considerations to create a playful, explorative experience with a minimum of parameters. The platform encourages users to manipulate time, light, and frequency to uncover hidden patterns in nature. Whether observing the rhythm of nocturnal wildlife, tracing the daily life cycle of a habitat, or compressing seasonal changes into a dynamic sequence, users actively participate in making ecological phenomena visible. For an easy starting point, a selection of predefined parameter sets provides ready-made compositions.

To ensure a smooth experience, WebGL-based rendering enables real-time transitions and fluid playback, even with large image datasets. The platform streams directly from the Mitwelten infrastructure, but for privacy reasons, only a carefully curated subset of pre-validated image data is available, protecting sensitive data, including human presence in certain images.

WalkApp

We developed the location-sensitive, GPS-based web application ***WalkApp***[21], to present our findings in several modes of presentation on mobile devices in the contextual situation of a walk through peri-urban nature. The app is hosted by our infrastructure backend and accesses data through dedicated endpoints of the Data API. This enables real-time access to insights produced by the ecosystem studies as well as the image data uploaded by the Field Access Point Nodes. The app also invites visitors of the Reinacher Heide reserve to upload photos of their observations via the reporting platform WildeNachbarn[22].

Panorama

The ***Panorama*** app was developed as a standalone media application.

5.4 Infrastructure Backend

The Mitwelten project's infrastructure backend manages and provides the necessary resources for data storage, processing, and analysis. It is designed to be robust, scalable, and secure, ensuring the integrity and availability of data collected by the IoT Toolkit. The backend comprises a suite of services and tools that work together to support the diverse needs of the project, from data ingestion and storage to analysis and visualisation.

The *Mitwelten* project studied different scenarios and configurations of hardware and software, with a diverse group of researchers and a wide range of collaborators. All services and data needed to be available to all involved in the project, which posed a challenge to infrastructure that goes beyond the scope of citizen science. The availability requirement in many places at the same time required the use of centralised, internet-accessible institutional infrastructure, provided by the University of Applied Sciences and Arts Northwestern Switzerland FHNW. While the IoT Toolkit can be set up by citizen scientists, the infrastructure backend requires in-depth knowledge to set up and maintain. Networking, storage and computing resources are critical aspects if such infrastructures are to be used by other interest groups such as nature conservation organisations, municipalities or citizen scientists. In Citizen Science we discuss the implications and opportunities to broaden the reach of our developments to benefit citizen science and DIY communities.

The *Mitwelten* Infrastructure Backend is conceptually built on three pillars: storage, the Data API, and services. Storage encompasses both file and database storage solutions for data persistence. The Data

[21] https://github.com/mitwelten/mitwelten-discover-app
[22] https://www.wildenachbarn.ch

API serves as the central interface for data interaction, streamlining access and management. Services encompass a range of supporting functionalities, including monitoring, authentication, gateways, and the hosting of the applications described in 5.3: Software Environment.

Most of the infrastructure backend is running centralised on one virtual machine in the datacenter of our institution. Despite the complexity of the infrastructure, the resource requirements are satisfied by what essentially is a standard consumer-grade device, with 8GiB RAM and utilising only 4 virtual cores of the hypervisor's 24-core 2.90GHz CPU. The host is running Debian GNU/Linux, the setup of which we automated using ansible[23], serving both as a provisioning solution and documentation.

Two important exceptions are the file storage solution and the Machine Learning Pipeline, which operates as a specialised service within a dedicated virtual machine environment, leveraging hardware acceleration to power our models. Both were hosted by our institution as well.

All components of the *Mitwelten* Infrastructure Backend are detailed further in Appendix D, including references to documentation and source-code repositories.

5.4.1 Storage

During the three ecosystem studies Bird Diversity, Pollinator Diversity and Human Presence, the sensors collected large amounts of data. Some were transferred manually using SD cards, others via 4G/Wi-Fi routers or via a LoRaWAN network, and stored in different system architectures.

File storage

In the beginning of the project, while we were drafting the designs for the ecosystem studies, it was not clear how much data we will collect nor how to store it exactly – this was part of the design process. The audio loggers have the most straightforward requirements and serve as a good example for the need for storage infrastructure. The SD cards in the Audio Logger nodes needed to be regularly cleared by moving the audio recordings to another storage medium. Very quickly several large collections of files accumulated, accompanied with manually maintained lists of meta data such as source device name, environment details and file names. As there was no protocol or naming convention on how to build a directory structure, those collections soon deteriorated, with typos in directory names, missing metadata and many redundancies across multiple portable hard disk drives, etc.

To solve this problem, and to build the foundation for further data collection of different device types, we set up a centralised, networked storage infrastructure based on the S3 file object storage protocol, hosted in the datacenter of our institute. This allowed authenticated users to upload massive amounts of data that would be accessible by the research team, and regularly backed up for protection from data-loss.

Soon after, the Image Capture nodes were connected to the same storage infrastructure. It was particularly urgent to move the image capture data away from the frequently overheating hard disk drives in the Field Access Point nodes, as this condition actually resulted in significant data loss.

This type of storage infrastructure allowed us to build services and internet-facing applications accessing our data collections: The Field Access Point nodes continuously uploading images, Label

[23] Infrastructure as code solution, https://ansible.com

Studio to show audio and image data in its user interface, and design interventions like the *Mitwelten WalkApp* or *WildCam TV* to stream audio and image data to mobile phones and installations.

Over the course of the project, the storage infrastructure underwent several upgrades to accommodate the ever growing need for more storage capacity. Towards the end of the field studies the total amount of raw data had reached 47 TiB. This data must be archived for at least 10 years to comply with SNSF requirements, so it was copied to hard drives. Online storage and transfer of large quantities of data can become very expensive quickly[24], which makes this type of storage infrastructure an unsuitable solution for self-hosted CS projects. Local storage on NAS systems is a possible alternative, as it allows access for local services and researchers. However, implementing internet-facing applications that rely on this data would be significantly more challenging.

Database

Our database infrastructure served as the central repository for structured data, complementing the file storage system by managing all records related to our sensor network, deployments, metadata, and analytical processes. Designed to ensure efficient data management and retrieval, the database stored and organised a wide range of record types, including sensor data, file metadata, device configurations, deployment details, taxonomic classifications, and machine learning tasks and results.

Beyond managing primary data collections, the database also functioned as a centralised data source. Even files such as audio and image recordings, though stored separately in S3 object storage, were meticulously tracked within the database, ensuring integrity through checksum validation and metadata management. This approach provided a unified view of all collected data.

At its core, the database was built on PostgreSQL, structured as a set of relational tables that defined how different record types were interconnected. The data model established clear relationships between entities: for instance, each sensor node (id, label, type, firmware version) was assigned to a deployment record (id, node id, deployment period, geolocation, description), which in turn produced audio files (id, checksum, storage path, duration, sample rate, etc.). These audio files could be linked to machine learning tasks, whose results were ultimately associated with specific taxons. By maintaining these structured relationships, the database enabled flexible data processing, dataset generation, exploratory analysis, and device management.

In addition to its role in data collection and processing, the database supported authentication services by hosting the data source for the authentication provider (SSO). Furthermore, it acted as a cache layer, reducing the need for repeated queries to external services during research activities. This included taxonomic and regional observation data imported from GBIF, as well as weather data retrieved from MeteoSwiss IDAweb[25], ensuring that frequently used datasets were locally accessible.

By centralising data management and linking sensor outputs with metadata and analytical workflows, the database formed the backbone of our research infrastructure.

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[24] at the time of this writing, the monthly cost to store 50 TiB on AWS S3 is $1200 USD, still excluding the cost of transfer.

[25] https://www.meteoswiss.admin.ch/services-and-publications/service/weather-and-climate-products/data-portal-for-teaching-and-research.html

5.4.2 Data API

While the database is responsible for the modelling and storage of data records, the Data API is the central interface for accessing and managing data across the *Mitwelten* infrastructure. Built using the FastAPI Python framework, it provided a unified and documented abstraction and access layer, ensuring seamless interaction with the underlying data while maintaining security and scalability. The Data API operated as an internet-facing service, while the database remained an internal, protected resource. Access control was a core function of the Data API, managed through a dedicated authentication and authorisation provider.

Mitwelten research team members were granted privileged access, allowing us to manage datasets, oversee deployments, and perform advanced data analysis. Public collaborators accessed the system via user accounts with restricted permissions, enabling controlled data interaction. Field-deployed devices authenticated using unique device keys, which could be revoked to protect data integrity in case a device is stolen.

As an abstraction layer, the Data API provided endpoints with application specific structures for interaction with data, allowing for the creation, validation, retrieval, updating, and deletion of records. This separation streamlined application development and ensured consistency in data handling across various services.

The key role of the Data API is best illustrated using a few examples:

- The *Explore* app queried API endpoints to retrieve aggregated machine-learning results, enabling researchers and collaborators to analyse biodiversity patterns.
- The *Deploy* app used the API to manage sensor node and deployment records, allowing us to track field installations.
- When environmental sensor measurements were received via The Things Network (TTN) Gateway, the Data API validated incoming data to confirm that the transmitting Sensor Node was registered and active.
- The *WalkApp* dynamically retrieved location-based content.
- To optimise bandwidth usage, before a Field Access Point uploaded a large file, its metadata was first checked against the API to verify validity and uniqueness. Once the file was successfully uploaded, the corresponding record was updated, confirming the file's existence in the dataset.

5.4.3 Services

Our service infrastructure was built on the containerisation framework Docker to deliver a robust and scalable platform. We embraced the principles of Infrastructure as Code, defining and managing our entire setup through code. This allowed us to host the majority of our services, including all web applications, as a set of isolated containers. This containerisation strategy enabled us to run and manage a diverse range of services concurrently, while maintaining clear separation and minimising dependency conflicts. A dedicated container within this orchestration layer handled network traffic management, including the crucial translation of subdomains such as explore, discover, data.mitwelten.org, etc., to their corresponding containers.

Authentication across our platform was secured and streamlined through Keycloak, an open-source single sign-on (SSO) solution. Keycloak managed user authentication for most of our web applications, ensuring that only authorised users could access sensitive data. Once authenticated via SSO, devices, apps, and researchers could seamlessly interact with the Data API.

To maintain the health and stability of our infrastructure, we employed a comprehensive monitoring system built around Prometheus. Prometheus collected metrics from Field Access Points, the Database service, and the underlying operating systems, providing real-time insights into their performance. Alertmanager, integrated with Prometheus, was responsible for triggering notifications when critical issues arose.

For our field-deployed infrastructure that relied on LoRaWAN for data transport, such as Pax and Environmental Sensor Nodes as well as Actuator Nodes, we operated services that acted as gateways for data transmission. This involved two key components: an MQTT relay, which picked up data from The Things Network (TTN) and forwarded it to our Data API, and our self-hosted MQTT broker, which provided an alternative to TTN, serving as a case study for a citizen scientist-run IoT data pipeline.

5.4.4 Machine Learning Pipeline

The Machine Learning (ML) pipeline ran on a dedicated virtual machine, designed to asynchronously process large volumes of data using specialised inference services for different models. Each service operated independently, leveraging CPU and GPU resources for parallel processing.

The **BirdNet inference service**, built on the open-source model *BirdNet* (Kahl et al. 2021), analysed bird vocalisations by retrieving tasks scheduled via the *Detect*[26] app from the database. Using the BirdNET_GLOBAL_2K_V2.1 model, it processed audio recordings by directly reading them from our file storage backend, running inference in parallel. Subsequently, the detection results were written back to the database. Similarly, the **pollinator inference service** integrated flower and pollinator models, but instead utilising Prefect[27] for its processing workflow.

The system's design was inherently extensible, allowing it to accommodate new models and support future studies. One example is the integration of BatDetect2 for bat call classification, highlighting the pipeline's adaptability to different research needs and data types.

Furthermore, complementary tools enhanced the pipeline's functionality: Import and export utilities help with flexible data handling, and a Label Studio integration allows to create custom datasets for validation of machine-generated classifications by experts and citizen scientists. A set of evaluation frameworks allow statistical assessment of performance and quality, leading into further refinements of our models.

5.4.5 Source Code Repositories

All components of the infrastructure backend and software environment are maintained as public source-code repositories on GitHub[28], ensuring transparency, reproducibility, and accessibility. By openly sharing our development work, we facilitated collaboration within our team, enable contributions from external developers, and support future adoption by citizen science projects or similar research initiatives. Each repository was comprehensively documented, providing clear

[26] The Detect app was developed for management and observation of machine learning tasks. https://github.com/mitwelten/mitwelten-detect-app
[27] https://docs.prefect.io
[28] https://github.com/mitwelten

guidance on setup, usage, and customisation, making it easier for others to deploy and extend our tools.

Beyond code sharing, our repositories played a central role in collaboration and project management. GitHub's issue tracking and development planning tools allowed us to systematically document bugs, track feature requests, and coordinate development efforts across the team. Additionally, we used a continuous deployment pipeline to keep the web applications automatically updated with the latest changes. For security-critical components such as this continuous deployment pipeline or other parts that required automated infrastructure deployment, we maintained operational clones of the public repositories within a self-hosted GitLab instance at our institute. This approach safeguarded access credentials and API keys, ensuring that sensitive deployment configurations remained protected while still benefiting from an open development model.

By structuring our software ecosystem around publicly accessible repositories, we not only fostered collaboration within the team but also laid the groundwork for long-term sustainability and adoption. Our open-source approach encourages citizen scientists, researchers, and developers to engage with and extend our work, reinforcing the project's impact beyond its original scope.

5.5 Field sensor systems

Building on the foundations of the IoT Toolkit, we have put together specific sensor sets[29] for the three ecosystem studies Bird Diversity, Pollinator Diversity and Human Presence, The IoT Toolkit's components were assembled during a series of collaborative workshops hosted at the Critical Media Lab of the Basel University of Art and Design FHNW. These workshops provided a multidisciplinary environment where team members from diverse fields of expertise, alongside external collaborators, engaged in a dynamic learning process centered around the technical equipment and its potential applications.

5.5.1 Audio recording and data analysis

For the Bird Diversity study, **Audio Loggers Nodes** were used to record bird calls. During three years, a 55-second audio file was recorded every minute, 24 hours a day, from spring to fall, at a sampling rate of 48 kHz. The audio loggers were placed in different characteristic habitat types of the three field studies. The main aim was to examine the quality of the different places and habitat types within the field studies and also to be able to compare the three field studies with each other. The conceptual framework of the study is detailed in Bird Diversity.

A set of 15 Audio Logger Nodes were assembled as part of our IoT Toolkit. The nodes were deployed in the field at strategic locations to capture the soundscapes of the specific habitat. The deployments were managed in the *Deploy* app. Regular site visits were scheduled to swap SD cards, replace and recharge batteries, and check both device functionality and environmental conditions to ensure continued operation. The audio recordings contained in the SD cards were subsequently uploaded to the infrastructure backend using the uploader desktop application, facilitating the verification and transfer of large volumes of data for subsequent analysis. The uploaded audio recordings were then

[29] These are covered in more detail in (Torpus et al. 2025) "A sensor toolkit for nature conservation monitoring: How can the public be involved?" published in German in the Mitteilungen der Naturforschenden Gesellschaften beider Basel.

processed using our custom deep learning pipeline based on the open-source *BirdNet* model (Kahl et al. 2021).

Across the three field studies, we collected 10 TiB of audio recording, consisting of around 2 million files. Running in the infrastructure backend, the BirdNET pipeline had continuous access to the raw data, processing the dataset in a total of 63 days of computing time, writing approximately 10 million inference results into the database. This allowed the data to be shared through the Data API by a multitude of other apps: The results, which included species identifications and associated confidence levels, were explored and visualised by citizen scientists using the Explore app. In the same app, the results were further compared with publicly available observation data from GBIF (Global Biodiversity Information Facility) to assess consistency and identify potential discrepancies.

Fig. 18: *Left*: Audio recording node housing an AudioMoth audio logger in a camouflaged electrical junction box, mounted in the pasture of the Merian Gardens, with a QR-code for general information about the study. *Right*: Open audio recording node with an AudioMoth audio logger and a rechargeable Li-Ion battery.

Defined by five specific locations and a date range between May and June of 2021, a subset of the BirdNET results was selected for further scrutiny and validation by citizen scientists using *Label Studio* and *Explore*. A qualified expert further subjected the selected subset to a manual cross-check with authoritative ornithological data sources. This step aimed to eliminate obvious false positives generated by the automated BirdNET process and to further refine the data for subsequent analysis.

The field sensor system and its analysis framework for the Bird Diversity study relied on components over which we had limited influence. Rather than training our own model, we based the BirdNET pipeline on a pre-trained model with its own intricacies. As a result, our evaluations remained relatively superficial. This contrasts with the Pollinator Diversity study, where we employed a much more in-depth approach in both development and analysis.

5.5.2 Image recording and data analysis

For the Pollinator Diversity study we worked with a collection of Image Capture and Filed Access Point nodes to record and identify pollinating insects visiting the potted flowers we had placed in different habitat types of the three field studies. The research interest has two aspects. One is to develop and evaluate a system of IoT components and software infrastructure for collecting data, training classifier models, and deploying classifiers for inference on edge-devices. The other is to examine ecological quality by studying the concentration of indicator species in different habitats. The conceptual framework of the study is detailed in Pollinator Diversity.

Fig. 19: *Left*: Final image recording node design with anRaspberry Pi 3B+ and PoE shield with the redesigned AP10 adapter, and a 16 MP ArduCam with auto focus. *Middle*: Open image recording node with a camera and a Raspberry Pi used for recording pollinators visiting daisies in the pot. *Right*: Access point housed in a blue barrel on a laser-cut wooden pedestal, equipped with a 4G Uplink providing internet-connectivity via Wi-Fi and PoE and a Pi 4 with a 2 TB disk to cache the photos.

Following the workshops in the assembly phase, the Toolkit nodes were strategically deployed across a variety of environmental contexts and configured to upload image capture data to the infrastructure backend. Eight **Image Capture Nodes** were mounted above the flower pots taking pictures at 15 second intervals daily between 10 am and 4 pm. The pictures were collected by 2 **Field Access Points** and uploaded to the infrastructure backend. Approximately 5 TiB of data was collected between May and September 2022, consisting of a total of around 1 million images. During the operational phase the Toolkit nodes were maintained and consistently nurtured as part of our ongoing citizen science initiative.

Fig. 20: *Left*: Interdisciplinary assembly workshop at the Critical Media Lab (participants wearing masks during coronavirus pandemic). *Right*: Pollinator setups ready for outdoor installation.

The deep-learning-based detection system, developed as part of a master's thesis (Wullschleger 2022), entailed the creation of a training dataset using image capture data from the initial Field study site "Dreispitz". This dataset was supplemented with additional images from the iNaturalist[30] platform to enhance the diversity of the training data, addressing the insufficiency of the project's own collection at that stage. The resulting flower dataset comprised 501 images containing 1653 labeled blossoms, while the pollinator dataset included 3679 images with 2687 labeled insects. Various deep-learning models were trained and evaluated for flower and pollinator detection, with YOLOv5 ultimately proving to be the most suitable framework. The training process involved experimenting with different models to optimise image scaling, image quantisation, model size, and framework-specific parameters (hyperparameters). This process encompassed the training of 25

[30] https://www.inaturalist.org

flower models, taking a total of 34 hours (an average of 1.36 hours per model), and 43 pollinator models, requiring 160 hours (an average of 3.72 hours per model).

Subsequent testing of the models on random images from the first field study site yielded promising results. The varying significance of the different performance metrics for each model, and their complex relationship with the training parameters, are documented comprehensively in Wullschleger (2022). The incoming larger datasets collected in the second field study had yet to be used to evaluate the models at this point.

Fig. 21: *Left*: Recorded camera image with ML-labeled frames of flower detections. *Right*: Recorded camera image imported into the software Label Studio for validation of pollinator identifications by citizen scientists (prevalidation, exclusion of basic failures) and experts (final validation, difficult cases).

The data-sets collected for this field study were processed by our deep-learning image inference pipeline using a **two-stage evaluation**: First, the blossoms of the potted species (either daisy or knapweed) were identified using the flower model. Second, flower visitors were located in these image crops, and finally assigned to one of the five morphospecies honey bee, wild bee, bumble bee, hover fly or fly. All predictions are recorded into the database including inferred class, confidence and coordinates of the rectangular bounding box.

Fig. 22: Identified honey bee, wild bee, bumble bee, hover fly and fly on either daisy or knapweed flowers.

A small, randomised selection of images was imported as sample dataset into *Label Studio* to validate the model predictions by citizen scientists (pre-validation for exclusion of fundamental errors) and by two entomologists (final verification of difficult cases). In a first step we validated the **flower model**: We generated new ground-truth by manually labeling the blossoms in the sample dataset. The manual labels were then matched to the predicted labels to estimate model performance:

Number of inspected images	311
Total number of flowers	580
True positives	292
False positives	3

False negatives	288
Precision	**0.990**
Recall	**0.503**
F1 score	**0.667**

Table 1: F1 score flower model

The initial goal was to assess the performance of the **pollinator model** on a small sample. When trying to create new ground truth from that sample it became clear that it is very difficult and time consuming to find pollinators at all. Already at that step we understood that the model performance would not be great, when we had a hard time recognising the pollinators by eye. As a basis to decide if the performance is good enough to continue with more in depth evaluation we decided instead to manually evaluate the model predictions (false positive or a range of confidence levels, low, mid, high). With this method we don't know about any false negatives, therefore we can only calculate the precision (positive predictive value PPV).

Number of inspected images	311
Total number of predictions	731
True positives	186
False positives	545
Positive predictive value	**0.254**

Table 2: PPV pollinator model

Class	PPV
fly	0.649
honeybee	0.054
bumblebee	0.000
hoverfly	0.167
wild bee	0.205

Table 3: PPV by class

The evaluation results highlight that the models are not yet sufficiently robust to be reliably used in real-world scenarios. This is due to a divergence between the initial training data and the complexities of real-world data, where numerous influencing factors were not adequately represented. To improve the performance, particularly for the pollinator model, further data collection and iterative training cycles are essential. This will involve creating a considerably larger and more diverse dataset that encompasses the range of environmental variations encountered in the field.

5.5.3 Mobile phone counting

For the Human Presence study we worked with the **Pax Counter Nodes** to estimate the number of individuals present at specific locations over time, in order to study the potential impact of human presence on the ecosystem. The study's conceptual framework is detailed in Human Presence.

The sensors each covered an approximate range of 10 meters and were configured to scan for Bluetooth signals every 30 seconds, with each scan lasting 3 seconds. The detected Bluetooth addresses were aggregated into 15-minute intervals, and the count of unique addresses was transmitted to the infrastructure backend via LoRaWAN.

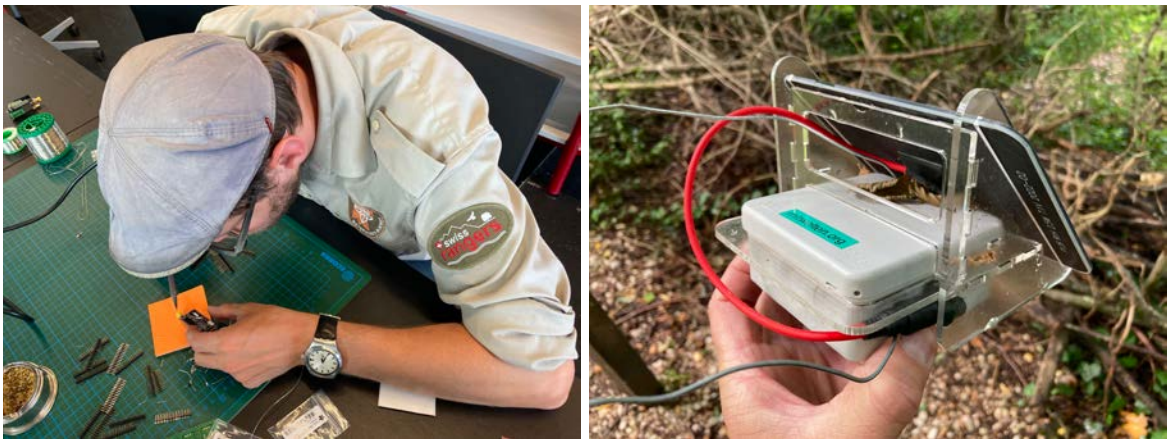

Fig. 23: *Left*: A ranger from the Reinacher Heide soldering a Pax Counter during an assembly workshop at the CML. *Right*: Pax Counter Node, housed in a case with an integrated solar panel.

To validate the accuracy of the Pax Counter Node, we conducted 12 surveys at a busy crossroads, comparing sensor data with human observations. The manual counts were synchronised with the sensors' 15-minute summation periods, allowing for a direct comparison between observed and recorded visitor numbers.

It was to be expected that the counts resulting from this type of sensor reading are inaccurate: people may have their phones turned off, carry several bluetooth enabled devices, or use mobile operating systems that randomise Bluetooth identifiers for privacy reasons. Additionally, some passersby may go undetected due to the gaps between sensor scans. These factors were reflected in the validation results, which showed a significant discrepancy between sensor counts and actual number of people present. Nevertheless, the rough estimates of local number of people over time has proven the setup to be successful for the observation of general trends in visitor distribution.

The PAX counter system has been redesigned and made available to park rangers, in a version that doesn't use the whole infrastructure backend, but produces CSV lists instead (see "Example Integration of Human Presence Study" below).

5.6 Citizen Science

Bridging the gap between citizen science and expert-led scientific research

The large scale collection of raw data in diverse and complex natural environments is very suitable for citizen science based research. Our IoT Toolkit presents a basis for such projects. There is a whole range of apps that enable the determination of individual field observations[31]. Our goal, however, is to conduct long-term studies with extensive data analysis to be able to draw conclusions about populations. The setup we implemented is using centralised infrastructure for processing the raw data generated by the IoT Toolkit, and is conceptually similar to established cloud-based subscription-based solution for the prediction of species[32]. What most of those solutions have in common though is the closed nature of their systems which often limits or even denies customisation, transparency, and accessibility for researchers and citizen scientists.

[31] BirdNET based Merlin Bird ID https://merlin.allaboutbirds.org; Flora Incognita https://floraincognita.de,
[32] Arbinmon Rainforrest Connection, https://arbimon.org; Plant AI / PictureThis, https://www.picturethisai.com

While the motivation for such closed loop systems often is an economical interest inherent in various business models, it is also clear that the complexity of the underlying models and data processing pipelines is a barrier for non-experts, and the distributed nature as well as the cost of infrastructure and maintenance is a strong limiting factor for research projects run by citizen scientists.

By designing our IoT Toolkit, software ecosystem and models to be open-source and modular, we aim to evaluate the possibility of opening up that closed loop to the broader citizen science community including municipalities, nature conservation associations and grassroots activists. In the following we discuss the **opportunities for citizen science and limitations that still require expert-led scientific research**.

The IoT Toolkit was developed through a bottom-up approach, beginning with local experiments and evaluations rather than following a predefined scientific master plan. Over time, we successfully established a solid foundation, conducting expert-led participatory workshops where citizen scientists and researchers collaborated to design and assemble components, subsequently setting up experimental installations in the field. This collaboration extended into data collection, system control, and ongoing maintenance, involving tasks such as replacing batteries, adjusting focus, and watering plants.

As data was continuously gathered in our storage infrastructure, our research focus shifted towards studying the collected information while simultaneously refining applications for data analysis, storage, and processing. We also worked on designing new formats for disseminating our findings. Throughout this process, we maintained an active dialogue with citizen scientists to enhance and tailor our hardware and software solutions for real-world applicability in citizen science projects.

The transition from basic data-gathering systems to a more sophisticated storage and processing infrastructure was essential to support our interdisciplinary research. Our team, distributed across multiple locations, managed distinct responsibilities within various research topics and studies. Among these, the development and training of machine learning models emerged as a key focus – particularly relevant to citizen science but also one of the most technically demanding areas due to its complexity and required expertise. This process begins with making the collected raw data remotely accessible to all involved parties for analysis, labeling, and training. However, depending on the scale of the infrastructure needed for centralised storage and processing, sustaining such efforts requires **institutional support**, **external funding**, or a viable **for-profit business model**. In our case our institution provided us with the necessary resources.

For instance, recording environmental audio with a single AudioMoth can effectively illustrate the scale of the issue. Using a typical configuration of 55 seconds per minute at a 48 kHz sample rate and 16-bit resolution, the AudioMoth generates approximately 7 GiB of data per day or 2.5 TiB per year (calculated as: 55 s x 60 m x 24 h x 16 Bit x 48 kHz ≈ 7 GiB/d ≈ 2.5 TiB/y). Based on our observed inference rate for the Bird Diversity study, processing this volume of data would require approximately 320 hours of compute time annually. In an experimental setup with 20 devices, the total recorded audio would amount to 50 TiB, translating to a projected compute time of 9 months. While the raw files could be discarded after inference, it becomes evident that retaining and ensuring accessibility of all data is essential for training new models.

Improving the accuracy and reliability of machine-learning algorithms is a challenging task. While developing the flower and pollinator models and evaluating their performance, we observed that a significant level of expert knowledge is required at multiple stages. First, producing high-quality ground-truth data mainly involves labeling, which, for large image datasets, is both time-consuming and costly. Correct species classification demands expert validation, making this task less suitable for citizen science. Second, assessing model accuracy requires a deeper understanding of statistical analysis and experience in fine-tuning models to identify and address influencing factors.

In natural environments, diverse and unpredictable conditions – such as background noise (e.g., soil, gravel, or chaff), focus shifts, object rotation, wilting, wind movement, and shadows – add complexity to the data. To improve model robustness, it is important to ensure that those factors are not only sufficiently accounted for in the ground-truth, but also considered carefully in the labeling process. This challenge would benefit considerably from the diversity and multitude of opinions and perspectives of crowd-sourced raw data from citizen scientists. Bias of machine learning models due to lack of diversity in the training data is a well known problem (Mavrogiorgos et al. 2024). Our findings suggest that **a joint effort between experts and citizen scientists offers a mutually beneficial approach**: experts provide the necessary validation and refinement, while the broad participation of citizen scientists contributes to more diverse and representative datasets. This collaborative approach enhances model accuracy, increases engagement, and makes machine learning applications in citizen science more inclusive.

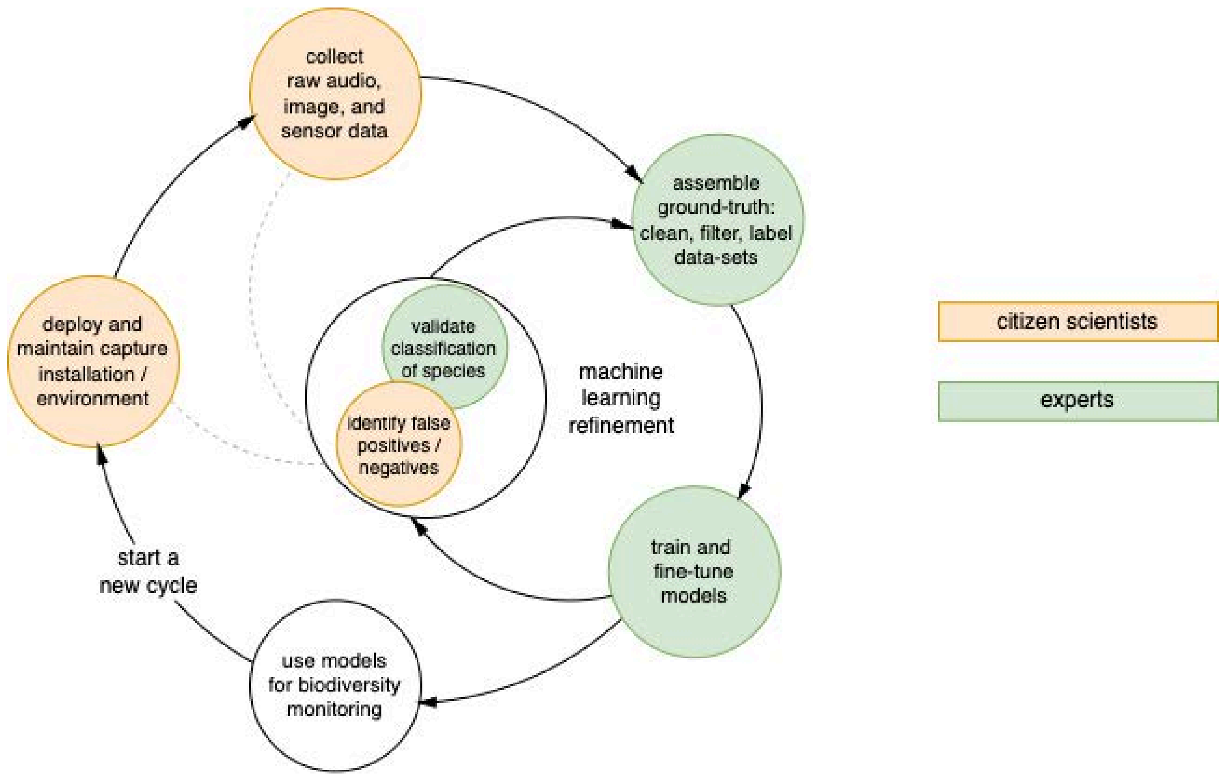

Fig. 24: Infographic explaining the iterative ML and experimental setup development process.

Citizen Scientists / Expert loop

Drawing from our observations, we see Citizen Scientists (CS) as an essential part of machine-learning based biodiversity research efforts. The Citizen Scientists / Expert loop involves CS building, deploying and maintaining the capture installation and the observed environment, subsequently collecting and uploading raw audio, image, and sensor data. Experts then produce ground truth from this data by cleaning, selecting, and filtering it to create datasets. This ground-truth is used to train models. Predictions from the models are evaluated by both CS and experts. CS may identify false positives, while experts check for correct species classification. At this stage, an iterative refinement cycle begins, where the model is continuously improved through successive rounds of training, validation, dataset expansion, and parameter fine-tuning. Insights gained from evaluating influencing factors inform ongoing adjustments in the data collection process, ensuring better results over time.

Once high accuracy and reliability are achieved, the model can be implemented, i.e. in biodiversity monitoring. At this point a new cycle can begin, where new toolkits are built based on the models, with the predictions inferred in the field contributing to crowdsourced, large-scale citizen science initiatives.

All steps in this loop present opportunities for knowledge transfer, where for example the protocol for correct labeling and species classification studied by CS, or observations and experiences maintaining the capture installations by CS provide valuable context to the whole process.

This joint effort also establishes a crucial basis for open research: **transparency and accountability in algorithm development** through the use of open-source software, shared protocols, and interoperable data formats. Furthermore it's crucial to acknowledge the inherent value of CS not just as a means to scientific ends but as a way to democratise science, engage diverse communities, and foster a deeper connection between people and their natural environments.

5.6.2 Application in citizen science projects

Since the IoT Toolkit was developed with citizen scientists in mind, it is particularly suitable for broader adoption due to its ease of use, well-documented open hardware and software components, and affordability. Its modular design allows users to adapt the system to different applications while keeping costs and technical barriers low. However, some level of technical expertise is still required, such as familiarity with platforms like GitHub, hardware tinkering, command-line tools and basic networking.

The other components, namely the software and infrastructure, require further development and sustained effort. Taking the Pollinator Diversity study as an example, it becomes clear that the raw image data collection using the IoT Toolkit is only the first step. Further storage and processing rely on the software environment and infrastructure backend, components not initially designed to be set up by citizen scientists. This makes implementation difficult for those without technical expertise. While we documented the flower and pollinator models as well as the codebase to build the infrastructure for processing and analysis, the implementation of its components requires specialised knowledge, particularly the pipeline to infer classifications from raw image data. The interconnected nature of the services and storage solutions demands expertise in system engineering. Although Label Studio is a valuable tool for dataset annotation and prediction evaluation, and suitable for a workflow involving citizen scientists, integration into the infrastructure is necessary. Further, the utilities we developed to process evaluation data and numerically assess quality and performance are tailored to our specific scenario. While this setup served the specific goals of the Mitwelten project, different projects have other requirements, resulting in the need for adaptation and integration.

To advance our developments and enhance their compatibility with citizen science, we propose two potential paths forward. First, streamlining deployment by simplifying setup processes and reducing software and infrastructure complexity. Second, integrating with existing citizen science initiatives to ensure interoperability with established platforms, datasets, and methodologies. The following examples illustrate how these paths could be realised.

Example integration of pollinator diversity

To integrate our pollinator diversity study into a practical, small-scale application, a set of IoT Toolkit Components including Image Capture Nodes and Field Access Point Nodes is required. The system would further consist of adapted software for the Image Capture Nodes, integrating the machine-learning inference pipeline using our pre-trained models with **edge computing.** This removes the need to upload or store the raw image data beyond the processing by the pipeline. The Field Access Point Node would run a streamlined Data API and Database, bundling only the necessary components to reduce complexity and resource requirements. This node would collect the inference data from the Image Capture Nodes and serve as a host for a simplified version of the Explore App, accessible through the nodes' local WiFi network.

This approach would be suitable for studying pollinating insects on a small scale, in a backyard or garden for example. The observations and datasets conducted in the Explore App could be shared with local municipalities.

Example integration of human presence study

The Human Presence Study in the Reinacher Heide nature reserve led to a design iteration of the IoT Toolkit and involved software components, demonstrating an effective integration for simplified deployment by citizen scientists. The collaboration with the local nature conservation association for our own study sparked interest among park rangers, resulting in an initiative to create an accessible monitoring system. This system consists of ten solar-powered Pax Counter Nodes with modified software, a LoRaWAN 4G gateway connecting to The Things Network (TTN), and a streamlined software solution to collect and store data in CSV format. The resulting setup allows citizen scientists to deploy and operate field studies on visitor distribution trends with minimal effort and maintenance. With well-documented hardware design and open-source software, the system remains sustainable and adaptable for future applications beyond the current field studies.

Integrating with existing citizen science initiatives

With some effort to comply with the specific data-formats and quality requirements, our available datasets – flower and pollinator images as well as bird audio recordings – can be contributed to established initiatives. But to enhance the reach of our work, we propose to extend our technological framework to interface with existing citizen science platforms. Such an integration would allow both raw and inferred data to continuously contribute to broader ecological studies:

GBIF (Global Biodiversity Information Facility)[33]: Our pollinator species classifications could be contributed to GBIF, supporting long-term biodiversity monitoring. By formatting species occurrence data according to the Darwin Core schema (Wieczorek et al. 2012), we could provide structured datasets that enable researchers to study species distributions, seasonal variations, and ecological trends.

iNaturalist[34]: Our flower and pollinator images – either as raw data for community validation or as inferred classifications – could be integrated with iNaturalist's database, enhancing its machine-learning models and enabling citizen scientists to engage in species identification. Through API-based uploads, we could establish a continuous data stream, ensuring that new observations contribute to public biodiversity knowledge.

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[33] https://www.gbif.org
[34] https://www.inaturalist.org

eBird[35]: Our bird audio recordings and inferred species identifications could be submitted to eBird, where they would complement citizen-reported observations. By aligning detections with eBird's taxonomy and protocols, we could contribute structured data on bird populations and seasonal migrations. Additionally, this would allow for comparative studies, contrasting human-reported observations with automated detections.

Arbimon: Our raw bird audio recordings could be uploaded to Arbimon, where automated recognition algorithms could refine species classifications. This platform would enable further validation through expert and community engagement, strengthening both our datasets and existing models. Additionally, Arbimon's data-sharing capabilities could facilitate cross-platform research by linking our findings to eBird and GBIF.

By pursuing these integrations, we aim to make our data more accessible and useful for both citizen science and professional research communities. This approach promotes a collaborative ecosystem, where automated detection, expert validation, and public participation contribute to a more comprehensive understanding of biodiversity and environmental change.

[35] https://ebird.org

Chapter 6 Learning with the post-natural land

Karolina Sobecka

Years ago, I tried to build a DIY device to visualize in real-time the concentration of CO_2 in the surrounding air. It was part of an art project and followed several other prototypes I made using an Arduino microcontroller—an open-source electronic hardware platform. While in those previous projects I used parts made for amateur “makers,” in this case I purchased sensors used in industrial applications, which did not come with DIY instructions but with sheets of technical specifications and calibration profiles. In retrospect, CO_2 concentration might have been the ideal measurement to pick to learn about the messiness of the process of establishing facts using scientific equipment. It was a demonstration of the challenge of “rendering nature technical,” highlighted by the DIY context, but characteristic of all knowledge practices. CO_2, undetectable by human senses, is elusive not only because of how diluted it is in the atmosphere (for every million particles only around 412 are CO_2) but also due to the constant movement of the air and therefore fluctuations in its concentration. Attempts to measure it instantly acquainted me with the slipperiness of what is, in any circumstances, a tricky affair of extraction of data from the complex field of experience. The experience taught me a great deal about atmospheric gases, microcontrollers, sensors, programming, generating, and making sense of data. But maybe most fundamentally, it also led me to consider both the very human and imprecise processes behind the construction of this knowledge, and the vastness of what is left uncaptured by human instruments and practices.

The *Mitwelten* project developed practices of working with technologies of environmental sensing to similarly expose the knowledge-making processes behind the numbers or images that we usually encounter in representations of nature, with the aim to open up the kinds of questions these new sensitivities enable us to ask.

The transformative potential of the DIY and citizen science initiatives of environmental sensing is often linked to the notion of “democratization” of knowledge production. Projects such as SafeCast, where communities developed homemade Geiger counters to monitor radiation after the Fukushima disaster, or citizen efforts to document pollution in “Cancer Alley,” demonstrate how these tools can make visible environmental injustices and foster collective action. Those examples show that providing communities with the means to generate and interpret data can challenge models of environmental governance and expertise.

In the *Mitwelten* project, which focused on biodiversity conservation, the aim was less to gather data to help establish political claims, and more on the world-making processes of knowledge and representation practices. The project asks what might alternative approaches to conservation look like if the very human processes behind environmental sensing and sense-making were informed by the more-than-human, relational perspective? This experimental approach, rooted in the need to reimagine how learning and knowledge transfer about the natural world occur, starts with the use (and often mis-use) of sensing technologies by non-experts, and with fostering grassroots communities of practice around these technologies.

Land as pedagogy

The *Mitwelten* project draws inspiration and guidance from the concept of “land as pedagogy” evoked by Leanne Simpson (2014) in her writing on the Nishnaabewin land-based knowledge practices. Simpson writes that these practices are grounded in reciprocal relations, ethics, and spirituality. Learning, or "coming into wisdom," takes place in the context of community and family. As Simpson writes, this framework lacks the overt coercion and authority, values, which have been normalized within mainstream western pedagogy, and counters the conventional notions of environmental expertise and authority. The process of coming to know is learner-led and situated, generating "theory" of a kind that is not just an intellectual pursuit, but rather is "intimate and personal, with individuals themselves holding the responsibilities for finding and generating meaning within their own lives" (Simpson 2014). Children of the Nishnaabewin community, who learn in this context, "know that wisdom is generated from the ground up, that meaning is for everyone, and that we're all better when we're able to derive meaning out of our lives and be our best selves" (Simpson 2014; Doerfler, Sinclair, and Stark 2013).

Media technologies might seem almost antithetical to the land-based knowledge practices, as they are primarily seen as extensions of the western science and education systems, reinforcing their models of authority and expertise, themselves structured by digital capitalism and extractivist logics. Yet, learning with the land of post-nature means learning with environments that are assemblages of ecological and technological, where human infrastructures, pollutants, and technologies are thoroughly entangled with the biological, geological and energetic processes. The *Mitwelten* project departs from the assumption that the values of knowledge practices developed by Nishnaabewin would also help to transform and reimagine how people engage with these post-natural environments and learn with them. The DIY use of sensing technologies can serve to engage with post-natural land without reifying the nature-culture divide of modernist dualisms, and—if it is structured by ethics and values of land-based knowledge practices—it can potentially lead to more just co-existence.

Environmental sensing technologies are often understood to have the capacity to modify the human subjectivities created by our unique ways of sensing and perceiving—expanding the human Umwelt, as Jakob von Uexküll termed the perceptual lifeworld of an organism. They might allow for better understanding of experiences beyond direct human perception, for example translating ultrasonic bat calls or gas exchanges between biosphere and atmosphere into a register of the human sensory range. Alternatively, one might speculate that sensor technologies generate their own, "alien" subjectivities: Jennifer Gabrys, for example, describes digital sensing as something that often happens alongside the human senses rather than as a prosthetic extension of them (2016a).

Both of these approaches draw on traditional definitions that tend to separate the body from the material equipment that makes it sensitive to the world. Instead, drawing on the more-than-human approach, and on the discourse on the cyborg, we can venture to understand sensing technologies as extensions of an assemblage—organic, technological, and social. We can consider closely how those entanglements shape practices of learning—training not only the perception and the practices of inquiry but also "learning to be affected".

Learning to Sense

Let's focus on one facet of the practices of "learning to sense" with the expanded sensitivities of technologies - quantification. As Science and Technology Studies scholars Arun Martin and Martin Lynch observe (2009), counting can be analyzed as an always context-dependent social practice which involves recognizing, classifying and arranging the things to be counted. The *Mitwelten* project's case study in Reinacher Heide (Torpus et al. 2025), which employed acoustic sensors to monitor bird calls, is a great example of the multiplicity of practices behind quantification today. While the techniques are very different than those Martin and Lynch considered in their paper, this case study raises similar questions as they encountered.

Counting, as Martin and Lynch note, is always entangled with assigning value and is bound up with the production of natural and social orders. Some counting is explicitly understood as political, such as surveys of lands, estimates of the size of a crowd at a protest march, or even calculations of the average global level of CO_2 concentration. Detecting bird calls might sound more "neutral," but such environmental monitoring is also often done to support a particular argument or agenda. For example, in environmental assessments conducted to permit an area for development, low-tech sensors enable consultants to provide monitoring results, which become "the ammunition" for one side or the other, generating evidence that the environment is of particular ecological "value." As one scientist put it, they enable consultants "to be able to go in and say, the black throated finch, for example, they surveyed for one week, didn't find it, therefore it's not there - despite it being a nationally listed species - and conclude 'therefore your development can go ahead'" (Ritts and Bakker 2021).

Martin and Lynch take as their example the controversy over the number of chromosomes in normal human cells which unfolded starting in 1920, with various experts arriving at different counts of chromosomes, until in 1956 46 became the established correct number. Based on a popular iconography we're familiar with, chromosome counting might sound straightforward, yet once we understand that it involves "obtaining tissues in which cells are dividing, arresting the chromosomes at the point of division, disentangling them from other cellular materials that may be mistaken for them, selectively staining the chromosomes, and squashing them flat so that they lie more or less in one plane" (Martin and Lynch 2009), we can understand how the mis-counts might happen. In the Reinacher Heide case study, detection and recognition of different bird species also involved an array of processes, from choosing the locations for installing the sensors, to recording for specific periods of time in different seasons of the year, to collecting the acoustic data, processing it with machine learning software, and cleaning the data - all processes that inevitably leave some uncertainty around the final numbers. Finally, as the bird calls were frequently misidentified by the software due to overlapping sounds or background noise, a complex data validation process was required.

As the examples above show, the multiplicity of practices behind quantification means that different experts can arrive at a significantly different count of the same thing. The numbers hide the contingencies created by these complex practices behind their aura of ostensible objectivity. Choices of techniques and tools, dis-ambiguations, discriminations, and creative cleaning or filling-in done at the professional discretion—what Martin and Lynch call the "hinterland" of counting - disappear behind the final numbers.

While the technical tools are often seen as offering a record of material reality that is uncontaminated by unreliability of human senses, the above examples show that every tool is part of social situated practices. Even more fundamentally, perception is mediated by theory, training, and context, even before it is mediated by devices. Lorraine Daston, a historian of science, argues that scientific method can be said to be itself a technology of perception that shapes what can be seen. It provides a training of the collective perception so that we can "form stable kinds out of confused sensations, generating order out of chaos" (Daston 2008). Daston quotes Ludwik Fleck, bacteriologist and philosopher writing in 1935: "Direct perception of form requires being experienced in the relevant field of thought. The ability directly to perceive meaning, form, and self-contained unity is acquired only after much experience, perhaps with preliminary training.” (Fleck 1935 cited in Daston 2008)

Daston discusses the Cloud Atlas, created in 1802 by Luke Howard, a chemist and amateur meteorologist, as an exemplary device for training the collective perception, one that taught the cloud observers to “see in unison” (Daston 2016). Alexandra Hui (2023) writes that similarly, standardization of representation of birdsong produced the effect of tuning the bird watchers’ perception, enabling them to hear specific sounds in the wild.

The implicit processes of trained perception are only then further linked to explicit mediation by tools, including descriptions, images, and instruments.

There is a flipside to the acquiring of habitual perception, of which Fleck and Daston were well aware. Once a particular way of seeing becomes ingrained, it may obscure contradictions or alternative patterns that might otherwise emerge. Once we are trained to see a particular form,“we lose the ability to see something that contradicts the form,” writes Fleck (Fleck 1935 cited in Daston 2008). As Daston writes, the benefit of being a novice lies in the ability to still see the contradictions, and—to see potential alternative patterns. It spells the “freedom from these habits. Novices can discern patterns that experts might overlook, precisely because their perception has not yet been shaped by dominant frameworks” (2008).

The novice is similar to the figure that Isabelle Stengers calls the “idiot”—someone who intentionally or accidentally fails to satisfy expectations of rational discourse or effective practice (2005). The idiot’s inability—or refusal—to align with dominant logics creates space for alternative ways of knowing and being. The idiot therefore holds a unique potential to disrupt entrenched ways of knowing.

The novice/idiot principle is often invoked in the artistic engagement with new technologies, which aim to offer an avenue for exploring the potential of environmental media to unlearn the habitual perception of nature. Art projects have the capacity to complicate the narratives surrounding environmental technologies, emphasizing their ambiguities and limitations while experimenting with their possibilities. Rather than framing technologies through utopian or dystopian narratives, artists often approach them with a criticality that Haraway terms “staying with the trouble.”

Art projects that engage sensing technologies also add the dimension of making things public. As artist Claire Pentecost writes about her practice: “I think of myself as a public amateur, someone who consents to start with "I don't know" and proceeds by learning things in public view, public so that we can put the process of learning itself in a space reserved for debating values, the discursive space we designate as art”[36]. I was following Pentecost’s lead when I was developing my CO2 visualization device. In the end, it successfully showed fluctuations of carbon in the air, for example when exposed directly to human breath, changing color from green (indicating the ‘normal’ conditions) to yellow (detecting the higher concentration of CO2 in exhaled air), or in response to varying environmental conditions (it turned deep red in an underground garage). But it was nowhere near scientifically “useful” precision. Instead, it became a device for public signaling of concern about CO2 in the air and knowledge of it in the first place.

DIY practices help to expose the “hinterland” of technically-mediated perception, and make it public, not only in a sense of being publicly presented and publicly accessible, but in the sense of being

[36] https://www.saic.edu/profiles/faculty/claire-pentecost

collectively negotiated and created. In documenting the negotiations of the techniques and assumptions embedded in sensing technologies, DIY practices can make the implicit explicit. Returning here to the land-based knowledge practices of Nishnaabewin, we can note that Simpson describes them as always take place in the context of community, and as a reflection of reciprocal relations. The knowledge generated this way does not claim a view-from-nowhere objectivity, but rather the partial perspective of embodied, relational positioning. Similarly, communities using low-cost sensors to monitor pollution or biodiversity are not just generating data; they are actively shape the epistemic and ethical frameworks through which that data is understood. This participatory approach challenges the hierarchical structures of expertise, supporting grassroots communities of practice that negotiate knowledge collectively. As Simpson writes about land-based pedagogies, such learning practices shape how the new sensitivities contribute to the construction of the socio-material worlds. "Engaging with the land, learning from and with it, is not to just "dream alternative realities" but to create them, on the ground in the physical world," she writes (2014). It is this aspect of making of alternate socio-material worlds that is also key for Jennifer Gabrys. She argues that the benefit of being a novice outweighs possible risks of grassroots applications of low-cost sensors, because even when environmental sensing projects are based on reductive premises, or are derailed by "idiotic" participants and fail to produce any of the desired outcomes, there is important work being done in in the making of alternative worlds.

Art projects that build on DIY technology contain a crucial step: when experimenting with new technology, artists don't simply stop at learning a skill like using a sensor, they instead tend to employ that skill to ask new sorts of questions. This is a step that is sometimes missing in DIY workshops that introduce sensor technology. Participants, ingrained in mainstream educational system, might fail to exercise the creative power of formulating questions about the world that this new sensitivity enables. Leaning further into speculative dimension, artists can reveal the relational and ethical dimensions of sensing technologies, and potentially foster reciprocal relations with more-than-human worlds.

Learning to be affected

What does it mean for the hybrid assemblages of human and sensing technologies and infrastructures to "sense"? Can we ask, speculatively, what it would mean to learn to sense with sensors in a way that is not oriented towards achieving an all-encompassing perspective, but towards cultivating the sensitivities needed to engage with the partial, situated, and contingent nature of knowledge?

Since the sensor-enabled expansion of perception lacks the dimension of affect that our embodied sensing is infused with, it is useful to discuss it in relation to a practice that Bruno Latour described as "learning to be affected" (2004). Latour's concept, connoting an unmediated embodied practice, builds on Vinciane Despret's theorization of affecting and affected bodies (Despret 2004). Central to this concept of embodied learning is understanding it as a process where not only one becomes sensitized to a world, but where the world in turn becomes more highly differentiated. "The more you learn, the more differences exist," wrote Latour (2004).

Cyborg bodies, in Haraway's framing, are not just equipped with additional tools but are fundamentally reconfigured by their entanglements with technology. A cyborg's affective capacity —its ability to be transformed by and respond to sensory input—does not arise automatically through the acquisition of new data. Specific practices of perception, and translation of representational media play a role in shaping this capacity. These practices involve not only technical skill but also an ethical and imaginative engagement with the practices of sensing. The affect created in this process is relational—it emerges from the interplay between the human, the environment being sensed, the media technology, and the world being created by this particular representation.

But the question of what it means to be affected by these phenomena through technological mediation remains open and complex. We can speculate around several strains.

Just as our perception is implicitly trained by our culture and education, sensor-equipped bodies are also trained to perceive through iterative, feedback-driven processes. Working with sensors involves trial and error, adjustments to devices and methods, and ongoing reflection on the outcomes. This labor of tuning and refining creates an intimate relationship between the perceiver and the sensing apparatus, fostering an embodied awareness of the sensor's affordances and limitations. This transforms bodies, bodily practices and awareness.

Sensors' data must be translated into forms that can be perceived and interpreted, such as visual graphs or audible playback. This translation process often invites an active engagement with the material being sensed, requiring the operator to listen, look, or interpret in ways that exceed passive observation. For example, sensors allow humans to "hear" rat giggles in bio-artist Kathy Hight work, fostering a visceral and embodied connection to the animal's lifeworld.

Foregrounding situated and relational aspects of sensing puts the attention on the fact that the affect created through sensors is shaped by the specific context in which the sensing occurs. A soil probe measuring carbon levels in an agroecological field is embedded in a web of relations: the farmer's practices, the microbial community, the sensor's calibration, and the larger climate narrative. Attending to these situated relations creates opportunities for an ethical, reciprocal engagement with the environment being monitored.

Finally, as sensors extend perception into realms that are not directly accessible to human senses, this opens up speculative possibilities for imagining more-than-human worlds. For instance, the ability to detect microbial exchanges in soil invites not only scientific inquiry but also poetic and imaginative engagements. What does it mean to "hear" the soil's microbial activity or "see" atmospheric aerosols as ecological agents? These speculative practices foster a kind of affect that is generative, creating new possibilities for relationality and care.

Haraway's notion of the cyborg invites us to embrace the hybridity and complexity of technologically mediated perception, while Latour's concept of learning-to-be-affected challenges us to cultivate embodied, situated practices of attention. Together, these frameworks offer a way to think about environmental sensing technologies as more than tools for data collection—they become instruments for fostering relationality, care, and speculative world-making. By approaching sensors as extensions of techno-ecological assemblages, we can explore how they create new possibilities for affective engagement with more-than-human worlds, opening pathways for learning that are reciprocal, situated, and transformative.

At their best, environmental sensing technologies can therefore serve as platforms for what Simpson describes as "land as pedagogy," enabling situated, land-based learning that respects the more-than-human agency. By revealing localized and culturally specific environmental entanglements, these tools can challenge universalizing frameworks and foster reciprocal relations with the natural world.

However, achieving this potential requires a critical engagement with the socio-technical systems that shape how data is collected, interpreted, and acted upon. Rather than positioning sensors as neutral mediators, we must consider how they co-construct material realities and social imaginaries. This involves attending to the specificities of their design and use, as well as the broader contexts in which they operate. By foregrounding practices of care and relationality, environmental media can support not only the documentation of biodiversity but also the cultivation of ethical and reciprocal practices of world-making.

In the spirit of "land as pedagogy," the *Mitwelten* project seeks to transform environmental sensing into a practice of learning and care. By embracing the partiality and situatedness of knowledge, it aims to foster new ways of engaging with the natural world—ways that honor the complexities and entanglements of life on a post-natural planet. Through this approach, the project invites us to reimagine what it means to sense, learn, and live within the more-than-human ecologies that sustain us.

Chapter 7 *Mitwelten* Design Interventions

Jan Torpus, Olivia Höhener, Christoph Küffer

7.1 Introduction

Olivia Höhener, Jan Torpus

Different networking strategies with non-human neighbors and the promotion of biodiversity are at the center of all presented concepts, developments and experiments and require a **post-anthropocentric worldview**. In peri-urban recreation areas, architecture and infrastructure should begin to **prioritize the ecological common good**, the promotion of biodiversity and the regeneration of global resources over human demands for comfort and luxury. They should turn away from the colonizing model of spatial zoning that separates regulated cultural and protected spaces from wild natural spaces and weather conditions. Urban districts characterized by concrete and car traffic, interspersed with green spaces and parks, should form resilient ecosystems with high biodiversity and quality of life for responsibly acting human communities.

The presented **practice-based investigations, experimental arrangements, design concepts**, and reflective observations are brought together to propose an integrative media-ecological design approach. They serve the overarching goal of developing new design strategies that contribute to a post-anthropocentric paradigm shift in terms of the sustainable preservation and promotion of biodiversity and the **overcoming of the underlying nature-culture dichotomy**. The interdisciplinary approach and the underlying cultural studies epistemology of the research project necessitate a variety of perspectives, methods and media presentation formats for the quantitative and qualitative data, analyses, drafts and findings generated.

While in chapter 4 we focused on technical infrastructures and the potential of sensor-actuator systems, in chapter 5 we describe **field studies and design interventions based on those electronic infrastructures**. The chapter is subdivided in four subchapters: In Citizen Science based Ecosystem Studies we describe the goals, interdisciplinary strategies, and findings of studies carried out in three peri-urban Field Study Sites. In Media Applications, we present four different media interfaces that were designed for the dissemination of the collected research data and findings and to make the local communities aware of the surrounding biodiversity. In Interspecies Platforms we describe educational design units and public space design proposals for the promotion of more-than-human cohabitation and in the final subchapter Participatory Installations, we introduce artistic media formats that were developed to raise awareness of parallel life forms and to engage local visitors with ecological processes.

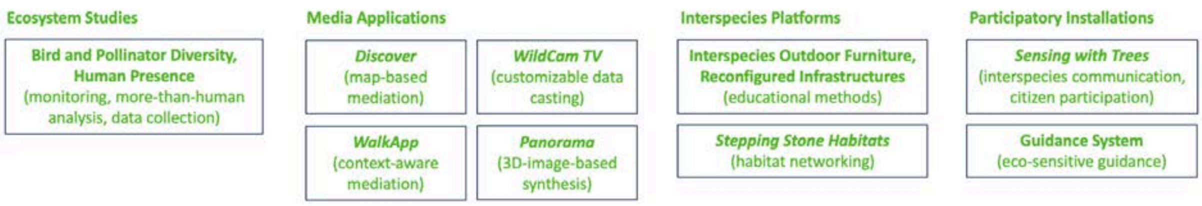


Fig. 25: Infographic on the design media developed in the *Mitwelten* project.

An introduction to the Citizen Science approach

In the ***Mitwelten* workshop "land as pedagogy"**, Olivia Höhener talked about the work of Citizen Science Zurich, an initiative of the University of Zurich and ETH Zurich, supported by the Mercator Foundation Switzerland. The centre's mission is to inspire and support people to engage in different forms of participatory research, to increase participation of citizens in academia, and to enable an effective collaboration between science and society. She presented the centre's services – ranging from consultations, practical project support and digital tools to educational offers – and gave insights into the different types of Citizen Science (CS), the people engaging in it and the power imbalances between the different actors involved in CS.

Citizen Science is a form of public participation in research that works across many disciplines and that comes with different flavours and names, including community-based research, crowd-sourced data collection, civic science, and more. Some definitions acknowledge the fact that a lot of people with an academic background participate in CS projects: "[Citizen Science] describes the participation of people in scientific processes who are not institutionally bound to this field of science. This participation can range from the short-term collection of data to the intensive use of free time to delve into a research topic together with scientists and/or other volunteers." (Bonn, A. 2016). Other sources, such as the Oxford English Dictionary, keep it simpler with definitions such as "scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions." (Oxford English Dictionary)

For **Citizen Science Zurich**, there is an emphasis on scientific research in order to clearly differentiate between other participatory projects in general. CS projects seek to generate new knowledge, include engagement of participants in different steps of the research process and are mutually beneficial for both academic and CS. With a focus on the latter, they are explicitly different from somewhat "extractive" forms of scientific research involving the public, where participants are passive, do not engage in research work and are often the subject of research.

There is a widely agreed on differentiation between three levels of participation of CS in research projects (see infographic below).

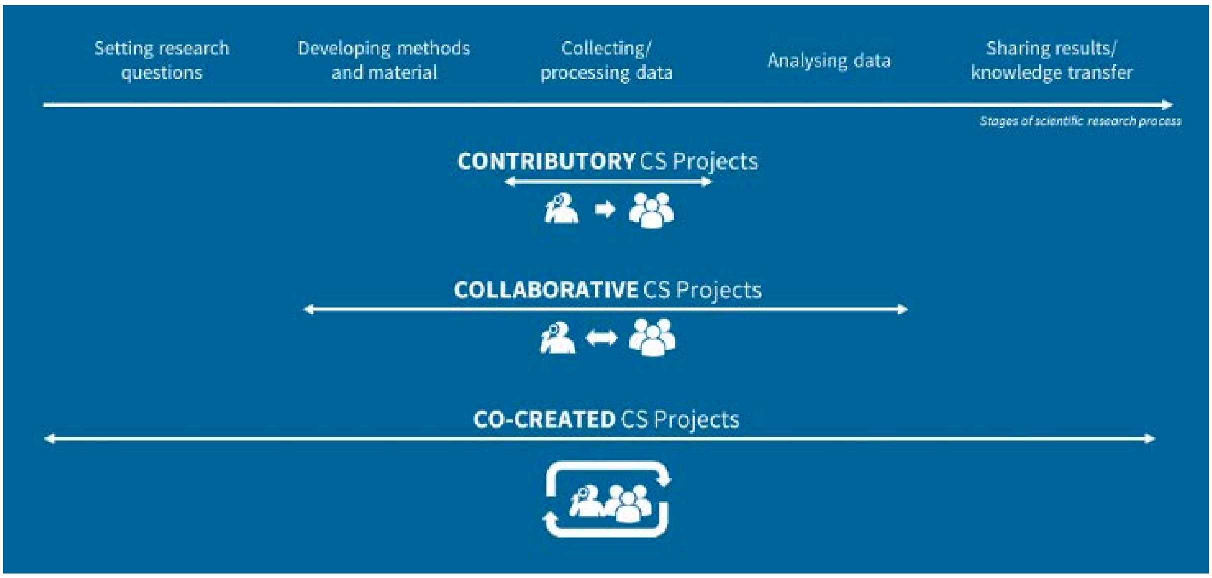


Fig. 26: Overview over three levels of participation in CS projects, Citizen Science Zurich

While Citizen Science Zurich specifically aims at the promotion of co-created CS, it is important to emphasise that all levels of participation have their advantages as well as their challenges. While "contributory CS projects", in which citizens usually participate in data collection and processing, are occasionally frowned upon as being somewhat exploitative of citizen's free labour, their upside is that they often have a much lower threshold to participate and therefore address a bigger general public. It is also important to keep in mind that not all individuals wish to be deeply involved in co-creation or take on responsibilities, nor do they feel they have the time for it.

Collaborative projects – in the centre, so to speak – also involve participants in the development of methods or materials as well as in data analysis, while "co-created CS projects" enable citizens to get involved in all steps of the research process. This includes project planning and design (definition of the research question, development of hypotheses, determination of research methods, planning of the implementation), project implementation (data gathering, data processing, data analysis as well as interpretation), publishing and the implementation of the results. In addition, citizens can also be involved in the critical reflection of the process, the evaluation of the project or take on project management responsibilities.

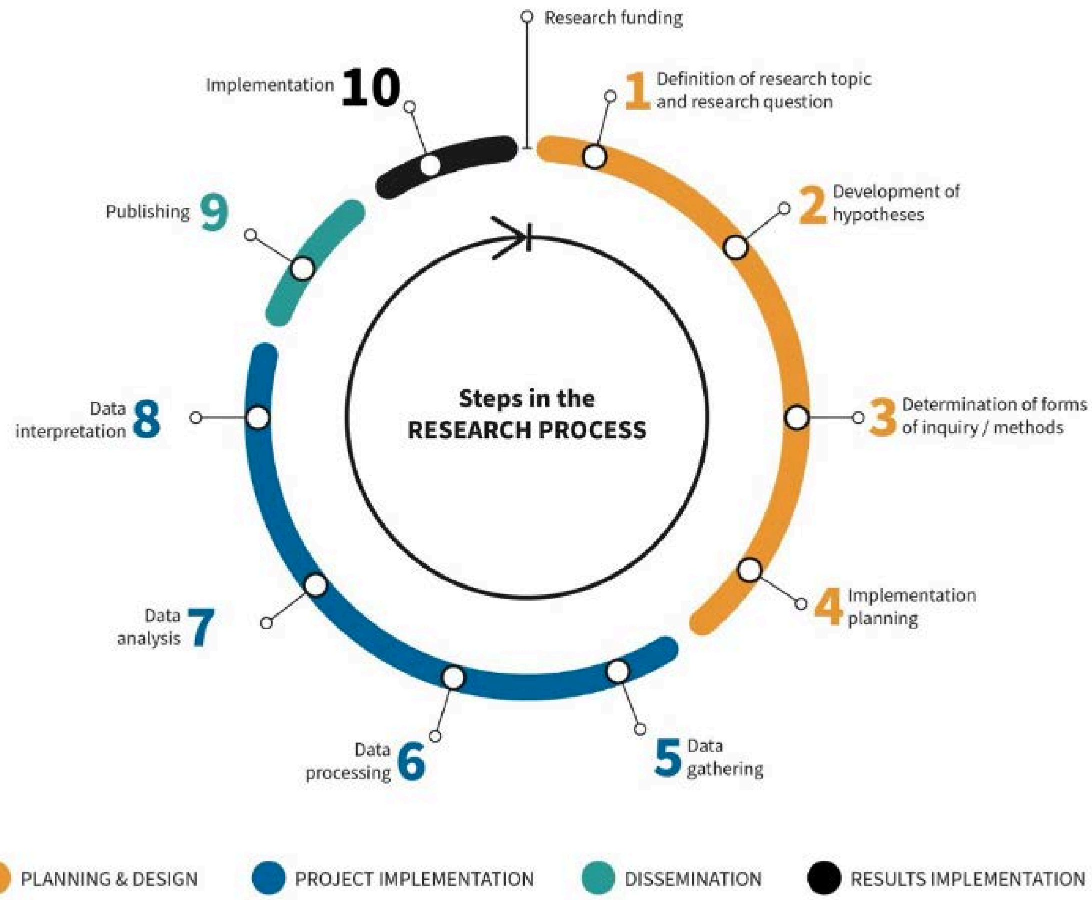


Fig. 27: Steps in an exemplary research process, Citizen Science Zurich

All three types of CS projects contribute to the production of new knowledge and depend on the involvement of participants from outside academia.

Citizen Science presents itself as an opportunity to soften the artificially drawn boundaries between science and society. It allows researchers to work together with civil society stakeholders in a holistic and sustainable approach and to contribute to solving pressing social challenges. Therefore, according to (Eitzel et al. 2017, 4) *"[...] attention to the terminology we use is an important part of effective* *practice. Because Citizen science is a form of knowledge production, citizen science terminology has the power to allow some peoples' knowledge to be included and the knowledge of others to be excluded."*

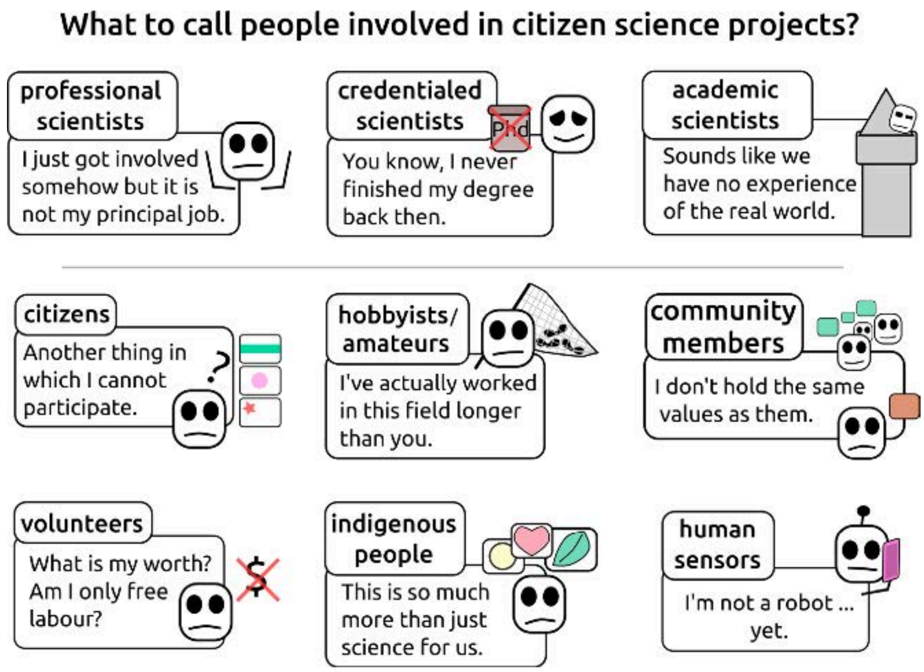


Fig. 28: Graphic by Eitzel et al., Citizen Science Terminology Matters: Exploring Key Terms. Citizen Science: Theory and Practice, 2(1): 1, pp. 4.

In the upper third of figure 28, we find the professional scientists. Their credentials seem to go hand in hand with a certain distance to the real world with its real problems and are only seemingly superior. The bottom two-thirds are amateurs, volunteers who want to do something good, or indigenous people and locals. The volunteers are frustrated because they feel they are being used as cheap labour for simple tasks without gaining any insight into the more complex processes and research objectives. The amateurs are frustrated that their (sometimes more extensive) experience is excluded from the scientific community and the scientific debate. And indigenous people as well as local communities are frustrated when academia ignores the fact that local challenges are not only a topic for research, but are actually about living and surviving under certain circumstances. In addition, terms such as 'citizen' or 'community' seem to exclude rather than include.

In reality, the distinction between academics and citizens is also not that simple, since academics are always also citizens, and the majority of people participating in CS projects has started or completed an academic education.

While figure 28 above highlights negative interpretations that Eitzel et al. encountered in commonly used names to describe people participating in CS, the impact of terminology goes even deeper: Not only does it influence the way participants are treated and valued, but also how they see themselves and the value of their participation in the research project. The terminology used and its value for the ones represented by it is in direct relation to the worth of their knowledge for academia.

Academia commonly distinguishes between two different kinds of actors: the academic "experts by training", who are paid for their work and publish peer-reviewed findings to get an "official stamp of approval" for their work, and the "experts by experience", who are involved in scientific research, but are unable to publish their findings and get recognition and approval. As a consequence, "training" generally seems to have more value than “experience”. This power imbalance also means that “experts by experience” usually don’t receive support from organisations or peers, don’t define research objectives, don’t receive funding or become a representative of the results. How can we challenge those notions and maybe even level the field?

Citizen Science has great potential to address those power imbalances by

- Allowing the co-creation of research projects and research agendas
- Allowing an equal representation of academic and civil society actors
- Giving access to resources (not only to funding, but also to research infrastructure)
- Enabling and promoting an equal dialogue between different approaches
- Refraining from hierarchical judgement of experiences
- Using low-threshold, non-scientific methods (such as artistic practices)
- Connecting participants, not only academic researchers
- Transferring knowledge into all communities
- Defining and measuring project success together

This means that expertise from outside of academia has to be brought in sooner, at the very beginning of the research process, not only towards the end of a project for validation and implementation.

Through the combination of professional research expertise with lived experience of individuals, CS can create the most robust and dynamic research questions, research processes and research products, including the validation of specific indicators, improved data quality, policy recommendations, improved scientific literacy and understanding of scientific methods, while at the same time creating communities of practice, increasing awareness or interest in (local) conservation initiatives, empowerment of communities to tackle (local) challenges to name but a few.

Citizen Science in the Mitwelten project

The interdisciplinary development process is one of the key strategies of the *Mitwelten* project and helped to examine the possible involvement of CS throughout the entire development process: from the construction of the IoT Toolkit and the necessary Software Environment, to the outdoor Citizen Science based Ecosystem Studies, the collection, validation and interpretation of the collected data and the final presentation of the data and findings to the public. As part of the research project, we only occasionally worked **with external citizen scientists, but within the interdisciplinary team we were able to test when disciplinary expertise was required and when lay people could take over**. The infographic (Fig 29) shows this development process, distinguishing between technology-focused tools and developments (blue), eco-design-focused processes (green) and the citizen science-expert collaboration process (red).

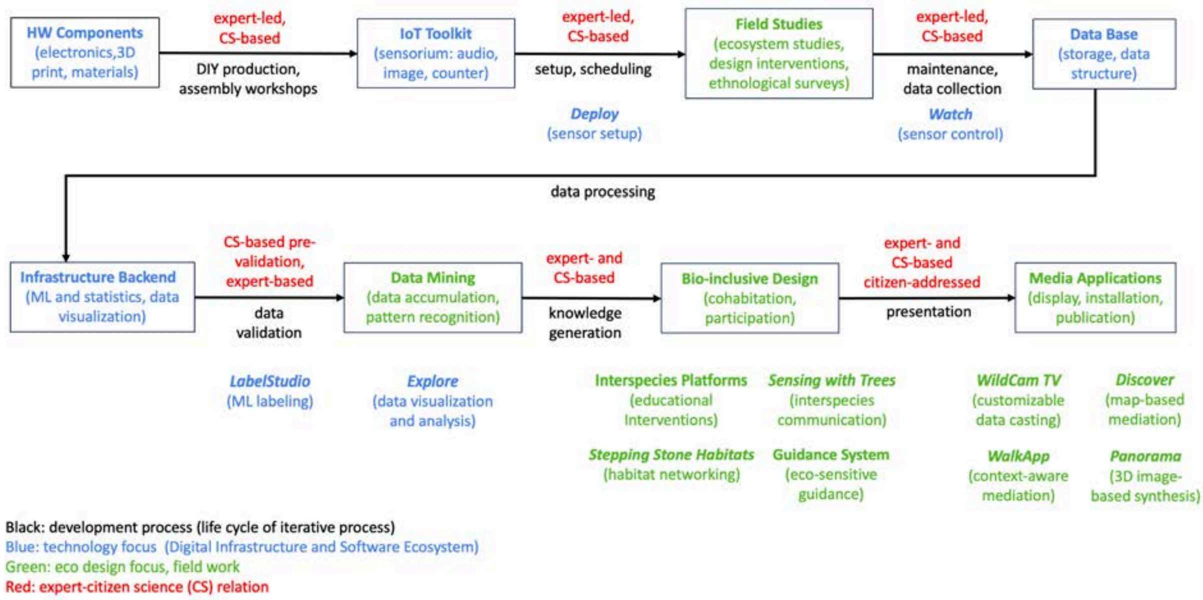


Fig. 29: Shows the entire development process of the *Mitwelten* approach and the verified CS contributions along the way.

7.2 Citizen Science based Ecosystem Studies

Jan Torpus, Christoph Küffer

Natural science principles

One research approach in the *Mitwelten* project was based on natural science principles. By prototyping ways to document the presence of species at the three field studies, we wanted to demonstrate how do-it-yourself tools can be used to **gain insight into the biodiversity in different urban habitats**. We focused on two indicator groups: five types of morphospecies of pollinating insects (Pollinator Diversity) and bird species (Bird Diversity). Human Presence was also monitored, as humans are an integral part of urban ecosystems. By using the same standardized measurement system along a gradient from urban to peri-urban habitats, we were able to compare species composition across sites.

We were in particular interested in collaborations between experts and citizen scientists for the joint development and use of environmental sensors and machine learning (ML) to support citizen science (CS)[37].

The experiments for the three investigations were designed in the interdisciplinary team and the Field Sensor Systems were developed to best answer ecological questions and minimize data management efforts. The **design and implementation of the sensor systems** were carried out by biological and technical experts. During the field work, however, non-experts of the interdisciplinary team and external environmentalists, rangers and design students were involved. They all used our Deploy software for sensor setup and registration in the field and our Monitor software for online control of

[37] We described the three studies and findings in the Reinacher Heide in one of our publications “Sensor-Toolkits für das Naturschutz-Monitoring. Wie ist ein Einbezug der Bevölkerung möglich?” (Torpus et al. 2025) (“Sensor toolkits for nature conservation monitoring. How can the local population be involved?”)The paper is aimed at the communities of nature conservation organizations and rangers and deals specifically with the issues raised by our partner the Reinacher Heide Commission.

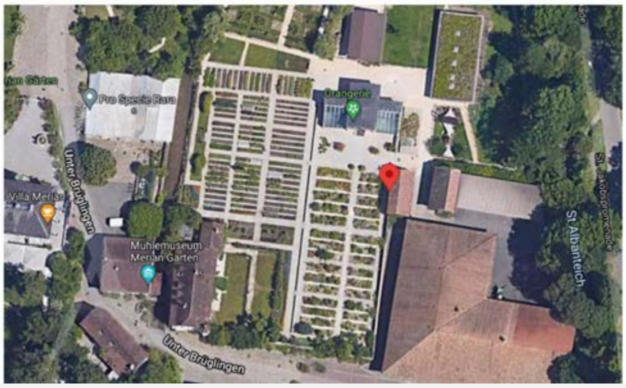
the data streams and battery levels. They also swapped batteries and SD cards, replaced faulty sensor nodes, took care of the flowers in the pollinator installations and the like. Based on this field experience, the software environments and hardware components were continuously improved for use for CS. Missing features were added, tasks that were unsuitable for field work were eliminated and the interfaces were optimized for laypersons. Since we worked with different power supply and data acquisition systems, we were able to make comparisons. Batteries and SD cards had to be replaced at approximately 10-day intervals. Charging the batteries and uploading data to the servers was also very time-consuming and led to data loss. We therefore came to the conclusion that solar panels and online data transmission should be used whenever possible. However, extensive data transfer via the LoRaWan network has a low bandwidth, which is why large amounts of data cannot be transported with it. Data analysis in situ via Edge Computing should therefore be considered. Installing sufficiently powerful solar panels is also a valuable option, but could not be used in some experiments due to the low solar radiation in dense vegetation and in the winter months.

7.2.1 Bird Diversity

ID: 1874-8542

Position: «Garten», 47°32'06.5"N 7°36'52.8"E

47.535135, 7.614674



Meta: Bird identification based on extensive sound recordings and ML evaluations. 2021-2023.

Research question: *"How can bird species in different habitat types be identified and compared using audio logger recordings and open source ML models?"*

Examination approaches:

- Development of a data pipeline for the storage and analysis of large amounts of audio data.
- Collaboration with citizen scientists on monitoring and validation tasks.
- ML-identification of bird species in different habitat types.
- Characterization of soundscapes in different habitat types.

Situation and objective

We recorded the singing activity of birds at different locations representing different habitat types per field study site with the Field Sensor System (5.5.1 Audio Recording and Analysis). The Bird Diversity study was carried out in all field study sites, and the comparisons across sites are documented in detail in the scientific paper Bird Diversity in Peri-urban Areas of the City of Basel (Torpus 2025). In this book, we only present the example of the Merian Gardens to **focus on the intersections between machine learning (ML), citizen science (CS) and expert based knowledge for bird species**

identification. We were interested to find out how the integration of ML data and CS expertise can improve the validity of bird song detections and how it can enhance our understanding of the qualities of urban soundscapes.

Investigation approach

We used two different approaches to **compare ML-based bird call interpretations with expert and CS knowledge**. On the one hand, audio-loggers were installed in five different habitat types – a park, a meadow, a garden, a pasture, and a pond – and maintained by citizen scientists within the interdisciplinary team. The ML-based identification of bird species was validated with existing CS datasets (ornitho[38], GBIF[39]) as well as CS knowledge for pre-validations and expert knowledge for final validations (using Label Studio). On the other hand, two expert citizens walked along a transect carrying mobile audio-loggers to compare the identifications of ML and experts. They walked along the five habitats described above (see Fig. 30) and monitored the present bird species in accordance with map-based ornithological standards. The transect study was carried out by Janosh Montandon and the detailed findings are documented separately (2021). For the data interpretations, we selected audio recordings of six weeks (May 9 to June 24, 2021), which includes both last migrants and breeding birds.

In addition to identifying the bird species, we also used the sound recordings to characterise the soundscapes. The method used did not allow the birds to be counted, as the same individual can sing several times in the same location. However, it is possible to make statements about the **acoustic presence of different bird species and their influence on the atmosphere perceived by humans**.

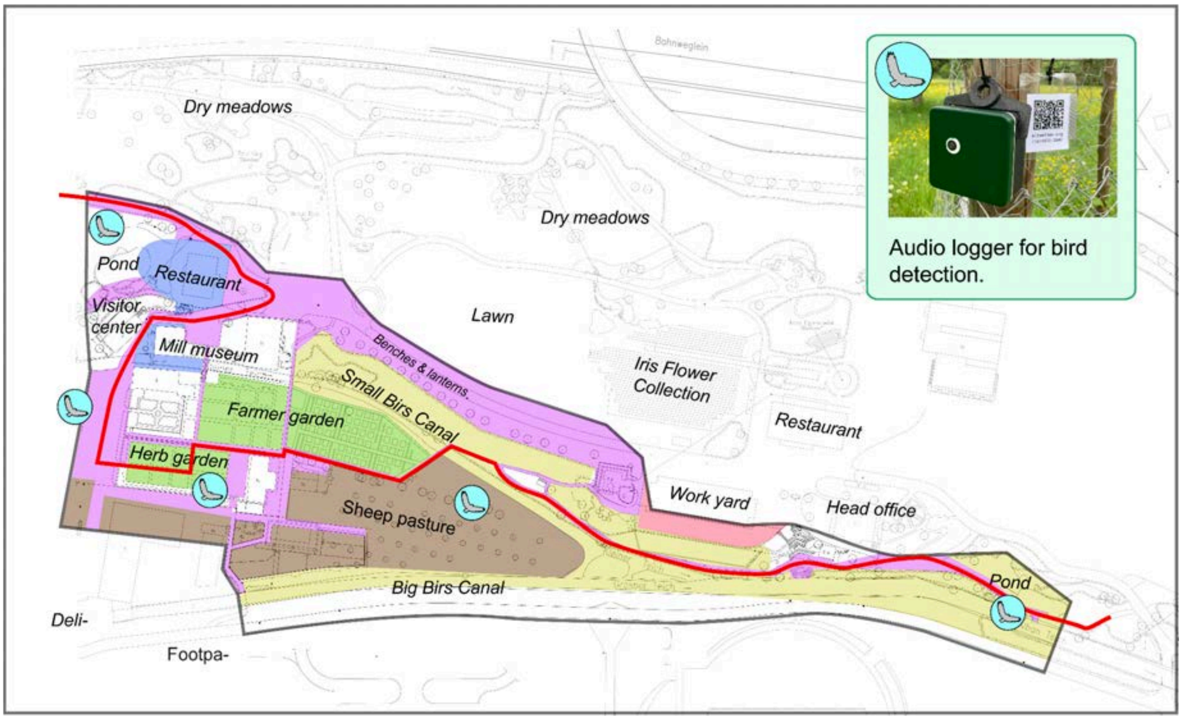


Fig. 30: Map of the Merian Gardens: The light blue icons represent the locations of the stationary audio-loggers. The red line represents the transect along which the experts walked. The colored areas indicate different types of habitats with varying environmental qualities and levels of human presence.

[38] https://www.ornitho.ch
[39] https://www.gbif.org

Findings

The **validation of the stationary bird audio-loggers** has shown that a preselection of questionable determinations can be carried out very well by citizen scientists and that experts only need to be involved in the determination of rare bird species. This is especially true in a urban perimeter environment, where the human presence has a major influence on the soundscape (Krause 2015). We categorized the sounds that led to **wrong bird identifications by ML** into (i) human voices or artifacts (anthropophony), (ii) weather and water sounds (geophony), (iii) other animal classes (e.g. water frog) or bird species (biophony), and (iv) noise. Almost half (49.4%) of the 87 misidentifications were other birds. These were especially longer calls from birds that integrate motifs resembling other species into their song. Birds of the same family or genus were also often confused, e.g. the crow by the hooded crow or the northern nutcracker, or the house sparrow by the Italian sparrow. In addition to bird calls, other animal vocalizations led to misidentifications (1.1%), e.g. black-crowned night-heron by water frog. Since we studied urban and peri-urban environments, human voices also contribute to a significant proportion of misidentifications (23%), especially when recorded from a distance and in the case of short and less melodious calls: little bittern (misidentified due to human voices), crane (sporting activity), hoopoe (laughing woman), barn owl, black-headed gull or curlew (screeching children). Also, human artifacts such as motors or mechanical devices lead to misidentifications (16%), with monotone repetitive or screeching bird calls usually being misidentified: shelduck (tractor engine), turtle dove (propeller plane), red-throated diver (car horn), skylark (sprinkler system), or barn owl (construction machine). Sounds of anthropogenic origin (anthropophony), thus accounts for 39% of misinterpretations, the weather (geophony) for 3.5% and noise for 5.8%. We found a gradient of increasing dissimilarity from bird song to other animal sounds, human voices and artificial noises.

For the **validation based on the transect data**, the ornithologists' statements were considered to be correct and possible errors on their part were not taken into account. The BirdNET (see 5.5.1 Audio Recording and Data Analysis) model identified an average of 35% of the birds detected by the ornithologists. The ornithologists were able to verify 84.3% of the birds detected by BirdNET and in some cases found additional species that had escaped them. Thus, BirdNET recognized the detected bird species with high accuracy but missed many species; especially birds at a great distance from the recording device. Other causes for errors were: interference of worn microphone with clothing, footsteps, anthropogenic environmental noises (voices, machines), and multiple bird calls recorded at the same time. Of the 87 misidentifications, 70 could be verified by citizen scientists without expert support (80.5%).

Our stationary bird audio-loggers allowed us to **compare the bird song soundscapes of the five habitat types** in the urban gardens. After the exclusion of incorrectly identified bird species, we confirmed the presence-absence of 76 species in total across the five habitats. Soundscapes contrasted strongly between habitats and varied during the day. The highest number of species was found at the pond (81.6% of all recorded species), followed by pasture (68.4%), park (65.8%), meadow (54%) and garden (30.3%).

We were also interested in characterizing the varying **soundscape characteristics** along a typical citizen’s walk in the park and the possibilities of application of ML to enhance the everyday soundscape experience of citizens. Being able to name bird species can connect citizens to nature and promote higher positive health effects (Cox and Gaston 2015). The soundscape at the garden was dominated by the charismatic and forceful songs of some birds during certain daytimes, e.g. the melodious songs of blackbirds, groups of swifts circling in the air, and European serin. The presence of species, such as the black redstart or house sparrow, was enabled through nesting opportunities in the old buildings and artificial nesting sites at the surrounding buildings (common swift, common house martin, great tit or common kestrel). This shows that the promotion of common species in an urban environment is not only beneficial for the well-being of local residents, but also has an impact on local biodiversity. Some songs at the site were less conspicuous, but knowing the bird's identity generates a richer natural experience (e.g. grey wagtail, common wood pigeon, treecreeper, green woodpecker, long-tailed tit). At the pond near the canal, a completely different concert could be heard, with several charismatic singers: robins, blackcaps, goldfinches, wrens. In addition, there were sounds present that are typical for this particular aquatic habitat, creating a context-specific atmosphere: reed warbler and common moorhen in concert with frogs. Overall, the pond location illustrates that even in an urban park setting and at a small spatial scale it is possible to create and maintain a rich and unique bird soundscape; and ML tools can help citizens to appreciate it.

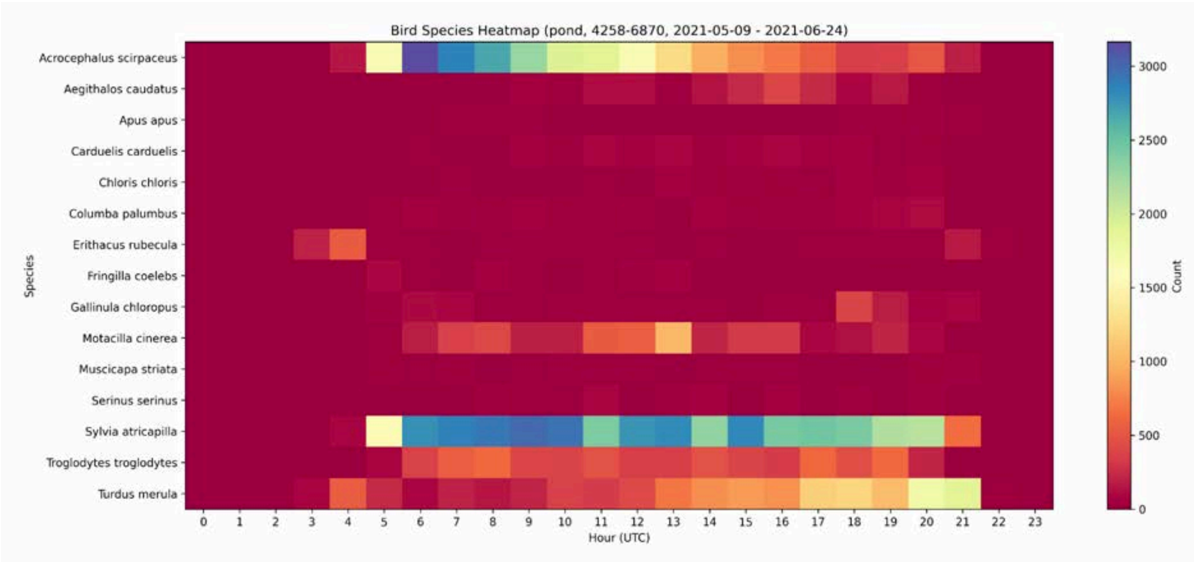


Fig. 31: Graphic representation of the 15 most present bird species at the "pond" site, with the singing activity displayed over time.

7.2.2 Pollinator Diversity

Meta: Determining pollinating insects using ML analysis of large photo datasets. 2021-2023.
Research question: *“How can pollinating insects be identified by ML analysis of large numbers of photos of blossoms taken at regular intervals?”*
Examination approaches: - Development of a phytometer experimental setup. - ML-identification of five insect morphospecies. - Collaboration with citizen scientists on assembly, monitoring and validation.

Situation and objective

Similar to the Bird Diversity study, we analyzed the three Field Study Sites and defined locations of interest according to different habitat types for the local pollinator communities. In accordance with entomological standards, we decided to **take pictures of the insects on flower heads** and therefore used the Field Sensor System (5.5.2 Image Recording and Analysis) to determine different morphospecies. To reduce complexity, in this document we will only present exemplary results from the Dreispitz area and focus on the interdisciplinary processes and the potential for CS.

Investigation approach

The monitoring of rare ecological events is a major challenge in field observation of ecological systems (Edwards Jr. 2005), and technological means are therefore welcome. In our approach **potted plants attracted pollinators** within a chosen habitat to the observation system where the pollinator installations automatically took pictures from 10 am to 4 pm for several months. The infrastructure was designed in an interdisciplinary team process and assembled in several assisted interdisciplinary workshops, in which external participants were also involved. In advance, the technical team developed the hardware from initial circuit diagrams to final plastic fittings, and tested prototypes in order to create complete assembly kits for non-technicians to assemble. More complex processes such as soldering or working with 3D printers were also included, so that non-technicians could literally get to grips with the technology. The installations were maintained by citizen scientists (CS) within the interdisciplinary team.

Fig. 32: *Left*: Map view of the pollinator setups in the Dreispitz area. *Middle*: Pollinator setups on the roof of a bicycle stand (blue markers). *Right*: Pollinator setups placed in a courtyard (red markers).

From May 1 to September 30, 2022, we placed two clusters of image-based pollinator installations in two different habitat types in the Dreispitz area: in a shady courtyard and on the roof of the bicycle stand. During that time span, the eight cameras took a total of 1 million photos. In order to identify pollinating insects in these images, we used our **ML object detection model** (5.5.2 Image Recording and Analysis) to classify **five morphospecies categories** (groups of taxa that are easily identified in the field, e.g. Albrecht et al. 2007): **honey bee, (solitary) wild bee, bumblebee, hoverfly, and fly.**

Thereafter CS checked random sets of pollinator images for false positives, by excluding obvious errors such as easily distinguishable insects (beetles, wasps, ants, etc.), gravel stones, buds, or other similar-looking objects. Finally, the investigation of only a small number of images required the help of expert entomologists.

Findings

With our approach we **gained insights into designing outdoor biological monitoring infrastructures** by means of machine learning and in collaboration with CS.

Firstly, we noticed that the implementation of our object detection model in a real-world field setting required expertise, experience and close interactions between specialists and practitioners. The performance depended on a wide range of factors such as the choice of the right plant species (flower head forming a contrast to the insects), the state of the plants (living organisms develop unpredictably), the materiality of pots and other mounting devices, the positioning of the flower pots (insect-dissimilar surface around the pot), and the image resolution and focus of the camera.

Secondly, we can confirm that the assembly of the electronic components as well as the maintenance (battery change, watering of plants, etc.) could be managed by assisted CS without an engineering background. Involvement in the assembly of the technology also helped non-technicians to better handle subsequent field work and maintenance. It is, however, important that the benefit is two-way: that CS not only contribute to science with their cheap labor, but that scientists also impart knowledge to CS and involve them in the knowledge generation process. The joint effort establishes a basis for open research: transparency and accountability in algorithm development through the use of open-source software, shared protocols, and interoperable data formats. It serves to democratize science by engaging diverse communities and fostering a deeper connection between people and their natural environment. As Voigt-Heucke, Müller, and Rostin (2023) point out, this is a promising avenue for improving the positive impact of CS projects on urban biodiversity monitoring.

Thirdly, we had to realize that the object recognition model provided a significant number of false positives, which were identified in a pre-validation by CS and a final validation by entomology experts. Due to the unreliability of the results, they will not be published, but note that the labeling of the images will be used for further training of the ML model and should lead to better results. At present, a CS, do-it-yourself approach with limited resources cannot yet quite reach the reliability of the state-of-the-art in the field (Bjerge, Mann, and Høye 2022; Li et al. 2021; Høye et al. 2021). Also, conceptually and as a proof of concept the applied process of using potted flowers as insect attractants, an image pipeline with automated ML analysis and the collaboration of CS and experienced entomologists seemed to work. It enables the close collaboration of experts and lay people and the cost-effective monitoring of a rare natural phenomenon: the presence of widely dispersed pollinators in an urbanized landscape.

7.2.3 Human Presence

Meta: Human presence identification in recreational areas and nature reserves. 2021-2023.

Research question: "How can human presence be identified in local recreation areas and nature reserves?"

Examination approaches:

- Development of a PAX counter-based device and investigation grid.
- Collaboration with rangers on monitoring and validation.
- Analysis of human guidance measures in nature reserves.

Situation and objective

In addition to the biological monitoring sampling of birds and insects, we wanted to capture humans in an equivalent way. In the case of humans, privacy and data protection laws come into play, while there are no such requirements for other habitat actors. To **determine the presence of people at certain places and times and to investigate their possible influence on the ecosystem**, PAX counters were used in all three field studies (5.5.3 Mobile Phone Counting). However, they were used most extensively in the Reinacher Heide, where they were supplemented by visitor surveys and expert interviews (Torpus et al. 2025). The aim of our project partner Heide Commission (nature conservation commission of the Reinacher Heide), was to find out which places were most frequented, how many people were near vulnerable conservation sites, if the new bathing area outside the nature reserve relieved an unofficial bathing area within the nature reserve, and if visitor management measures (barriers, prohibition signs) were effective.

Investigation approach

To answer the above questions, we designed a network of PAX counters together with the Heide Commission and the park rangers. We held assembly workshops with the park rangers and the devices were maintained by CS within the interdisciplinary team. The **solar-powered devices counted the presence of people carrying mobile media** and the sum of the detected Bluetooth addresses within defined time windows (buckets) was sent to the database via a LoRaWAN network. For data protection reasons, the Bluetooth addresses were not identified. For the evaluation we chose a set of 12 PAX counters between July 18 and October 17, 2023, using the project's Explore software. The Pax counts were compared by the CS with counts of visually observed visitors during the same time windows.

Findings

The PAX sensors counted between 6,017 and 110,452 detections of people with cell phones, or similar mobile devices. This corresponds to between 64 and 1200 detections per day. The PAX counter detections **confirmed the hotspots of visitor presence: during the observed summary-autumnal period**, the frontrunners were the two recently launched bathing areas (New Bath South: 92,013 and New Bath North: 52,368, total: 144,381) near the nature reserve and the transit route used by bicycles (Bridge Crossing: 110,452) at the nature reserve and adventure pond. This access to the river outside the nature reserve was used four times as often as the access within the nature reserve (Heide Bath: 35,407), which indicates that the new bathing area has a relieving influence on the nature reserve. By contrast, the counts revealed that ecologically sensitive areas, such as the kingfisher breeding wall (Kingfisher North: 6,017 and Kingfisher South: 7,335) continued to be regularly visited by a relatively small number of people despite barriers and prohibition signs. The sensitive, but publicly accessible Beaver Trail (14,763) was also unexpectedly often walked compared to the parallel main axis (Heide South: 24’580) (ratio 3/5).

It has to be noted, however, that the number of people present does not necessarily correspond to the number of visiting individuals, as people are counted more than once if they stay longer than one counting time window lasts. The **figures therefore only represent the density of people present per time unit and not the number of visitors**. To make it more difficult to track down cell phones, some telecommunications providers also dynamically assign new Bluetooth addresses from time to time, which leads to additional detections. Since the same errors were calculated for all locations, they could be put in relation to each other, but the system cannot be used to count visitors in places where people linger. The solar-powered Pax counters proved to be low-maintenance, but like all other devices, they could no longer be used in the colder months of the year because of the internal batteries that get charged by the sun. Although we posted signs in the study area informing people about the investigations, we did not receive any critical reactions or queries from visitors of the Reinacher Heide.

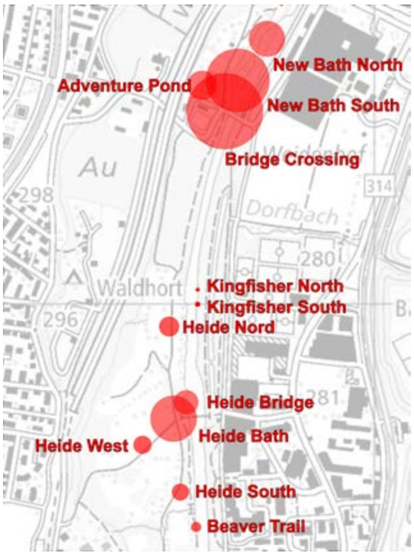


Fig. 33: *Left*: Visualization of the distribution of the detections at the 12 locations in and near the Reinacher Heide nature reserve. *Right*: The newly opened bathing area (New Bath North/South) outside the nature reserve gives residents the opportunity to enjoy nature in a considerate way, thereby reducing the pressure on the adjacent Reinacher Heide nature reserve.

7.3 Media Applications

Jan Torpus

Introduction

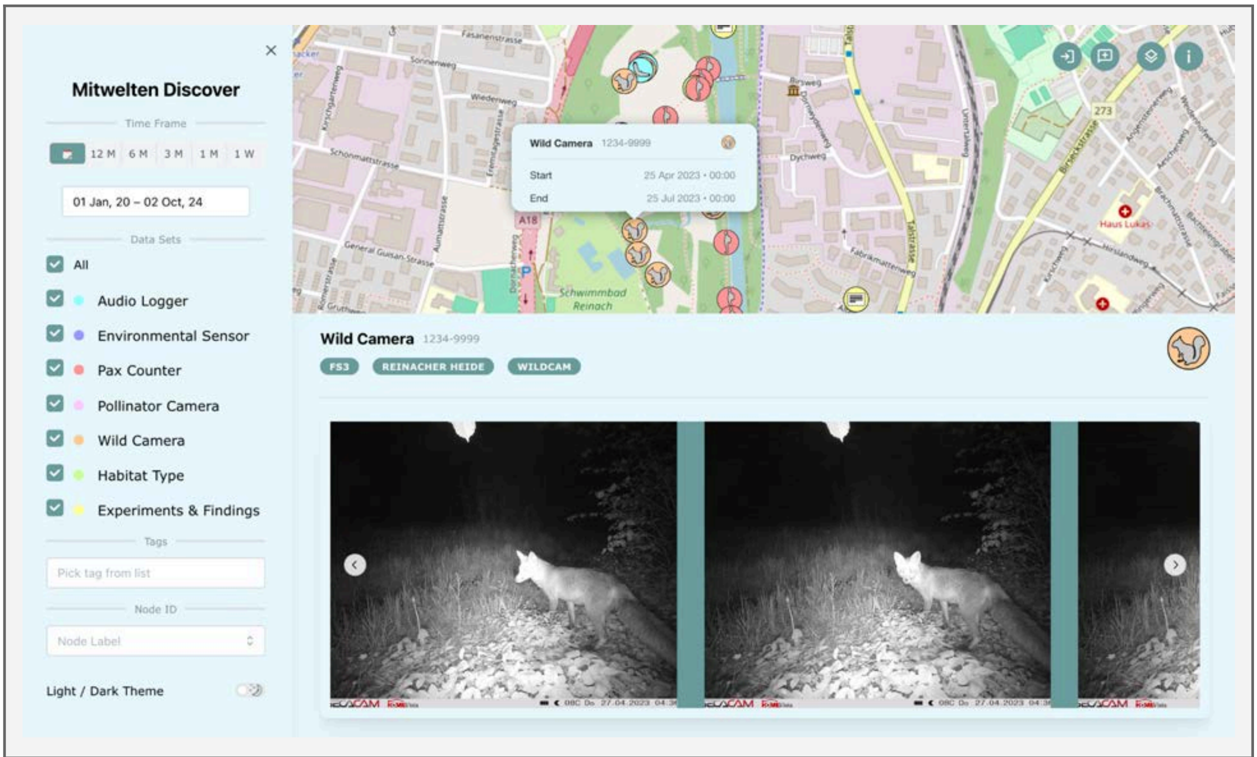
As part of the *Mitwelten* research project, we developed and investigated a set of media formats for communicating information to the general public. The aim was to **make people aware of the locally existing ecosystems and their sometimes unspectacular but indispensable inhabitants to generate a more-than-human environmental understanding**. We are aware that the abstraction, aestheticization and curated visions of complex, messy ecological systems are once again cut for humans and that media implementations are not accessible to other habitat actors. We have, however, decided to develop partly reductive and **playful formats for a more intuitive human access to our findings and to evaluate them in terms of their use for information dissemination and public engagement**. From a technological point of view, it was important that the mediation approaches were based as much as possible on the project's data sets and findings and that they had dynamic access to the research database. In this sense, the media applications are output channels of the IoT toolkit and should be generically applicable for other locations and research projects.

We developed and investigated the following four different media approaches:

- ***Discover***: an atlas-like, map-based information display with selection and filtering functions
- ***WildCam TV***: a cinematic image sequencer
- ***WalkApp***: a GPS-based, context-aware web app
- ***Panorama***: an interactive 3D image-based approach

The developments are not finished products, but fully functional prototypes that we have used to examine different forms of research data integration and processing, and their impact.

7.3.1 *Discover*



Meta: Map-based online information platform for the public. https://discover.mitwelten.org

Research question: "How can research results be presented online in an easy-to-understand way for the general public?"

Examination approaches:
- Map-based online information platform with established selection and filtering tools.
- Mixed methods approach: empirical and qualitative data, multimedia formats.

Situation and ecological challenge

During the *Mitwelten* project, a significant amount of data was collected and analyzed using the Explore application to gain scientific insights. However, the aim was also to prepare the **data and findings for the public and to make them accessible online**.

Media-ecological approach

We decided on an **atlas-based approach**, where the data sets and results can be accessed in graphical visualizations in the geographical context. As part of the interdisciplinary research project, quantitative measurements were carried out with the technical devices, but qualitative surveys such as interviews and questionnaires were also conducted. This **mixed-methods** approach is the basis for the different types of information that are presented here together. The various types of media collected, such as texts, images, sound or video recordings, ensure a rich multimedia experience.

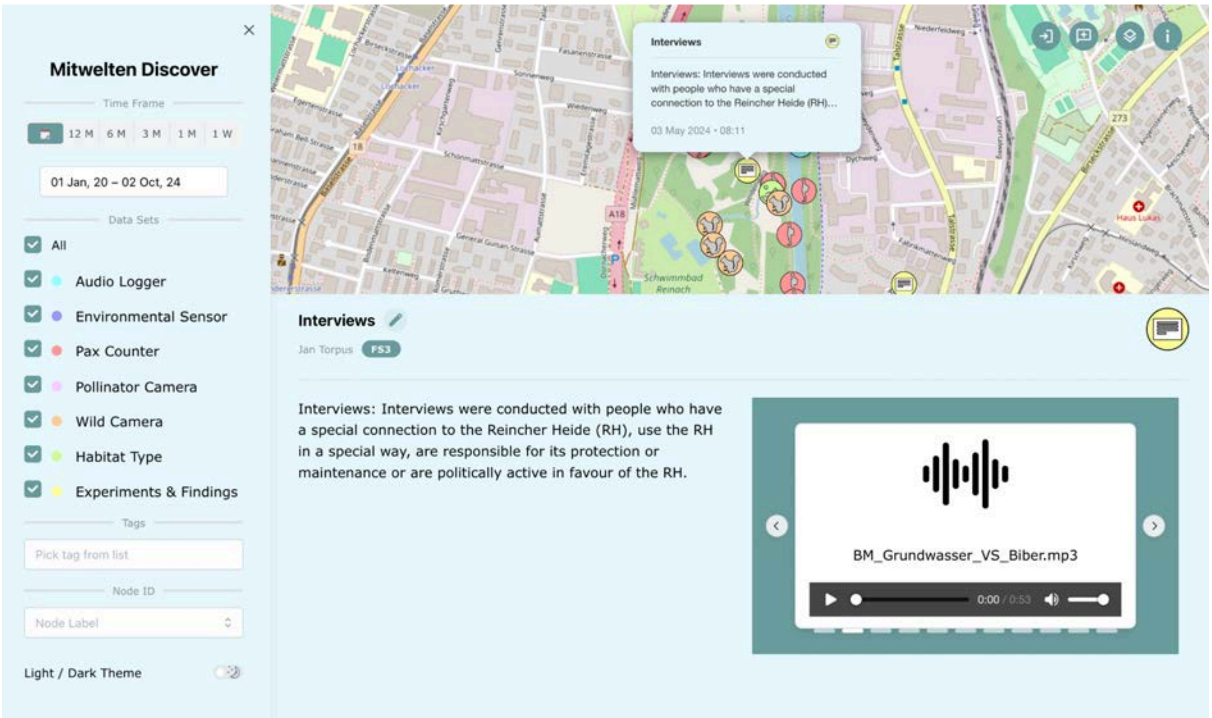


Fig. 34: Screenshot of the *Discover* GUI, with selected expert interviews that were conducted in the Reinacher Heide and are offered for listening.

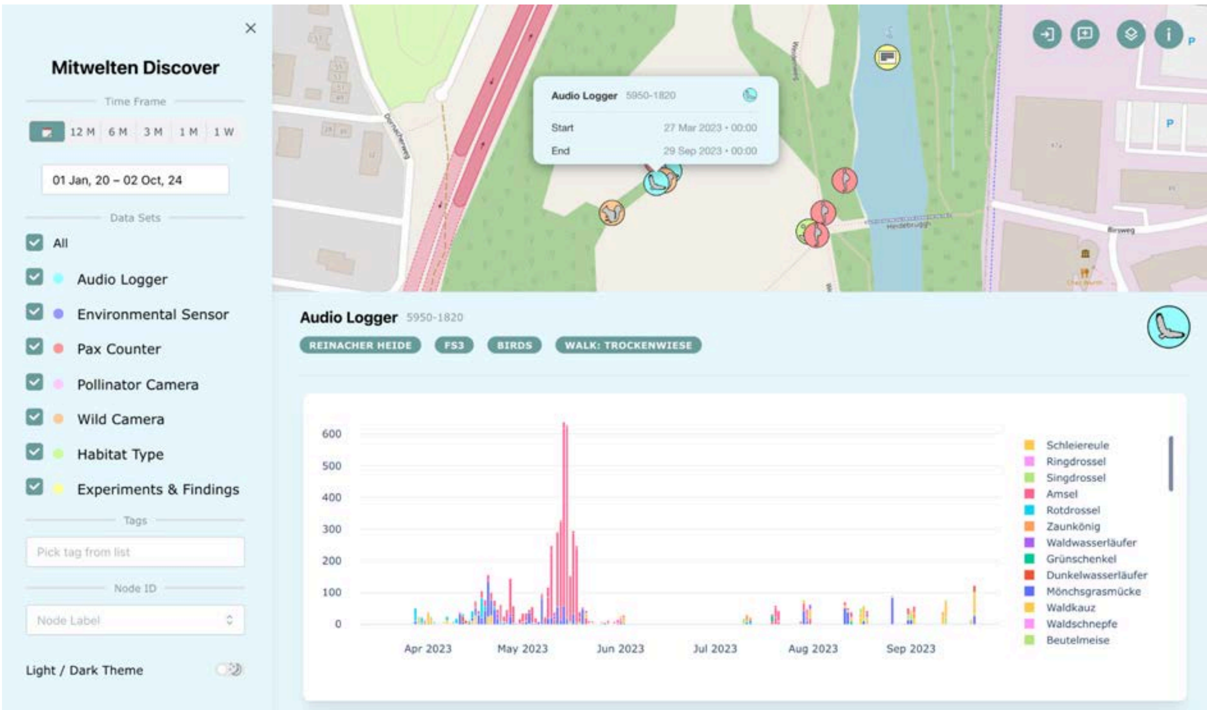


Fig. 35: Screenshot of the *Discover* GUI, with an audio logger selected in the Reinacher Heide. The identified bird species and the frequency of their singing are displayed over time.

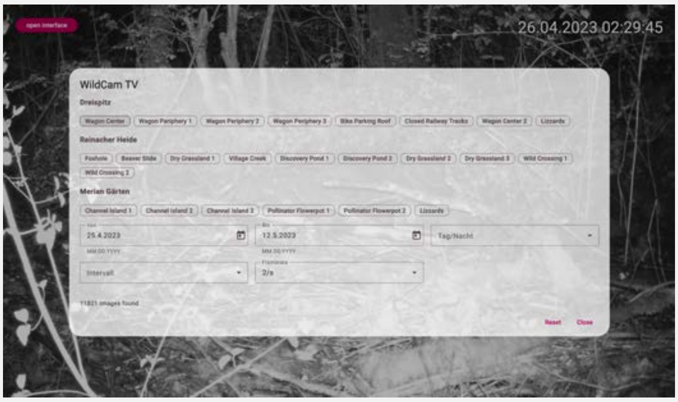
Concept and development

Historic maps first represented political, cultural and religious boundaries of states and illustrations about important historical events and were later also used to depict the earth's surface, vegetation, climate zones, economic use, population density, or similar. Maps became important in connection with religion and imperialism and later became powerful instruments of colonization with Eurocentric worldviews and territorial claims that marginalize indigenous cultures and perspectives. In the *Mitwelten* project we were aware of the critical power of maps, but they were not investigated further. We took advantage of their practical use for localized data visualization and implemented **map-typical categories and iconographies** linked to corresponding information and diagrams of the collected data. The ability to **retrieve digital data from the database in near real time**, and to place it on a map with dashboards for the public to understand is the central approach of the *Discover* app. The developed graphical user interface (GUI) uses functions that are culturally established such as maps for localization, calendar views for selecting the time span, or checkboxes for selecting topics. This classic approach served as a baseline for comparing the potential of artistic and more abstract forms of information transfer.

Findings

The *Discover* app was developed over a long period of time and was optimized through many debugging tests and assessments by the interdisciplinary team. Since the online information platform used an atlas-based approach with **culturally established selection and filter tools**, it was easily understandable for users from different backgrounds. Since the platform was not designed for an exhibition or presentation in a public space, but to receive the full attention of interested visitors, the data was provided objectively and with detailed information and features. The *Discover* and *Explore* apps offered registered users to leave notes and freely describe their findings and observations after exploring the published data sets. However, the feature was hardly used by non-team members and would need to be advertised or explicitly used in team processes. The long-term maintenance of registration functions and comment areas is also costly and was disabled for the archiving of the project. The quantitative **data sets were obtained directly from the database**, while general information and summarized findings were prepared using the ***Discover*-editor**. The difference in the origin of the data sets was not recognized in the homogeneous interface.

7.3.2 *WildCam TV*



Meta: Cinematic interactive exhibition platform. Exhibited at “Civic” during the “MESH Festival”, September 23 – October 20, 2024. https://tv.mitwelten.org

Research question: *"How can scientific image sequences from wildlife cameras be used to make people aware of local parallel life forms?"*

Examination approaches:
- Cinematic exhibition platform: interactive real-time image sequencer.
- Interactive customized, gamification and storytelling strategies for user engagement.
- Conversion of scientific data sets into publicly available storytelling media formats.

Situation and ecological challenge

People are often unaware of the parallel worlds that coexist alongside their own. This is mainly due to the daily routine, lack of attention and understanding of the behaviors of non-human cohabitants, as well as humans' day activity and limited night vision. Biological processes such as plant growth cannot be perceived either, as they are too slow for human senses. The goal of *WildCam TV* was to develop a **media format with unusual perspectives and time intervals that allows people to experience these hidden animal worlds** and nature phenomena in a local context.

Media-ecological approach

Wildlife cameras are frequently used by biologists to take pictures of wild animals to identify the present species of a habitat and their behaviors in order to derive conservation measures. For WildCam TV, we use recordings made as part of the ecosystem research as footage: images of animals that were taken in hidden places as well as the pictures of plants taken for the Pollinator Diversity study. The images that were taken for biological purposes were technically compiled and presented as an interactive, storytelling graphical user interface (GUI).

Fig. 36: *WildCam TV* exhibited at Civic discourse and exhibition space at the Academy of Art and Design FHNW. Images of the daisies are selected that were used for the Pollinator Diversity Study. Time lapse makes it possible to experience plant growth and decay.

Fig. 37: The photo shows a stone marten standing under a railroad car on a disused track. In the image sequence, all the animals found at this location are lined up one after the other in temporal order.

Media design context

The first physical flipbooks or kineographs were documented in the middle of the 19th century. Leafing through small brochures allows viewing a series of images, which gradually change from one page to the next, creating the illusion of movement through the rapid succession. The human eye perceives continuous and smooth movement if at least 12 images per second are viewed and the changes between the individual images are small and regular. The same illusion of movement has been used in film since the end of the 19th century and in video since the 1930s, where 24 to 60 frames per second are usually recorded to capture and reproduce dynamic scenes.

As the images from a **wildlife camera** are all taken from the same location, only the snapshots of crossing animals activated by the motion sensor can be seen against a background that hardly changes. When browsing through these images, the recorded sequences therefore appear like **animated stories**, even if the images were sometimes taken hours or days after each other. By playing with the interval and frame rate parameters, the user can influence the design and story of the animation. From image sequences in which little is happening, pictures can be selected at longer intervals and played back faster, and in those in which there is a lot going on, all pictures should be played back more slowly, even without creating the illusion of movement. This engaging interactive approach is used to make the photos recorded for biological investigations accessible to the general public and to draw attention to parallel worlds of non-human actors.

The term sequencer comes from music and refers to an electronic device or software for recording, playing back and processing data for music production. A relatively small volume of data is normally used, which can be varied by transposing and changing the tempo to produce a vast number of different sounds. The term **image sequencer** is used for image rendering engines or in connection with image sampling, which is used by visual jockeys at music events. *WildCam TV* can be understood as such, even if it is less about artistic effects and the images are not alienated so that they can also be used for biological purposes as an image viewer.

Concept and development

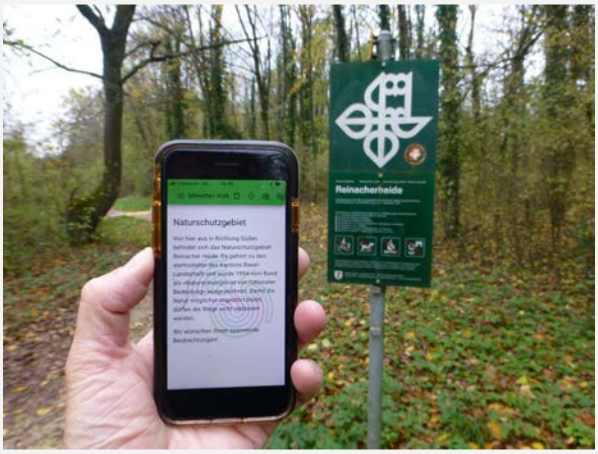
The *WildCamTV* exhibition took place in the CIVIC discourse and exhibition space at the Academy of Art and Design FHNW, before and during the MESH festival. It was based on image material recorded as part of the biodiversity investigations in the Dreispitz area and in the Reinacher Heide and stored on the *Mitwelten* database. The **flip-book-like still image sequencer** is based on parametric selection criteria such as: camera, time period, day or night time, interval, and framerate and composed in near real-time, directly from the database. If no parametric changes are made, the image sequences have a default setting that presents the content in a comprehensible way. The potted flowers are, e.g., played with an interval of an hour and a framerate of 1 frame per second to make plant growth perceivable.

Findings

During the exhibition of WildCam TV, we **observed the visitors interacting** with the platform and conducted spontaneous interviews. To draw the attention to the installation, a teaser was shown that was generated from randomly compiled image sequences. It was encouraging to see that images of animals captured by wildlife cameras are attractive and also prompted random passers-by in the entrance area of the Civic to view the sequences. However, the step of becoming active and using the interactive features presented a different hurdle: only a few people started experimenting with the image sequencer. Some sequences were recorded on campus and were recognizable to the local community and therefore watched with particular interest. The personal relation to places, which are inhabited by more-than-human actors in a parallel world, created special attention and hopefully also **understanding and empathy for the more-than-human neighbors**.

A central goal was to work with the collected data sets and convert them into publicly accessible media formats. **Playing the still image footage at different speeds and intervals allowed different stories to be told**. In a sequence, it may appear as though the mouse has only just escaped the stone marten, even though hours have passed between the two scenes. The repurposing of scientific material was most evident in the flower images of the “Pollinator Diversity” study, which illustrated the growth of flowers in time lapse. In addition to its entertainment potential, the image sequence generator is also useful for biological research, as it enables a quick search in the database for species and situations of interest.

7.3.3 *WalkApp*



Meta: GPS-based outdoor information app. http://walk.mitwelten.org

Research question: "How should a location-based app be designed to provide local information about natural events at first hand and encourage users to get involved?"

Examination approaches:
- Context aware presentation of research results for the public.
- Gamification strategies for user engagement and empathy generation for non-human actors.
- Investigation of media formats and user participation.

Situation and ecological challenge

People visit peri-urban recreation areas and nature reserves for a variety of reasons: to relax, observe nature, go for a walk, walk the dog, do sports, meet friends and much more. They are often not informed in depth about the different habitat types and their inhabitants and are also not aware of how much work goes into maintaining such areas. With the *WalkApp*, we tried to **inform visitors on site and to involve them by context aware content presentation and participation**.

Media-ecological approach

A key feature of the *WalkApp* is that the *Mitwelten* datasets of the Reinacher Heide nature and recreation area are presented in the local outdoor context. Images, texts, infographics or sound documents are offered location-sensitively and thus context aware via private mobile device. A **medial expanded walk should feel like you are on a walk with a biologist friend** who occasionally points out interesting biological phenomena or sociopolitical conflicts. The eyes should not be constantly fixed on the mobile device so that the surrounding nature receives sufficient attention. Only when users approach a hotspot, they are alerted by a beep to a possibly interesting topic. The app also invites visitors of the Reinacher Heide to upload photos of their observations via the reporting platform WildeNachbarn.

Related work

Content editors such as Foxtrail[40] or Push[41] enable organizations or communities to enrich areas of particular interest with location-sensitive media feeds (text, photos, videos, sound) and to offer them as educational trails or edutainment games. The aim of the *Mitwelten* project was therefore not to

[40] https://foxtrail.ch
[41] https://www.pusch.ch/fuer-gemeinden/umweltkommunikation/naturpfade

develop another app, but to compare different communication formats and to **retrieve the collected sensor data directly from the database and prepare it in near real time in a compact format for mobile devices**.

There are also editors such as Spotteron[42] that are designed to set up apps for citizen science studies, and many such apps have been developed in recent years and are increasingly seen as valuable tools by the scientific community (Silvertown 2009; Dickinson et al. 2012; Sullivan et al. 2014; Worthington et al. 2012). The apps are often designed for analyzing data sets that cannot (yet) be carried out with AI or are aimed at the outdoor space that needs to be explored. Despite all the benefits for science, the apps should be entertaining, and the citizen scientists should learn something about the objects of investigation and research methods. On websites such as Schweiz Forscht[43] or EU Citizen Science[44] interested citizens can choose from a variety of projects according to topic, task type and level of difficulty in order to participate in research. Citizen scientists can choose from tasks such as annotation, image, audio or video recording, classification or labeling, data entry and analysis, geolocation, observation and identification, measurement, problem solving, description or transcription. Sometimes an online introduction or a learning unit is required, which also brings citizens into contact with the experts and the community. Sometimes equipment needs to be borrowed, but often the task can be accomplished by simply using one's own cell phone or private computer with internet access. In the ecological context, e.g., citizen scientists can help to create the first world map in color of the night and to locate global light pollution (Cities at Night[45]), measure river water levels to quantify the impact of global warming (Crowdwater[46]), record observations of seasonal changes in plants to document climate change (PhaenoNet[47]), and much more. The WildeNachbarn[48] reporting platform, which is linked to our *WalkApp*, allows the citizen science community to upload photos of animals they have observed in defined local areas. They are published on a map and in the *WalkApp* but are also evaluated by experts to draw conclusions about the populations of different species.

Concept and development

The development is based on a hiking trail through the Reinacher Heide and the *WalkApp* only works if the user is within the defined perimeter. However, the programming is designed to be as generic as possible so that it can be used for other locations. *WalkApp* users can choose from **three different experience mode channels** that enrich the hiking trail in different ways:

1. In '**Living beings and habitats**' users are informed about the different types of habitat and their inhabitants. Texts, photos and data visualizations are used to provide basic information about developments in the local recreation and nature reserve and about the flora and fauna. This mode also includes simplified representations of the empirical evaluations of the measurements taken in the field.
2. In '**Points of View**', users are offered audio documents of excerpts from expert interviews. Scientists, politicians and operators present their positions and needs, some of which are in conflict.

[42] https://www.spotteron.net
[43] https://www.schweizforscht.ch
[44] https://eu-citizen.science
[45] https://eu-citizen.science/project/45
[46] https://crowdwater.ch
[47] https://www.phaenonet.ch
[48] https://www.wildenachbarn.ch

3. In ‘**Contributions of the Community**’, photos taken by visitors of the Reinacher Heide are presented. The visitors are invited to participate by uploading their documented observations via the reporting platform www.wildenachbarn.ch.

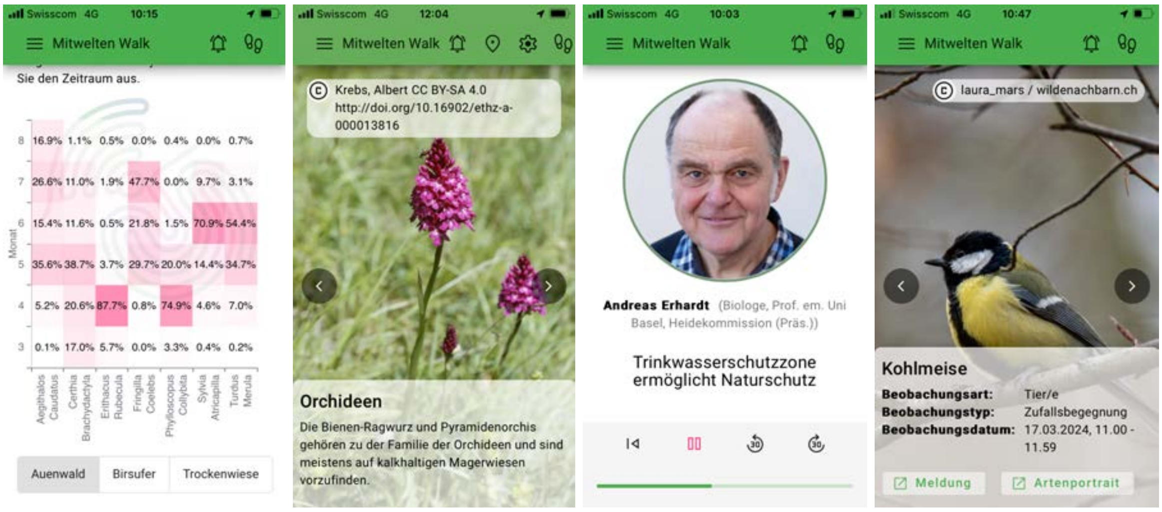


Fig. 38: *Left*: Screenshot of experience mode ‘*Living creatures and habitats*’ displaying the results of the Bird Diversity Study at the location of the alluvial forest. *Middle left*: Screenshot of experience mode ‘*Living creatures and habitats*’ displaying a pyramid orchid. A short description and the credits of the photographer are also provided. *Middle right*: Screenshot of experience mode ‘*Points of view*’ displaying a portrait of the speaker and the topic. Audio controls offer stop or replay features. *Right*: Screenshot of experience mode ‘*Contributions of the Community*’ displaying a deer. A species portrait and the reported observation can also be directly accessed via the Wild Neighbours reporting platform.

Findings

In 2024, we installed the final version of the *WalkApp* in Reinacher Heide and invited the public with information boards to use it, presented it at public events and asked the participants to complete a **questionnaire**. We also went on walks with four media and environmental experts and asked them to complete an extended questionnaire.

The evaluation showed that younger participants were more interested in the GPS-based WalkApp and there was potential to generate attention and promote empathy for ecological interrelationships. However, older nature lovers in particular were reluctant to use it. The use of technology has not only been criticized as a distraction from the natural experience, but there also seems to be a general oversaturation of apps. A basic principle was that **only datasets were shown that had a connection to the place currently being visited**. This local reference, embedded in a walk, made the information more tangible and staged it as a more personal experience. The location-specific selection and the content reduction for a mobile display, however, required a considerable amount of customization. The opportunity to switch between the three **experience mode channels** during the walk was frequently used and rated as very entertaining. The experience mode ‘Living beings and habitats’ was the most traditional information approach and was often considered a bit too overloaded due to the amount of information staged on the path. The radio play-like, audio-based experience mode “Points of View” was particularly appreciated because it did not require the eyes to be directed at the screen and because it included controversial political debates. ‘Contributions of the community’ worked quite well since it was orchestrated by our partner Swild and its WildeNachbarn network.

7.3.4 *Panorama*

Meta: 3D image-based online publishing format. http://pano.mitwelten.org

Research question: *"What potential do interactive 3D images have for helping people to put themselves in the position of non-human actors and as a publication format?"*

Examination approaches:

- Interactive 3D rooms for the improvement of empathy for non-human actors.
- Gamification and storytelling strategies for user engagement.
- 3D image-based publishing of research results for the public.

Situation and ecological challenge

It is difficult for humans to put themselves in the position of animals and plants, especially without anthropomorphizing their views. We have therefore explored a **medium that allows the perspectives, needs and services of non-human actors in an ecosystem to be made more tangible**. With the help of interactive 3D photography, immersive virtual spaces can be playfully accessed and different viewpoints interconnected.

Media-ecological approach

Panorama is an exercise based on situated imagining of relations and conditions between various types of actors of an ecosystem. To get a better understanding of the different perspectives, tasks and needs of other people, animals, plants and things, we have selected a few key actors and analyzed their situations and correlations: e.g. a gardener, a lizard, a willow, a rubbish bin, or an ambient sensor. From the standpoint of such actors, 3D images were taken, and the relations to the other actors were made accessible through interactive links that lead to their 3D image spaces. The **medium was also used to place additional text information and multimedia content** such as photos, historical illustrations or audio clips from interviews and field recordings. Empirically collected and processed data sets can also be accessed in the spatial context and displayed in the form of PDFs.

Related work

The media approach used for the Panorama app is based on **Quicktime VR** developed by Apple in the 1990s. It imitates the personally perceived space with a surrounding virtual photo sphere that can be turned around and offers non-linear interactive navigation by embedded interactive hotspots that allow jumping from one such sphere to another. The game 'Myst' in 1993 achieved cult status with this simple media approach and was only replaced by a virtual 3D model for the Unreal Engine 4 in 2020. The 3D photography approach, however, enables a fast realization with high resolution images, captured with inexpensive 3D cameras, and achieves a good illusion of world making. The **first-person journey used is now a standard for many game types** and allows the exploration of unknown worlds from a subjective perspective of a chosen character (avatar) with different abilities to act in the virtual environments. For the *Mitwelten* project, we have made use of this virtual world approach to enable users to put themselves visually in the shoes of other actors of the ecosystem. **New technologies can also be used in physical space to enhance the illusion of immersion**. In their work 'Animal Superpowers' (2008)[49], Chris Woebkens and Kenichi Okada have developed wearable devices for children to allow them to experience the sensory perceptions of animals. The work 'Bat Billboard' (2009)[50] developed in collaboration with Natalie Jeremijenko also contributes to bringing people closer to the parallel world of animals by making the acoustic spectrum of bats audible to humans.

However, **role-playing games** are not tied to new technologies and have been culturally established around the globe for hundreds of years, which is not surprising as they are already intuitively developed by children. In addition to entertainment, they are also used in social education, behavioral therapy and psychology. Only through the power of imagination and the exchange with other role-players can intense experiences be generated and the perspectives of other players be experienced. Such mental transformations can be reinforced by dressing up in accordance with the assumed role or imitating the behavioral patterns. The author of the book 'Being a Beast', Charles Foster (2018), wanted to know what it was like to be an animal and conducted a few experiments accordingly. He lived as a badger for weeks, sleeping in a hole in the ground and eating earthworms, or spent hours curled up in his garden and rummaging through garbage cans like a city fox. He describes the attempt to explore what it is actually like to live in the world of another species as a fascinating neuroscientific challenge.

Participatory and design-led workshops such as those organized by MoTH Cities[51] aim to help people move beyond a human-centered perspective by engaging with grassroots community gardens. The first workshop focused on urban planning for multispecies cohabitation and the second on urban interspecies relationships across different scales. The aim here was also to take on the role of other living beings and experience the correlations in the ecological structure. The academic organizers Sara Heitlinger and Rachel Clarke are also co-editors of the book Designing More-than-Human Smart Cities: Beyond Sustainability, Towards Cohabitation (Heitlinger, Foth, and Clarke 2024). Another example of role-play is the 'The Treaty of Finsbury Park'[52] multi-year project, developed by the EU Horizon 2020 funded research project CreaTures (Creative Practices for Transformational Futures). The fictional Live Action Role Play (LARP) is based on the story that other species rose up, demanded the same rights as humans and now negotiate new rules in interspecies assemblies. Masked human players act and think like dogs, bees, trees, grasses, squirrels, and beetles to change the way they

[49] https://chriswoebken.com/Animal-Superpowers
[50] https://chriswoebken.com/Bat-Billboard
[51] https://mothcities.uk
[52] https://treaty.finsburypark.live

perceive and participate in local urban green spaces, to find new strategies for promoting biodiversity. As part of the *Mitwelten* project, we suggested role-playing to the students as a technique for exploring the Dreispitz area before their design interventions. We encouraged them to mentally walk through the site as their chosen target species – e.g. as a lizard or a butterfly – and imagine what is relevant to them, where obstacles occur and how problems could be solved.

Concept and development

The design experiment was carried out as part of the field study in the cottage garden and the surrounding meadows of the Merian Gardens. On the basis of the analysis of the various local environmental actors, we developed a game-like tool that could be used to visualize their situation and correlations. By **clicking on embedded graphical links, users can switch between different panoramic locations and thus adopt the viewpoints of the respective actors**. Icons anchored in the photographs represent related actors and make them selectable, with a pop-up window appearing when the cursor is rolled over to briefly introduce them. A circle around the icon with two arrows describes the correlations between the currently visited and the rolled-over actor. A menu offers additional functions, such as an integrated map view, animated rotations or a reset to the starting point.

Fig. 39: Screenshot of the panorama application: The visitor has taken on the perspective of the crop plant fennel. Even if the fennel does not experience the world with human senses, this can be used to draw attention to its needs, services and correlations with other actors.

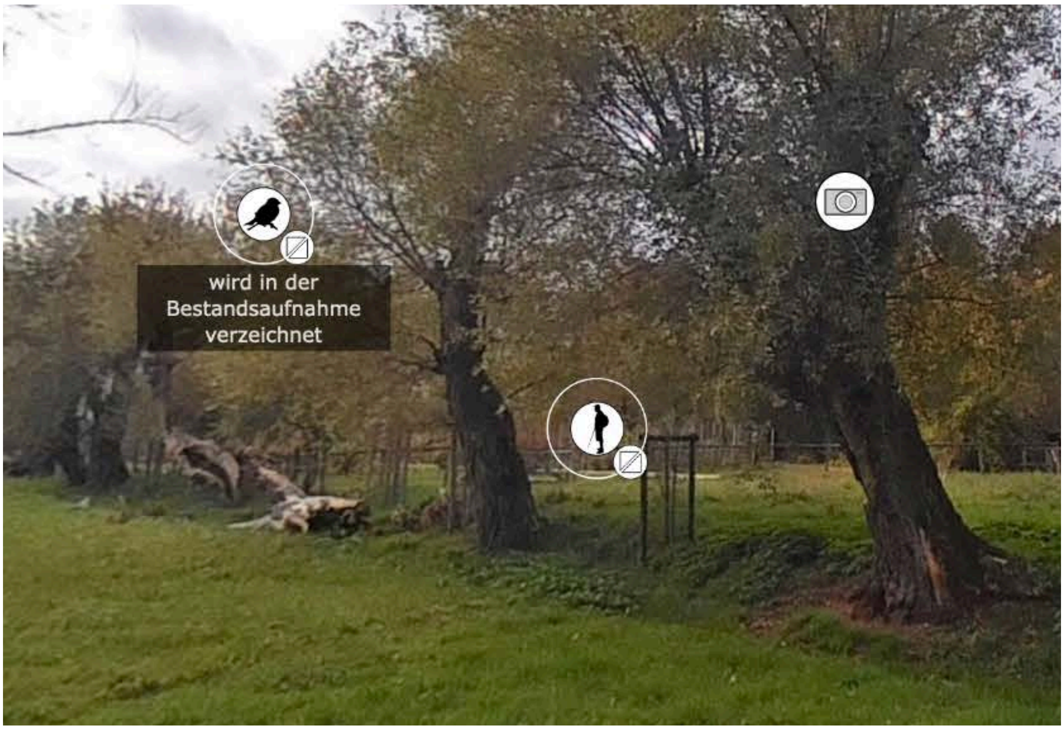


Fig. 40: Different types of navigation aids are offered and icons can be clicked to get additional information about the actor and its situation and the correlation with other actors.

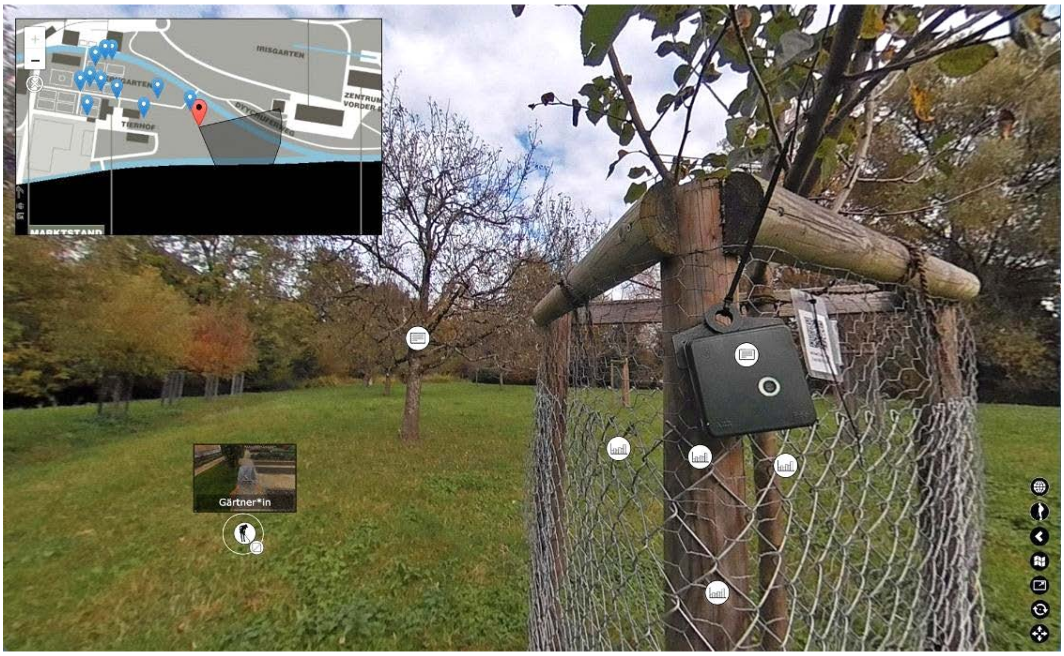


Fig. 41: Screenshot of the panorama application: On the pasture, the agency of the technical device audio logger is addressed, with which the presence of other actors such as birds and insects can be identified and, if necessary, protective measures can be derived.

While the perspective of the house sparrow sitting and singing in the ivy on a building façade is relatively easy to understand, the needs, services and correlations of the rubbish bin can only be grasped through a certain mental abstraction: it also has a lifespan, has the "need" to be regularly equipped with new waste bags and emptied and offers wild animals a set table, while it serves as a waste disposer for humans. The change of perspective from sheep to lizard, for example, illustrates the different open spaces of farm and wild animals, and the perspective of the PAX counter, which records the presence of visitors, shows the range of effects of a sensor for visitor management purposes.

Findings

The *Panorama* app was tested and assessed by colleagues of the interdisciplinary team and the staff of the Merian Gardens. Although the technology is not new, the **immersive interactive 3D medium** still has the power to surprise and attract. The exploratory and playful media approach was well received and led to inspiring role-playing games. The **perspectives of the human, more-than-human and material actors in the ecosystem** were understood and users began to reflect on the different forms of use and correlations. The main navigation was also understood, since functions such as the map view, full-screen mode or home button are familiar from the digital world. However, the ring around the symbols, which indicates the correlations between two actors, needs to be made more pronounced: it is crucial to the approach, but as an interactive element too hidden.

The assigned brief information often has only a phenomenological relation to the systematically organized investigations of the field study. They abstract certain aspects of their type of actor, e.g. their biological, social or functional classification. The 3D image-based publishing format is ideal for embedding multimedia content that relates to things or situations in the images. Embedding and associating content with panoramic images also seems to facilitate memorization. However, if something is lost, it is difficult to be rediscovered and the medium would therefore need an encyclopedic addendum. Or the other way around: the approach works as a role-playing game that serves to become aware of the role of otherish ecosystem actors, but not as a publication medium.

7.4 Interspecies Platforms

Jan Torpus

Introduction

The research project's design practices and interventions are intended to show how non-human stakeholders can be considered and included in design processes, thereby creating novel, ecologically valuable results. For the Interspecies Platforms, we pursued the following **research question**:

"What forms of cross-species coexistence can be stimulated in peri-urban areas through the design of media-ecological infrastructures?"

The value-based model and future scenario of the co-worlds is rooted in the ecological constitution of the respective landscapes and habitats. This also applies to those areas that have been **colonized with settlements** or appropriated for business, transport and infrastructure. Here, the needs of the human species and its societies have taken absolute precedence over those of other living beings and their biological habitats. In these areas, it is not only a question of preserving the remaining green spaces, but also about establishing new types of buildings, infrastructure and economic cycles in urban planning and open space design. The restructuring process goes hand in hand with the emergence of new lifestyles and ways of life, which ideally produce both a new culture and a revitalized ‘material’ living environment. The *Mitwelten* project is based on such considerations and attempts to make a small contribution in this sense.

Latour's 'symmetrical anthropology' from the context of **actor-network theory** (ANT) propagates the epistemological equal treatment of all entities of an ecosystem as actors: humans, animals, plants and abiotic elements such as things and technological components (Kneer, Schroer, and Schüttpelz 2008; Latour 2007). The 'political ecology' derived from this calls for a transition from the doctrine of the domination of nature to the participation of all the living and non-living world in society. It serves as a model for the *Mitwelten* project, where the terrain, abiotic elements such as pathways, park furniture, and technological devices are also understood as ecosystem actors. Field research is used to follow the concrete interactions of the actors found within an empirical context. Ultimately, this leads to a reflection on the role of things not only as objects, but also as actors in field research (Giaccardi et al. 2016). The approach, however, does **not aim to equate machines with living beings,** nor does it mean ignoring the enormous power imbalance between humans and animals and deriving an automatic success of prioritizing sustainability and biodiversity from this. On the contrary, the project follows the hypothesis that this ontological reconfiguration (Buller 2014) promotes human sensitivity and leads to new scope for action. The understanding of the interdependence of technologies, people and the environment enables a creative design approach in the service of living beings and the spaces interwoven with them.

Open space design is currently undergoing a reorientation: while assessment criteria such as aesthetics, functionality and comfort were previously focused exclusively on people, nature conservation measures were understood as negative restrictions. With their '**Animal-Aided Design**' method Weisser and Hauck (2017) demonstrate how animals can be integrated into the design process in a creative way, and not only when required by the authorities. *"The presence of animals is therefore on an equal footing with all other necessary planning decisions, such as whether an open space should be equipped with parking spaces."* Before embarking on the design process, specific questions about the target species must be answered: Which species (potentially) occur in the development perimeter? What is their activity radius? Is this area freely accessible or are there insurmountable barriers? Does the target species find everything it needs for its life within this activity radius? Food, nesting sites, breeding partners, water, etc.? The Urban Interspecies Furniture System must therefore be planned as an integral part of the local ecological context. In the *Mitwelten* project, the concept of AAD is extended by that of Actor-NetworkTheory (ANT). It understands ecosystems not only in the biological sense, but also includes humans and non-human entities such as objects and devices. As these can also have a major impact on the system they are integrated as relevant actors in the planning process.

The term **Habitecture** (MacKinnon 2014) is made up of the terms habitat and architecture and combines scientific knowledge about the basic needs of plants and animals with design principles for their habitat requirements (food, shelter, reproduction, etc.). Specifically, poses questions such as: How much interior space does an object offer? Which species can retreat into it? If the hiding places are large, more different species can retreat into them, but the competition is also greater. Small hiding places are therefore an advantage for species that depend on them. Can the material used serve as a habitat and food source? E.g. wood that is as untreated as possible so that insects can live in it. Is the soil substrate used varied and natural? Sandy to gravelly substrates, for example, provide nesting sites for various wild bees; too thick a layer of mulch means that the soil is no longer accessible as a nesting site for many species. Is the planting suitable for the animals? For example, flowers should be insect-pollinated, not wind-pollinated; plants should be as native as possible and thus serve as a source of food. Conifers are often less suitable because they are very protective of their leaf material and therefore do not serve as a source of food. Are there enough structures available? Lizards, for example, do not move across large open areas because they are not protected from predators. They need a network of hiding places. Are species in urban furniture protected from human disturbance (noise, physical disturbance, litter, etc.)?

According to AAD and Habitecture, the first step in design implementation is to obtain information on the behaviors and needs of the living organisms to be integrated. But moreover, their ecosystem services can also be taken into account. Biodiversity is indispensable for human well-being. In addition to knowledge or labor (human capital) or physical capital (e.g. machinery, production facilities), the economy also speaks of natural capital, i.e. the economic value of a landscape area, of which biodiversity is a central component. In its "Action Plan Biodiversity Strategy Switzerland", the Federal Office for the Environment (FOEN 2012) distinguishes between four different types of ecosystem services: basic services, provisioning services, regulating services and cultural services. Cultural services include intrinsic value such as recreation, general well-being, aesthetic enjoyment or spatial identity. A berry bush , for example, produces food, binds CO_2, cools the air through transpiration (photosynthesis), protects against erosion and promotes human well-being as a green, structure-forming spatial element. As a pollinator, a bee is of enormous importance for regulating plant growth and agriculture, produces honey and enriches the experience of nature in summer with its buzzing. With this background knowledge and the certainty that such values are promoted at federal level, students should be encouraged to include biodiversity-promoting measures in their design proposals.

As part of teaching units, we analyzed two campuses of the University of Applied Sciences and Arts FHNW and designed different multi-species infrastructures and furnishings.

7.4.1 Interspecies Outdoor Furniture



Meta: 2023 | FHNW campus Brugg/Windisch | semester project *SociaLandscapes*, collaboration with the HGK BA Interior Architecture and Scenography.

Research question: *"How can street furniture be designed to create contact zones for humans, animals and plants, and thus promote biodiversity?"*

Examination approaches:

- Design opportunities for interspecies outdoor furniture.
- Biodiversity-promoting design methods for education: extended 'Animal Aided Design'.

Situation and ecological challenge

In 2013, the FHNW Campus in Brugg-Windisch was extended by new buildings and outdoor areas and would ten years later be furnished with temporary 'meeting landscapes' as part of the

SociaLandscapes scenography workshop[53]. The development of scenographically subtle spaces, user-oriented design and the multidisciplinary environmental interventions were of central importance. In addition to the aesthetic, functional and social needs of human users, non-human living beings, such as animals and plants, were also to be included in the planning process. Reference was made to **post-humanist and anthropo-de-centric world views** and the potential contribution of design to ecological issues was assessed. The *Mitwelten* team contributed with ecological expertise and biodiversity-promoting design approaches. We handed out lists of possible wild animal and plant species that could occur on the campus and used an **extended version of the 'Animal Aided Design'** (Weisser and Hauck 2017) approach for interspecies cohabitation. In addition to the needs, services and agency of the animals, we also considered the needs of plants, objects and devices. One exercise consisted of selecting a target species (animal or plant) and an infrastructure element to examine them in terms of different requirements and design criteria. Profiles were created according to the following aspects: Species (animal/plant/fungus/object/other), materiality, appearance, spatial scale (size, distribution), environmental needs (habitat type, hiding place, shelter, etc.), physical needs (food, livelihood), behavior in the environment, mobility (action radius, type of locomotion), enemies (animals, traffic, weather conditions, etc.), conservation status (species protection status), ecological service, interrelationships with other actors (conflicts/synergies).

Related work

Urban outdoor furniture is usually designed to meet people's needs, such as sitting while waiting, relaxing, socializing, waste disposal and the like. They usually consist of uniformly designed elements that are combined according to the requirements of the respective situation. Companies such as the Dutch design collective Streetlife[54] sell off-the-shelf solutions for furnishing public urban spaces with "green benches" and "Tree Isles". The more radical proposals on the subject of urban outdoor furniture systems are made by students around the world. The award-winning generic, modular street furniture family 1x1 Urban Furniture System[55] by Mykolas Seckus and Antonio Gandolfo offers temporary, scalable, spatial interventions in urban space. Another example is Urban Gatherings by Elias Kateb, Sami Daccache, and Carel Marso, that is based on modular elements with specific functions that can be combined to create numerous application options[56]. More exceptionally, the solutions incorporate technological features such as water management for plant irrigation, energy supply for illumination, WiFi or even workout stations for energy production. The CityLight Street Lamp by Zhongren (Eric) Zhang[57], for instance, is an award-winning system that motivates passers-by to use exercise machines to charge the batteries of street lamps, to generate green energy and enhance community wellness and awareness. The Vegetal Bus Stop by Florent Prat[58] is a shelter with an integrated lighting and a water recycling and irrigation system. Another example is Ameba[59] by Paola Edith Mora Baz Dresch and Salvador Emilio Lluch Sicard, an award-winning bench with integrated solar panels with power supply and USB ports.

[53] SociaLandscapes - Topographies of the Common on the FHNW Campus Brugg-Windisch https://www.fhnw.ch/de/die-fhnw/hochschulen/hgk/institut-zeitgemaesse-design-praxis/projekte/projekte-innenarchitektur/socialandscapes
[54] https://www.streetlife.nl
[55] Denmark, 2020, https://competition.adesignaward.com/design.php?ID=102377
[56] Beirut, 2019, https://www.livelicity.com/projects/urbangatherings
[57] USA, 2011, https://www.coroflot.com/ericzzr/CitiLite-20
[58] France, 2009, https://www.designboom.com/project/vegetal-bus-stop
[59] Mexico, 2013, https://www.behance.net/gallery/9121777/Mobiliario-para-exterior-(banca)

Biodiversity-enhancing measures

In this section we give an overview of some types of common outdoor furniture providing public support in streets, squares or parks to explore the potential for biodiversity-enhancing measures.

Seating and tables:

- **Situation**: They are single or grouped units that are dispersed in waiting or recreation areas.
- **Humans**: sitting, socializing, pick-nick, working
- **Biodiversity**: These installations are problematic since the contact is very close and there is a lot of human movement. E.g. insects like to nest underneath tables, where humans move their legs. Animals can find food leftovers or are fed. This is problematic since salty human food is not healthy for the animals, but the encounters are promoting empathy.

Litter bins:

- **Situation**: They are placed close to food supply areas and the bags are regularly exchanged. They are designed in such a way that it is difficult for humans to illegally litter and that large animals cannot reach them.
- **Humans**: waste disposal
- **Biodiversity**: They can serve as feeding grounds. Rats, corvids, sparrows, foxes, raccoons or similar can find food sources and therefore increasingly become synanthropes in urban areas. Here again the food source is unhealthy but builds the basis for cohabitation.

Potted plant beds (without soil connection)**:**

- **Situation**: They cause more maintenance efforts and create insurmountable barriers for certain types of animals. They should therefore only be applied if the floors can’t be unsealed because of the infrastructural situation.
- **Humans**: natural relaxing atmosphere, spatial separation, privacy screening, shade provider, lower temperature caused by plant transpiration
- **Biodiversity**: This is the most obvious and promising niche for the use of biodiversity-enhancing measures: Coverage of basic needs can be optimized by adjusting position, access, size and species-appropriate planting for feeding, drinking, hiding, mating, and nesting. They can be equipped with nesting aids, bird baths, drinking troughs, moist substrates, etc.

Roofed waiting areas (e.g. bus stop)**:**

- **Situation**: They offer a big opportunity since they are microarchitectures with a protected roof and sometimes are equipped with power connection. The structure also makes it possible to collect rainwater or generate solar power. They are installed in similar formats at regular intervals throughout the city and peri-urban areas.
- **Humans**: waiting, socializing
- **Biodiversity**: The roofs can be covered with moist substrates and organic structures to foster spontaneous seeding of ruderal and pioneer plants. The regularly installed structures also make it possible to install nesting aids for birds and flying insects, bird baths, drinking troughs, etc. Stops where people pause are also valuable for raising awareness: biodiversity-promoting measures can be communicated on the spot by means of posters or digital information displays.

Street lamps:

- **Situation**: They offer a big opportunity since they are installed in similar formats at regular intervals throughout the city and peri-urban areas and are connected to the power grid. Park lamps are sometimes equipped with motion detectors so that they are only activated when people are present. Street lamps that are lit all night have a negative impact on the behavior of insects and bats and should therefore be upgraded.
- **Humans**: Security and visual support along passageways and streets during the night.
- **Biodiversity**: They can be used as a support for series of nesting aids, bird baths, drinking troughs or similar (see Stepping Stone Habitats).

Walls and fences:

- **Situation**: Vertical structures with textured surfaces offer small plants and animals a place to retreat or even habitat.
- **Humans**: architecture, spatial separation
- **Biodiversity**: Vertical gardens have recently become trendy in densely populated areas since they take advantage of surfaces that are not fully occupied by human infrastructures. They can be equipped with biodiversity-enhancing measures, including watering systems and nesting facilities and the choice of the right plants can offer feeding grounds for animals. IHowever, it is always a question of whether the vertical garden in question is for ornamental purposes and whether spontaneous colonization by animals is regarded as vermin and plants as weeds and undesirable, or whether there is a biodiverse concept behind it.

Educational concept criteria

Apart from the greening with plants – to create a more natural atmosphere, provide shade and lower the temperature by plant transpiration – hardly any non-human creatures are normally included in the urban outdoor furniture design process. This is where Interspecies Platforms come into play to meet the needs of animals and plants in urban spaces. During the *Mitwelten* research project concepts were developed and teaching units conducted at the Basel University of Art and Design FHNW. They were intended to raise students' awareness of the topics of biodiversity and interspecies cohabitation, explore what ecological contributions can be made in the disciplines of art and design and how the topic can be made tangible for the public. Among other things, the students' task was based on the following concept criteria:

- Financial and political feasibility: small effort, big effect (low-hanging fruits)
- Improvement of habitats for plants and animals
- Raising awareness among local stakeholders and residents
- Use of existing infrastructures, connection points, mechanisms and processes
- Collaboration with existing initiatives (residents, local associations)
- Generic systems: modular elements for situational adaptation

Student works

Seven accompanied student groups analyzed different locations on site, developed design models, assembled seven outdoor installations and finally visualized and documented their works. To illustrate the content and design process, the students were asked to keep a process book, produce physical working models, generate CAD plans and 3D models and present a poster. In our opinion, two projects have combined biodiversity-promoting measures with human-social aspects in specially interesting and completely contradictory ways.

Student project: *Der Auftakt* (The Prelude)
Team and responsibilities: Anouk Amrhein (biodiversity), Muriel Brülisauer (documentation), Silvan Seifert (protocol), Neva Vogel (communication & coordination)

Fig. 42: Student project 'Der Auftakt'. *Left*: Poster representing the concept. *Right*: Intervention on the campus through a zoo-like fenced-in area with information boards about small soil organisms.

Concept: The fenced-in piece of lawn is home to around 1.8 trillion creatures per cubic meter below the earth's surface. This biodiversity, which is imperceptible to humans, is to be made more visible through the intervention. A fence bearing the slogan 'Ich sehe was, was Du nicht siehst' ('I spy with my little eye') invites visitors to explore and provides information about some of the species that are typical for these kinds of soils. The zoo-like enclosure excludes humans rather than confining the animals.

Student project: *RuhePool* (RestPool)
Team and responsibilities: Sinan Brenne (protocol), Lena Rollwage (biodiversity), Sophie Borter (communication & coordination), Maria Gojevic (documentation)

Fig. 43: Student project 'RuhePool'. *Left*: Physical 1:20 model of the planned intervention. *Right*: Longer-term usable installation on the FHNW campus in Brugg-Windisch.

Concept: A stepped wooden structure installed in the hollow of a pine tree is a shady place to linger and work and a social meeting point. The furniture is oriented like an auditorium towards the pine tree and the surrounding hedge, so that nature takes center stage.

Findings

The extended ‘Animal Aided Design’ approach proved to be a useful pedagogical tool during the ideation phase of the SociaLandscapes projects, as one student in each working group was responsible for advocating the inclusion of animals and plants in the encounter zones. But in the prototyping phase, interpersonal concepts dominated and hardly any new infrastructural interfaces between the species were developed. The focus would need to be more clearly aligned to interspecies habitat in a subsequent workshop. The installations, however, integrated well into the campus environment, drawing attention to biodiversity through their intentional use of situational topology and creating opportunities for visitors to engage with the more-than-human world.

The student project Der Auftakt succeeded in **drawing attention to small, discreet organisms that play a significant role in ecosystems**. With a good dose of humour and by erecting a large fence and information boards about the creatures, they elevated the small soil organisms to the level of animals admired by humans in zoos. These organisms deserve recognition for their work, but the approach of exhibiting them and reporting on them scientifically puts humans at the center once again. Alternatively, visitors and passers-by could have been invited to garden, to touch the soil, to experience the habitat of these soil dwellers and their parallel world, and to find out about measures to improve their lives and the soil quality. In opening up the last sanctuaries for animals and plants to humans, the ‘RuhePool’ student project unintentionally increased environmental pressure. **The concept of creating a greater awareness of the beauty and complexity of nature was used mainly to expand people's access to it, without promoting genuine cross-species cohabitation.**

As the semester project’s name Socialandscapes suggests, the main focus was on proposing ways to improve informal human exchange on the campus. The inclusion of animals and plants was a less central part of the task and was only marginally implemented in most of the projects. The task of multi-species cohabitation is entering a largely uncharted design territory and should therefore be given greater focus in order to develop concrete solutions.

7.4.2 Reconfigured Infrastructures

Meta: 2023 | Basel Academy of Art and Design FHNW | educational unit ‘CoCreate’.

Research question: "How can found objects, furniture and infrastructure be repurposed or recontextualized to help promote biodiversity?"

Examination approaches:

- Awareness raising through artistic interventions.
- Activism for biodiversity promotion.
- Biodiversity-promoting methods for education: extended 'Animal Aided Design'.

Situation and ecological challenge

City infrastructures and public furniture systems for parks and streets are designed to support people during leisure activities, while waiting for public transport, with illumination at nighttime, or similar. Unfortunately, non-human actors of those habitats are usually not incorporated in the planning and design approaches. The infrastructure and public furniture should be improved with regard to their biodiversity potential and to better meet the needs of non-human life forms.

The aim of this teaching unit, which was carried out with students from the Basel Academy of Art and Design FHNW (HGK), was **not to design bio-inclusive urban furniture, but to examine and reconfigure existing campus installations**. Minimal interventions, activism and visualizations were used to draw attention to deficits in the promotion of biodiversity and to promote ecological integration design. The appearance of other life forms should also lead to greater human understanding and empathy for their perspectives and needs. In addition to the actions and prototypes, the students were asked to make suggestions on how future infrastructure should integrate biodiversity functions by default.

Activism and role-play

As part of the weeklong *CoCreate'23* workshop[60], HGK students from different degree programs jointly developed design interventions on the campus that drew attention to the **potential of biotope networking**. As a basis for this, they were introduced to the potential of horticultural interventions in urban areas (site types, plants, soil conditions, seeds) and possibly existing plants and animals (lead or target species) related to the existing areas and infrastructure of the campus. The basic needs and services of the creatures were analyzed, how they can be optimized through design interventions and at what point it becomes irresponsible to expose them to the sealed area and dense road traffic. In order to capture the local ecological structure of living and abiotic actors holistically, we again used the extended 'Animal Aided Design' approach (see 5.4.1 Interspecies Outdoor Furniture).
Inspired by **reconfiguration strategies and guerrilla gardening tactics**, students were searching the campus for ecologically valuable areas and infrastructures and architectural elements that were constructed for human needs and could be modified and reutilized as corridors, hiding places, feeding grounds, or nesting facilities for non-human actors. A valuable strategy was the use of the **affordance concept**, which made it possible to put themselves in the position of animals and plants. The term originates from the ecological perception approach of James J. Gibson (1979) and was transferred to usability research of designed artifacts by Donald Norman (2013). Affordance is the property offered by an object to a subject (human or animal). Depending on the subject, affordance can trigger very different forms of use and behavior. A stone, for example, can be used by a human as a projectile or tool. However, if it is lying on the ground, humans must be careful not to trip over it when walking. From the perspective of a mouse, a stone can be a lookout point or a hiding place behind which the cat suspects a mouse. Through **role-playing**, the students were able to slip into the perspectives of their previously defined lead or target species and imagine how they would behave on campus.

[60] https://www.fhnw.ch/en/degree-programmes/art-and-design/cocreate

Student works

After defining the more-than-human actors the students wanted to support and by spotting the infrastructures they wanted to reconfigure, five working groups developed ecologically accommodating design solutions. They staged prototypical design interventions and visualized speculative design visions. Two projects have in our opinion combined biodiversity-promoting measures with activist communication approaches particularly well and will be described below.

Student project: *Seed Sculpture*
Student team: Belén Comotto, Vincent Julmy, Marina Klein-Hietpas, Benedict Weber

Fig. 44: Top left: Sculpture garden after the workshop in 2023. Bottom left: Sculpture garden one year later in summer 2024. Right: Public invitation letter for the final presentation.

Concept: The project was inspired by the idea of seed bombs, which are used in guerrilla gardening as a method of illegal sowing, where earth balls with plant seeds are thrown like snowballs into the areas to be ecologically upgraded. The soil was prepared according to instructions from the internet but the concept adapted to the potential of the HGK campus: The students incorporated the soil into a sculpture that would slowly erode through the weather and give the seeds the basis for germination. Visitors of the presentation event and passers-by were invited to create their own sculptures with the prefabricated soil and thus create a sculpture garden.

Student project: *Connectivity corridor*
Student team: Simon Balmer, Celia Hug, Christian Langlotz, Pascal Lüthi, Benjamin Opderbecke, Andrea Tschan, Tanja Wiese

Fig. 45: A working group drew attention to the renaturation potential of the railway tracks of the former industrial area. *Left*: Passers-by had to cross the marked connecting corridors uncomfortably and were thus made aware of their ecological design opportunity. *Right*: Information boards were used to inform passers-by about the basic concept, which could be applied throughout the Dreispitz industrial area.

Concept: The railway tracks, which can be found all over the former Dreispitz industrial site, also run across the HGK campus and are to be transformed into ecological networking corridors between ecologically valuable areas. The students intervened by covering an asphalted track with ballast stones, installed a trolley equipped with plant pots and stuck yellow tape to mark the corridor's potential for improving biodiversity. In addition to the field work, they created a visual montage to show the final intent of a fully functional ecological corridor on the heavily sealed HGK campus.

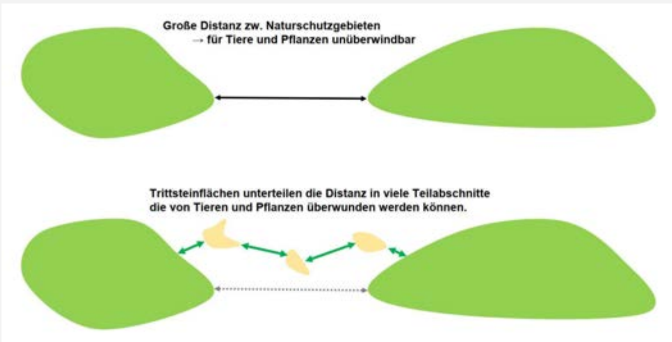
Findings

The students who took part in the *CoCreate'23* workshop, made suggestions how objects, furniture and infrastructure on the HGK campus could gain added value for biodiversity through repurposing or recontextualization. They were asked to attract attention and encourage passers-by to participate by means of activism, prototypical interventions and the presentation of visions of the future. Their first proposals were quite radical and exactly what should have been implemented: remove the large sealed surfaces with pneumatic hammers instead of designing indicative elements. After several discussions, however, we agreed on **institutionally permitted interventions** to make the human campus inhabitants aware of the needs and the potential of improving cohabitation with other life-forms.

One student group used **sculptures as culturally established exhibition objects in public space, which offer the basis for the proliferation of biodiversity through their materiality and ephemerality.** The sculptures created from moldable fertile soil mixed with plant seeds suitable for the habitat, one year later had disappeared and been converted into a flower bed. Although the framework conditions were created by humans, the approach shows how plants can be integrated into creative working methods via longer-term processes. Another student group indicated how the paved railroad tracks of the Dreispitz area could serve as a **networking corridor** and called for their renaturation. The ballast stones they used to indicate the animal passageway created an obstacle and forced passers-by to cross it with caution, generating the necessary attention. The incorporated trolley equipped with plant pots represented the botanical transfer made possible. The information boards illustrated what the space on the campus could look like so that animals and plants can spread out. The students also taped yellow shapes to the tracks, inspired by organic forms and reminiscent of a crosswalk for nature. These could be further developed iconographically to be used as recognizable signals throughout the Dreispitz area, raising awareness of the presence of other life forms. Efforts to standardize implementations are political and economic in nature, and no such stakeholders have yet been involved in the development process. However, the intervention had a concrete impact on campus planning: the inner courtyard was ecologically upgraded and there are plans to unseal the disused railroad tracks.

The actions and prototype interventions served as feasibility studies and for evaluation in the field. The idea to use them as a basis for the development of more far-reaching visionary transformation proposals worked well. Due to the **limited financial resources** available for nature conservation, we see potential in examining existing infrastructures for their expandability and thus incorporating standardized biodiversity-promoting measures in the medium term.

7.4.3 Stepping Stone Habitats



Meta: 2023 | Campus of the Basel Academy of Art and Design FHNW | concepts and student projects.

Research question: “How should minimal, modular stepping stone biotopes be designed so that they can be attached to existing infrastructure and contribute to biodiversity connectivity?”

Examination approaches:
- Ecological models as wicked requirement profiles for design tasks.
- Design Thinking strategies and standardized infrastructure for animals and plants.

Situation and ecological challenge

A third of all species in Switzerland are threatened, 95 percent of dry meadows have disappeared, as have 82 percent of moors and 75 percent of floodplains. Therefore, in 2012 the Swiss Federal Council established Strategie Biodiversität Schweiz (FOEN 2012) and in 2017 further developed the Swiss Biodiversity Strategy Action Plan (BAFU 2017) in coordination with international conventions. It was decided that **the whole of Switzerland should have a functioning ecological infrastructure by 2040** and that various environmental measures must be developed in order to preserve the diversity of species and habitats. In addition to promoting a sufficient number of valuable habitats, their connectivity is also of central importance, especially for genetic diversity. Wildlife-friendly corridors are usually made up of hedgerows and wildflower strips, with the addition of piles of branches and stones to provide sufficient shelter and food. In densely populated, sealed urban areas, however, they can hardly be laid out continuously, which is why the establishment of regularly occurring Stepping Stone Habitats to bridge the gap between one natural habitat and the next can help (especially for birds, insects and plant seeds).

Media-ecological approach

In the context of the *Mitwelten* research project, concrete solutions for the ecological principle of Stepping Stone Habitats in urban areas were examined. As space and financial resources for promoting biodiversity areas are limited, the conditions and potentials were analyzed and the focus and **requirement profiles** drawn up. We decided on the following design requirements:

- Focus on heavily sealed urban areas, without access to the ground
- Design of mini stepping stone biotopes for birds and insects (mobile through the air)
- Standardized, modular components that can be combined depending on situational needs: feeding grounds, nesting opportunities, hideouts, etc.
- Industrial design units as supplements for existing infrastructures: mounting on regularly distributed structures as e.g. streetlights or street signs
- Materiality and functionality: heat and humidity regulation, weatherproof, sustainable, inexpensive (based on existing components), vandal-proof, waste-proof
- As autonomous as possible, easily accessible for maintenance
- Optional technical features: power supply (e.g. for sensors, recording media), included irrigation system

Related products

The starting point for the design of the modular system are proven methods of supporting the flora and fauna in populated areas: flowerbeds, nesting aids, bird baths, bat boxes, drinking troughs, etc. These products, which are offered in garden centers, are usually correct in terms of materiality and mass, but often have dubious design approaches, such as bird nesting aids that look like gingerbread houses. To date, there are no modular systems on the market that can be combined as required and integrated into urban infrastructure systems on a large scale.

Concept and development

Apart from the design, most animal aids commercially available are valuable, especially the experience gained with the dimensions and materials. This study, however, goes a step further and focuses on solutions with different modules that can be installed on ubiquitous street lamps in varying combinations, depending on the ecological situations. Different design approaches were discussed and projected. One design took up the geometry of the sectors around the lamppost and tried to arrange different modules in an aesthetic, material-saving, easy-to-assemble and maintain way. Another approach pursued the integration of rainwater harvesting, the creation of shade, and the integration of technical monitoring devices.

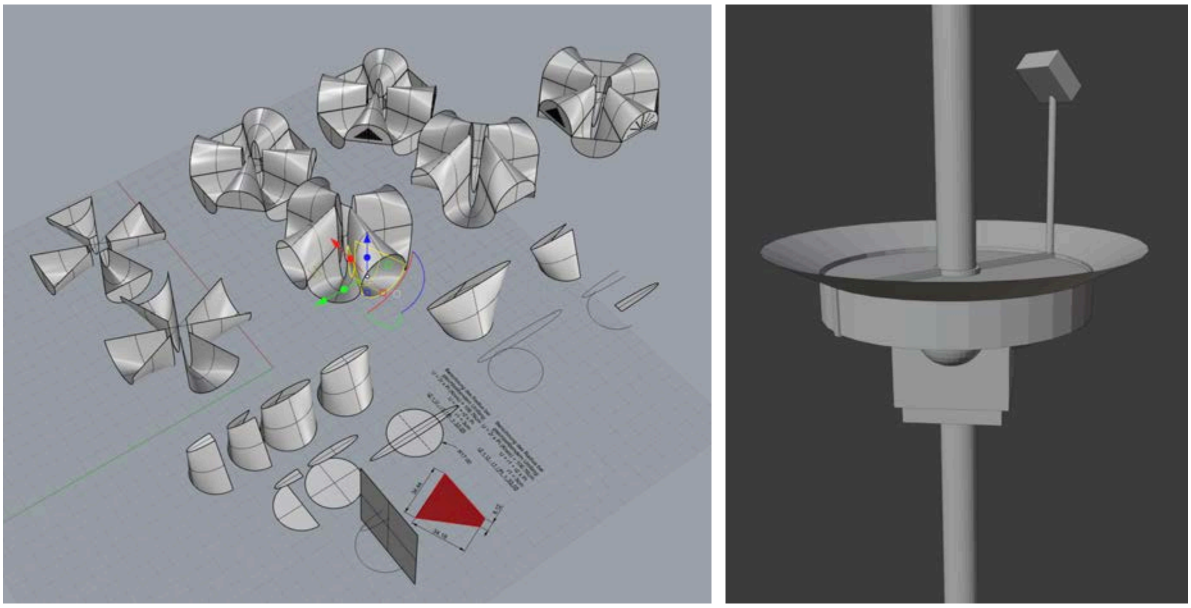


Fig. 46: Two design studies for modular Stepping Stone Habitats to be mounted on urban infrastructure. *Left*: Design study for the combination of modular plant beds, nesting boxes for birds and insects, and bird baths fixable around street lamps. *Right*: Design study including rainwater harvesting and integration of technical devices connected to the power supply.

As part of the *CoCreate'23* workshop a student group also addressed the topic and designed the **modular system 'Trittsteinwelten'** (Stepping Stone Worlds) that included other functions for biodiversity promotion.

Student team: Moritz Häberlin, Reto Monigatti, Timotheus Trinkler

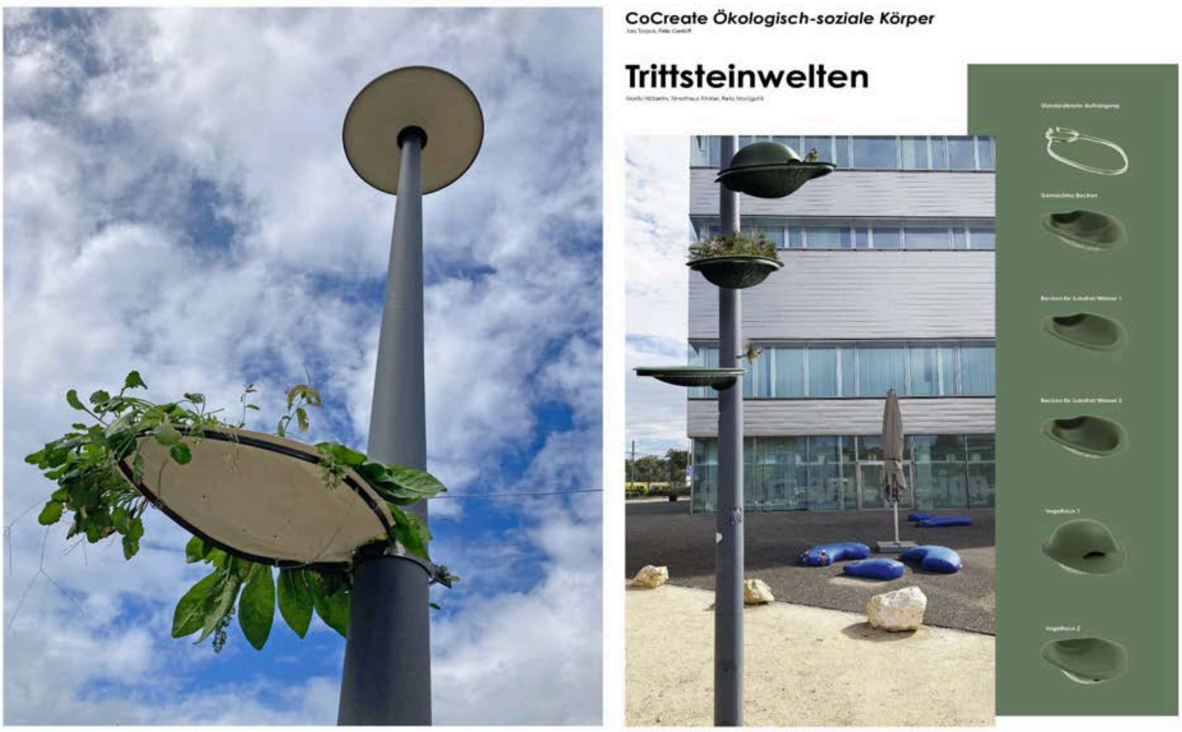


Fig. 47: Student work 'Trittsteinwelten' for heavily sealed urban spaces. *Left*: A prototype mounted to a street lamp on the HGK campus. *Right*: The students documented their ideas on other modules for the "Trittsteinwelten" system.

Findings

The development of stepping stone habitats to bridge ecologically valuable natural habitats in sealed urban areas confronts industrial design with "wicked problems" (Rittel and Webber 1973; Buchanan

1992). It requires the design to meet the physical needs of non-human users while also being in accordance with the surrounding ecological environment. Hanging up bat boxes, for example, only makes sense in areas where there are enough insects for them to feed on. Since animals and plants cannot provide direct feedback, field trials with prototypes are necessary to evaluate the way in which the design implementations are used. The production of prototypes also raises specific questions about manufacturing steps, costs, material resistance to weather and solar radiation, assembly and maintenance. Working with metal structures on sun exposed street lamps might cause overheating and humidity, and 3D-printing materials are to be proved in outdoor conditions. Due to the maintenance effort, irrigation systems should be automated but standing water should not have a negative impact on neighboring nesting sites or the spread of the tiger mosquito. When combining different types of animal aids, it would also be interesting to study whether synergy cycles could arise between the different modules. For example, if the plant bed could provide food and nesting material and the bat droppings could fertilize the plant beds. The combination of ecological knowledge and evaluation methods with designerly ways of knowing and tinkering can help to optimize these design proposals in iterative development cycles.

Although the developments meet ecological requirements, the aesthetics are geared towards human perception. The use of leaf-shaped flowerbeds is certainly conducive to human acceptance in the cityscape, but nature should also be given free rein and unintended forms of non-human use observed and incorporated into a long term development process. In addition to the specific implementations, the concepts are also meant to open a debate about introducing animal and plant supporting features into the human-oriented environment as serial components. On the one hand, the approach was praised during the interdisciplinary presentations as a secondary plant and animal habitat layer integrated into the ubiquitous human infrastructure. On the other hand, the biologists criticized that the 'hanging flower bed' approach could be used politically as a welcome loophole to avoid more radical interventions, such as unsealing the soil to create real ecological corridors. Political bodies and decision-makers, such as the city gardening and departments for environment and energy, should therefore be included in further efforts to standardize the implementations.

7.5 Participatory Installations

Jan Torpus

Introduction

By means of participatory installations, we experimented with our IoT Toolkit in a more playful way and tried to display sensor-measured data sets with multimedia features to create an informed responsive environment. In this context, the term **New Media Art** is relevant, since it encompasses modes of expression that have been developed with the help of new media and emerging technologies. According to Oliver Grau (2016), *"New Media Art was coined by the interrelation of art and science from its very beginnings, because the sciences often acted as an engine of innovation and a reservoir for (aesthetic) inspiration in various art practices [...]."* A frequently used means are sensor-actuator systems, to represent data streams in alternative ways in order to render them more perceivable and experienceable and there are many examples in media art of how data sets can be presented in physical form. For years, Rafael Lozano-Hemmer[61] experimented with light spots to represent personal signals to other places and scales. Remote Pulse (2019), e.g., is an interactive

[61] https://www.lozano-hemmer.com

installation consisting of two identical pulse-sensing stations at two interconnected separate locations, transmitting personal bio data in real time into light flashes in a public setting. The artist Nils Völker[62] works with dynamic inflatable installations. Ninety Six (2024) is composed of columns made from conventional blue garbage bags, inflated and deflated, color lit and sounding to create an atmospheric light space. The movement of the deforming surfaces in former installations were also used to represent data streams. The London-based art collective and collaborative studio Random International[63] in 2012 created the impressive Rain Room, in which people can walk through an installation where it rains from the ceiling without getting wet. The easily measurable position of the visitor is set in scene with water valves, generating an impressive experience. The Living Room installation (2023) uses light to create the same effect.

The term **Ambient Information Systems** (AIS) should also be mentioned here, since it describes physical, tangible representations of information in the environment (Pousman and Stasko 2006). Many prominent experiments, like the ‘ambientROOM’ developed at the MIT (Wisneski et al. 1998) or Natalie Jeremijenko’s[64] ‘Dangling String’ (1995) at Xerox PARC, have been conducted further in the past but today's technologies allow more reliable and real-time measuring and data representation at low cost. Information mediated in this way, is not asking for full user control but occasionally shifts from the periphery to attention (Weiser 1999) and we therefore consider it to be a subtle tool for careful guidance: drawing attention to ecologically interesting situations and guiding people away from delicate situations without strictly signalizing prohibitions.

By extending the IoT Toolkit with new actuator nodes for light (Color LED Pixel), sound (Bluetooth Speaker) and a physical animation (Direction Indicator), we developed participative and guiding concepts for open spaces. The actuators transfer sensor values back into the physical environment in a dynamic-regulatory manner and thus contribute to the design of an environment with a certain autonomous agency. The participatory installations promote consideration and encourage participation and creative engagement for biodiversity. Following Hörl (2016), participation can be understood as a determination of the fundamental ecological relation. The concept of 'tools for conviviality' (Illich 1975) brings together media formats, strategies and tools that enable people to develop a life-affirming relationship with their environment. Illich positioned the concept of conviviality in opposition to the primacy of technical productivity, advocating the use of technology in the context of an ethics centered on life.

7.5.1 *Sensing with Trees*

[62] https://nilsvoelker.com
[63] https://www.random-international.com
[64] https://news.ycombinator.com/item?id=28351064

Meta: Interactive outdoor installation. Summer 2024, campus of the Basel Academy of Art and Design FHNW.
Research question: "How can passers-by be made aware of critical ecological issues by artistic means and invited to participate and thus take responsibility?"
Examination approaches: - Internet of things technologies for ecological communication. - Interactive media art as epistemological setup.

Situation and ecological challenge

Climate change is leading to more extreme weather conditions and is therefore becoming an existential challenge for all living beings. In urban areas, more frequent floods, water shortages, and heat periods are aggravated by sealed surfaces and the lack of water-storing infrastructures. The campus of the Basel Academy of Art and Design FHNW is also heavily sealed and sparsely planted in order to minimize maintenance. Due to the noticeable climatic changes and the global media coverage, the threatening situation seems to be gradually reaching society and a rethink in urban planning is slowly gaining in importance.

Media-ecological approach

With the media artistic intervention *Sensing with Trees* we intended to address the consequences of climate change in urban areas by making it more tangible based on the specific situation of local campus residents. We gave our more-than-human neighboring campus trees a voice: They were equipped with a tool with which they could attract people's attention by complaining loudly that the ground was very dry and that they were thirsty. A watering can, which was positioned next to them, invited passers-by to water the trees, whereupon the moaning fell silent. The installation was therefore not only intended to raise awareness of the critical situation, but also to **encourage responsible action and cross-species collaboration**.

Context and development

To implement the concept of *Sensing with Trees*, we chose a group of young aspens, that are planted next to the bicycle parking in a marly substrate to inhibit the growth of weeds. As they are centrally positioned they are effectively staged for passers-by. The implemented hardware components were part of the IoT Toolkit and included **sensors for moisture and motion as well as media players and loudspeakers**. The humidity sensors were buried in the ground to record soil moisture, the motion sensors fixed to the tree trunks to capture the presence of passers-by and the media players and loudspeakers hung in the tree branches to play the tree's voices. The recorded sensor values were analyzed in real time by processors and simple decisions were made: If a person passes close enough by the tree and the soil moisture is below a minimum value, sound files with complaints are played via the loudspeakers. Various test runs were carried out to calibrate the sensors, determine biological values, and to ensure sufficient scenic responsiveness for passers-by. The watering can was on the ground next to a water barrel that could be used to refill it.

Sensing with Trees literally gave the trees a voice by trying to **convert the values of the moisture sensors into statements that people can understand**. Different sound files were developed and compared: anthropomorphic sounds, like calls for water, were more obviously understandable and other more abstract sound files included bioactivity sounds of trees. We were very aware of the risk of human appropriation, which Kari Weil (2012), in her theories and representations of animal otherness and human-animal relations also refers to, when asking *"how others can be given a voice ... how to approach difference without appropriating or distorting it"*. As silent, immobile creatures, plants were long underestimated in the context of evolution. It was known that they reproduce vegetatively or via blossoms and spread via seeds with the help of the wind or animals. It was later recognized that a plant's nutrient cycle in which energy is produced with water and sunlight through the chlorophyll of the leaves is a finely tuned mechanism that uses carbon dioxide and excretes oxygen, a basic element for all life on earth. But it is only recently that we have begun to understand the communicative potential of trees. The **Wood Wide Web** is a nickname for a process of how trees can communicate and support each other through their root systems, through cooperation with fungi and their mycelium networks, and also through messenger substances that are spread with the help of the wind. If trees receive enough water and sunlight, their contribution to the ecosystem as providers of shade, a cooling system through transpiration and as oxygen producers in urban areas is immeasurable. The extraordinary system, which has developed over millions of years, does not need moisture sensors in the soil to know whether the tree is receiving enough water, or loudspeakers to communicate with peers. However, the proposed prostheses could help them to translate their needs in a way that humans can understand.

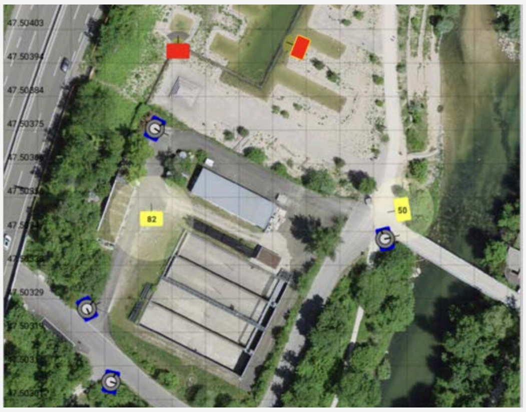
Fig. 48.: *Left*: Moisture sensor with antenna. *Middle*: encased off-the-shelfcommercial speaker. *Right*: Watering can for passers-by to interact with.

Findings

For our media-artistic experiment Sensing with Trees, the sensors and actuators of our IoT Toolkit worked very well as a **prototypical approach**. Long-term solar power supply was not taken into account in this case because the installation was set up for evaluation purposes only. The obvious approach of integrating the water distribution system available in urban areas was not an issue either, since this experiment was about raising public awareness and taking responsibility. The IoT Toolkit's 'Little White Cubes', which house the technological components, make the system uniform, clearly recognizable and adaptable to different situations. But for an ecodesign installation, in which the **appearance, perception and generation of emotions** are of crucial importance, the housings are too prototypical and not appropriately embedded in the environment. They stand out from the organic world representing technology, while they should actually fade into the background and leave the stage to the main actors, the trees. When installing the devices, we were able to take advantage of the morphology of the tree by placing the loudspeakers as sounding fruits in the crown, motion detectors for human presence on the trunk and humidity sensors in the root system of the tree. However, installing solar panels is problematic as they have to compete with the chlorophyll leaves of the canopy in this experimental setup. Using the tree's own energy system would, of course, be natural and desirable. No attempt was made to use the tree's communication channels either; instead, the devices were connected wirelessly via Bluetooth.

As for the specific implementation of the communication system between trees and passers-by, there is still work to be done. We installed the media art installation on campus and observed the interactions of human passers-by from a distance, taking field notes. Most of them did not perceive the staged situation and the transmitted message, although we experimented with **sound files of different levels of abstraction**, including transpirational sounds produced by trees. Even the clearest (and questionable) prompt for action – the trees pleading for *"Water!"* with a human voice – was unsuccessful with most passers-by who were unfamiliar with the installation. The approach would need to be introduced culturally, which could be achieved through media information, information boards and a longer implementation for the local communities.

7.5.2 Guidance System



Meta: Outdoor guidance system. Based on the IoT Toolkit and a simulator tool.

Research question: "How can people and animals be guided away from tricky situations or pointed to interesting phenomena as gently as possible using an IoT guidance system?"

Examination methods:
- Ambient information system for gentle intuitive guidance.
- Ecologically embedded IoT technologies for nature conservation.
- Map-based deployment software for IoT-embedding

Situation and ecological challenge

In peri-urban and recreational outdoor areas, humans and nature often come into conflict. The needs of humans for balance and leisure activities usually take priority over those of animals and plants for food, nursery and safety. There is often **unintentional human disturbance**, which is also caused by negligence and ignorance. Prohibition signs and barriers, however, are often seen as a restriction of freedom rights in the 'great outdoors' and are also deliberately disregarded and extensive information signs are perceived as patronizing or not read. A guide system based on IoT technologies (sensor-actuator systems) is intended to offer solutions to this problem.

Media-ecological approach

The media-ecological guidance system is based on networked sensors of the IoT Toolkit (cameras, audio-loggers, PAX-counters) that are installed in the outdoor space. The processed measurement data are presented by means of an ambient information system with networked actuators (loudspeakers, lamps, and motors), as well positioned in the outdoor space, to have an audiovisual and physical effect on environment users. In this way, human, animal or plant activities can be recorded and decisions can be made depending on the situation as to whether a conflict between humans and nature could arise or whether a phenomenon could be used to make people aware about natural processes and foster cohabitation. **Based on feedback from the media-ecological infrastructures and data analysis the environment receives the agency to guide and distribute people or vehicles as gently as possible through the environment**. The long-term goal is to develop a guidance system that can address all environmental actors – not only people and vehicles, but also animals. Vulnerable groups such as hedgehogs, toads or bats that are also sensitive to light and noise could be diverted when traffic volumes are high or, conversely, given free rein in certain zones at the important twilight time by distributing human users differently.

Context and development

There are already well-developed apps for road traffic that are designed to prevent accidents between cars and animals. The wildwarner App Wuidi, for example, warns anyone driving through an area with an increased risk of deer crossing with a warning signal. The data for the wildlife warnings is based on danger zones reported by hunters and motorists as well as a proprietary algorithm. Physical facilities such as wildlife crossings, flashing warning signs for wildlife passages or road fences for mammals or amphibians during migration are also increasingly common infrastructure in Switzerland. However, these systems always focus on people and their roads, and problems with collisions are often only solved in a makeshift manner after construction completion when problems arise. Ship collisions with whales in the Mediterranean, e.g., are now leading to discussions about changes to shipping routes and seasonal speed regulations. However, as this leads to delays and economic losses, political regulations are necessary. Before human traffic routes are built, the ecological situation and the needs of all involved actors should therefore be analyzed in detail and included in the planning.

Although the underlying concept intends to include the guidance of all environmental actors, the *Mitwelten* study for currently addressed humans. For the **ambient display design process**, an analysis of the selected study area had to be carried out in order to determine which parts of the environment had to be classified as sensitive and which zones and passages were used intensively by people. Based on this, different types of indications had to be determined and standardized: e.g. *Please stay away. Please be attentive. Please go this way. The place in this direction is free/occupied!* As we were designing ambient displays, which are intended to offer an alternative to prohibition and information signs, design issues relating to the staging and coding of information came into play. The question arose as to which media forms of ambient displays are technically less demanding and what disturbances they can cause in the environment. It must be decided where the ambient displays are to be placed, whether they should be mounted on existing structures or distributed on the ground and which fixation mechanisms are most adaptable. Also, if light-based indications should use culturally established codes like *red* for stop and *green* for go, or if gestural signals with a number of flashing lights pointing in one direction are understood and complied. Whether sound-based indications can be transmitted by connotations of friendly or rejecting sound codes, and whether the motorized arrow needs to be animated since it gets insufficient attention in the wild and in the social context of recreational outdoor activities.

We developed new actuator nodes for the IoT Toolkit and carried out technical feasibility studies with the extended sensor-actuator system. The sensor nodes developed for the empirical studies could be used for the monitoring of the environment:

- Pi cameras were used to take pictures of pollinating insects to be identified by machine learning (Pollinator Diversity)

- Audio-loggers were used to record Bird songs to be identified by machine learning (Bird Diversity)
- Motion and distance were used to detect presence and activity
- Humidity and temperature were used to capture environmental parameters
- PAX counters were used to count humans with cell phones (Human Presence)

For the guidance system we developed new actuator nodes (ambient displays) to become integral units of the IoT-Toolkit:

- Servo motors were used to create a rotatable indicating arrows
- LED lamps were used to guide by colored light codes (small light points on the ground to minimize disturbance)
- We encased commercial Hama loudspeakers as standard nodes to guide by sound (low levels to minimize disturbance)

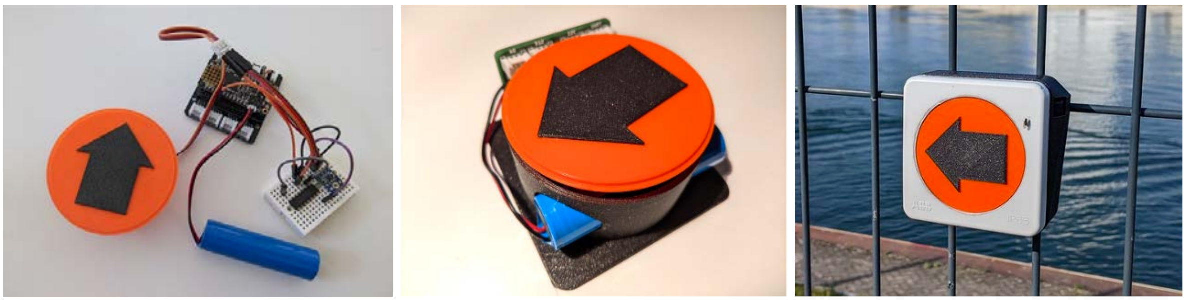


Fig. 49: The waterproof physical direction indicators, composed of basic electronic components, were assembled in 3D-printed housings and electrical junction boxes to be tested in the field.

Fig. 50: Indoor test series were carried out with the LED lamp “Color LED Pixel”.

The topic of long term energy supply was not addressed in the feasibility study but can be solved by solar panels or batteries used in the IoT Toolkit.

Also, a **map-based deployment software for the planning and maintenance** of the networked IoT system was prototyped. It enables the monitoring of the data flow of already installed IoT nodes in the field and the simulation of nodes that are being planned. Installed physical nodes transmit their data to the application, while simulated sensors generate mimicking values.

Various situations were devised in the Field Study Reinacher Heide. In the scenario presented on Fig. 51, people are **led to a point of interest**. For the detection of environmental activity, distance sensors (red) are set up in the area of the pond. The control algorithm aligns the guiding actuators with the most active sensor. For the guidance, indicating arrows (blue-grey) are installed at path crossings. In addition, PAX sensors (yellow) are located at points where people might potentially gather during an activity and where it can be assumed that social activities are taking place. The same system can also be used to guide humans away from sensitive locations: If too many people are detected in one place, e.g., the system can lead them to other places or, in the case of sensitive ecological activities, keep people away from a place.

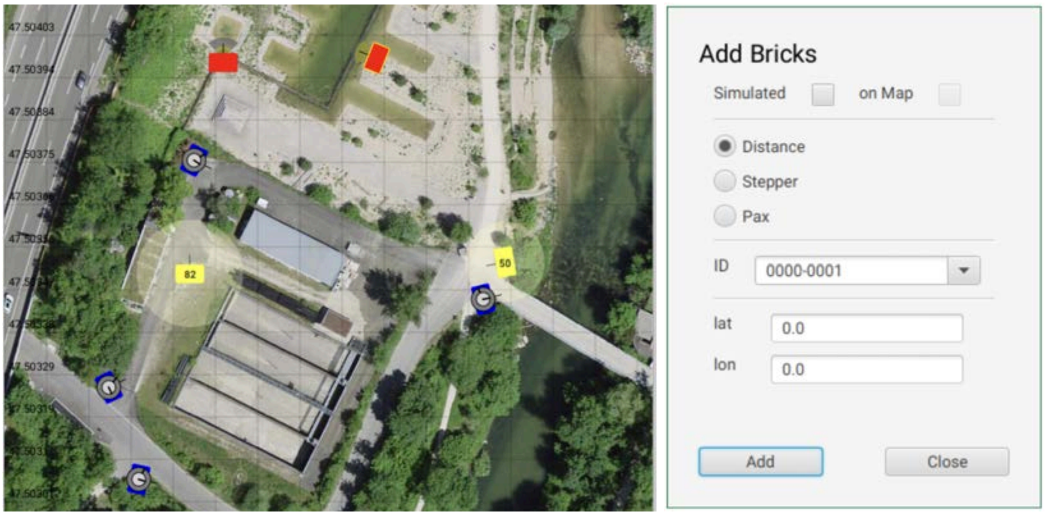


Fig. 51: *Left*: Screenshot of the map-based deployment software for the implementation of the Guidance System in the peri-urban recreational area Adventure Pond in Reinacher Heide. *Right*: With the interface users can select different types of “Bricks” (sensor or actuator nodes) to be placed in the simulation of the environment.

Findings

The development of an IoT Guidance System that is as gentle as possible on humans and animals has provided some insights into **possible applications and implications**. The technical feasibility studies have shown that the IoT Toolkit enables such implementations. Existing sensors can be used to detect critical parts of the environment as constant measuring channels, and the actuators, including our developed media applications, as output information channels. Since the measured data can be processed in near real time and quick decisions can be made based on fixed thresholds, the existing infrastructure could also be integrated alongside the media channels. Irrigation systems could be de/activated, paths opened/closed or street lights switched on/off. To simulate an implementation, we developed a software for the maintenance and planning of such a guidance system. It showed that it is possible to monitor sensors that are already installed in the field and combine them with virtual sensors that still need to be deployed. Different environmental activities can be simulated and the placement of different sensor and actuator channels placed accordingly.

The feasibility of an application is one thing, its possible implications something else. There were discussions in the interdisciplinary team about the compatibility of audiovisual media installations with nature. The use of light and sound in a peri-urban environment may not be as disturbing as in untouched nature, but despite this, the approach was **viewed very critically from a biological point of view**. Design questions arose as to how and where the media indicators would work best and be least disturbing. The original idea of the guidance system was to serve humans and animals. There were team discussions about guidance for hedgehogs, toads or bats, for example, and how to lead them away from dangerous places and traffic routes and towards valuable feeding and shelter sites. Mechanical installations such as wildlife crossings, road fences for amphibians, street lamps that only come on when there is movement on the street are already being implemented. During the development of the light and sound-based codes, however, it became clear that it would be even **difficult for humans to understand abstract ambient information systems**. To reach a larger part of the society, universally understandable signals similar to traffic lights would have to be used over long periods of time. The good intention of artistically embedding information in nature to attract people's attention and raise their awareness for nature could quickly degenerate into state paternalism in the leisure sector.

We therefore conclude that a guidance system with distributed multimedia nodes in nature is difficult to implement, even at the political level. An ambient information system would only be justified in a human-centered environment as a nature-sensitive artistic installation. However, the IoT Toolkit could be used to inform the recreation-seeking population with information kiosks or mobile applications to generate attention based on the local context, as investigated with our *WalkApp*. We also see potential for improvement in linking more distributed, sensory environmental measurements for ecologically critical situations with the existing infrastructure, which should be adapted accordingly and incorporated into urban planning projects from the beginning.

Chapter 8 Responsibility in Postnatural Environments

Karolina Sobecka

Worldmaking, as a technique for anticipating and intentionally shaping the future, has become a common framework across ideological and institutional spectrums—from the IPCC's predictive models to the speculative practices of neoliberal techno-optimists, to feminist STS and post-humanities scholars. The embrace of this technique was propelled by chaos and complexity theories in the 1970s. The vision of a non-linear world they revealed reshaped the notions of action and agency. At its core, worldmaking arose from the recognition that the future is not preset by deterministic laws of nature but is instead contingent and open to intervention. This acknowledgment reframes uncertainty not as shortcoming in prediction but rather as a source of freedom: the freedom to shape the future representation and materialization of particular realities. Peter Bernstein expressed this idea in Against the Gods, writing, "We are not prisoners of an inevitable future. Uncertainty makes us free" (1998).

But, as psychologist and philosopher Viktor Frankl put it, "freedom is only part of the story and half of the truth," with responsibility comprising the other half (2006). Frankl famously suggested that the United States' Statue of Liberty on the east coast should be mirrored by a Statue of Responsibility on the west coast—a reminder that our freedom to shape the world obligates us to do so ethically. Echoing these concerns, responsibility has become a central theme in contemporary environmental research. In post-natural environments, where the entanglements of human, nonhuman, and technological agents dispel the illusion of clear boundaries between culture and untouched nature, the questions around responsibility take on critical urgency. Yet, it often remains unclear what is meant by responsibility and how it can be realized. Across different perspectives, it has led to divergent interpretations. While all worldmaking approaches start with the acknowledgment of indeterminacy in nature, seeing nature as plastic and change as contingent, the understanding of the implications of that insight vary significantly.

Environmental media, as tools that mediate postnatural entanglements, are often linked to the notions of responsibility associated with technical solutions or citizen science applications. Yet, as the *Mitwelten* project explored, the environmental media's role and potential use can be far broader. The first step in approaching environmental media might therefore be to differentiate between how various environmentalisms conceptualize responsibility, and how these definitions underpin the respective justifications for action and uses of environmental technologies.

Models of responsibility in different environmentalisms

Ecomodernism has been a dominant form of environmentalism in the West. *An Ecomodernist Manifesto* (Breakthrough Institute) defines the social-material-natural world envisioned through this perspective, and that world's promise of freedom. It exemplifies a humanist approach, pivoting around the value of human freedom. Technological development is posited as the main engine for realizing the preferred world, with the pliable nature as a resource to be molded into desired outcomes. Ecomodernism believes advanced technologies will lead to decoupling human development from environmental impacts, suggesting that through technological progress, humanity can "shrink its impacts on the environment to make more room for nature" (ibid). Ecomodernist approaches advocate for the proactive design and management of ecosystems as "Garden Earth." Here, the metaphor of the garden, reflects a human-centered model of stewardship, emphasizing humans' role not just as participants in ecosystems but as active managers shaping ecosystems toward desirable, stable, and productive states (Ellis 2011; Cannon and Kua 2017). The metaphor of Earth as a garden is rooted in the critique of nature-culture binary—the idea that nature is "wild" or separate from humanity; instead, it recognizes that nature and culture are deeply intertwined. Ecomodernists emphasize that humans have shaped environments for millennia, from the cultivation of crops to the creation of urban landscapes. What makes the Anthropocene distinct is the scale and intensity of these interventions, requiring a new level of intentionality and responsibility. For ecomodernists, the recognition that humanity has already become a dominant geological force, fundamentally altering Earth's systems, is not necessarily something to bemoan. Rather than framing this influence as inherently destructive, advocates of this perspective of 'good Anthropocene' see it as an opportunity for deliberate and responsible planetary stewardship. The metaphor of gardening frames responsibility as an ethic where care is management. In a garden, the gardener doesn't simply let plants grow wild but intervenes selectively to foster growth, prevent harm, and create balance. Similarly, proponents of the "good Anthropocene" advocate for humans to act as planetary gardeners who can restore degraded ecosystems, protect endangered species, and create new habitats in the face of climate change and biodiversity loss.

Feminist and posthumanist scholars offer nuanced critiques of the ecomodernist approach, for example concerning its alignment with what has been termed "environmentalism of the rich," showing how this perspective often reflects the interests and comforts of affluent societies. They further argue that the ecomodernist focus on technological solutions may inadvertently perpetuate existing power structures and inequalities, as these approaches often align with capitalist and technocratic paradigms that prioritize economic growth and control over ecological systems.

Feminist approaches that understand ecologies as fluid, lively, and self-willed do not envision nature primarily as a system subject to human intervention; rather, they advocate for responsibility as an ethics of more-than-human care, which involves attuning to the needs of others. For scholars like Karen Barad, entanglements are "relations of obligation" (2007), demanding attentiveness to the asymmetries and ethical dimensions of these connections. Such approaches resist simplistic narratives of ecological stewardship or control. Instead, they recognize the need to engage with the plurality of lifeworlds, the agency of non-human entities, and the emergent possibilities that exist within ecosystems.

While both perspectives acknowledge the dynamic and contingent nature of ecosystems, their interpretations of the implications of this insight diverge significantly. Ecomodernists view ecological plasticity as an opportunity for human innovation and intervention, aiming to manage and optimize nature for human benefit. Posthumanists, however, advocate for a more humble approach that respects the autonomy of natural processes and the intrinsic value of all forms of life, cautioning against the hubris of assuming humans can engineer ecological outcomes without unforeseen consequences. They caution against imposing human-centric visions of what ecologies "should" be, emphasizing the importance of allowing diverse forms of life to emerge, even in environments altered by human activity.

This divergence underscores a fundamental debate about the role of humanity in environmental restoration and supporting biodiversity, including arguments about whether to actively manage and control ecological systems through technological means, as ecomodernists propose, or to adopt a more restrained and respectful stance that acknowledges the limits of human knowledge and the value of ecological autonomy, as advocated by feminist and posthumanist scholars.

There are many nuanced differences in environmentalist thought, for example one inspiring approach that is gaining recognition are indigenous perspectives, which emphasize reciprocal relationships with land, water, and nonhuman life and incorporate spiritual and cultural dimensions. In these approaches humans are called to act as caretakers who maintain balance and reciprocity, honoring ancestral and spiritual connections to place. For this discussion, however, I will focus on a few examples of visions of environmentalism that center technology.

One approach, which shares aspects of ecomodernist and posthumanist perspectives is that exemplified by Timothy M. Lenton and Bruno Latour's in their concept of Gaia 2.0 (Lenton and Latour 2018). It builds upon James Lovelock's original Gaia hypothesis, which views Earth as a self-regulating system. In this new vision, humanity assumes an active role in enhancing Earth's regulatory capabilities, making it a more conscious, deliberate process. Gaia 2.0 suggests that humans, through technologies such as environmental sensing and artificial intelligence, can help the planet achieve a new level of self-awareness and resilience. Lenton and Latour frame this as a moment of unprecedented opportunity: humanity's technological prowess can be harnessed to align human actions with planetary boundaries, enabling sustainable coexistence. While Gaia 2.0 emphasizes collaboration between humans and planetary systems, it risks anthropocentric overreach, where technological interventions are seen as the primary solution to ecological crises.

James Lovelock himself takes these ideas even further, in his *Novacene: The Coming Age of Hyperintelligence* (2019). He extends the Gaia hypothesis into a speculative future where hyperintelligent entities—possibly AI—collaborate with humans to manage Earth's systems. Lovelock argues that these entities will possess a level of computational power and decision-making capability far beyond human capacities, potentially ushering in an era of enhanced planetary self-regulation. This vision positions hyperintelligent systems as indispensable allies in combating climate change and biodiversity loss. While Lovelock's optimism about hyperintelligence is striking, it also introduces significant ethical dilemmas. The delegation of ecological management to hyperintelligent entities raises concerns about transparency, accountability, and inclusivity. If hyperintelligent systems make decisions based on algorithmic logic, how do we ensure these decisions align with diverse human and non-human needs?

A sobering critique of such technophilic optimism is offered by STS scholars. One example is discussion by Orit Halpern, Robert Mitchell, and Bernard Dionysius Geoghegan who write about the proliferation of "smart" technologies in environmental and urban governance (2017). Their concept of governance by the "smartness mandate" refers to the legitimacy data-driven technologies lent to technocratic management systems, under the guise of objectivity, efficiency and resilience offering to impartially optimize and manage systems. While these technologies promise greater precision in monitoring and mitigating environmental problems, the authors highlight their potential to centralize power and undermine democratic accountability. Halpern et al show how governance by the smartness mandate can veer into dystopian territory when it becomes a pretext for algorithmic control. The authors also discuss how "smart" environmental solutions often prioritize metrics that are easily quantifiable, such as carbon emissions or energy efficiency, at the expense of less tangible but equally important values, such as cultural practices or biodiversity. Would technologically enhanced planetary knowledge structures have the capacity to integrate diverse forms of knowledge, including those that non-human agency and value ecological unpredictability?

These examples show that the concept of responsibility has wide ranging consequences for the use of environmental media and needs its own focus and rethinking. Can humanity act to protect ecosystems without imposing its own visions of what the planet ecologies "should" be? How is responsibility reconfigured by the shift of agency from humans as direct environmental “stewards” to humans as designers and overseers of the tools that will act on their behalf? What does “learning to be affected” mean with regards to working with environmental media?

Rethinking responsibility

Drawing on the feminist and posthumanist thought, two key anchor points emerge for rethinking of responsibility in regards to environmental media: foregrounding of material accountability and of attentiveness to deep more-than-human entanglements that constitute the world. For Barad, becoming emerges out of different possibilities occurring at each moment and comes into existence through the fusion of social and material phenomenon. Learning to be affected.

A third anchor emerges from a closer look at the tensions within the posthumanist perspective itself. It might be best explained by Thom van Dooren (2014) writing in his book “Flight Ways” (): “Inside rich histories of entangled becoming—without the aid of simplistic ideals like “wilderness, “the natural” or “ecosystemic balance”—it is ultimately impossible to reach simple, black-and-white prescriptions about how ecologies “should be.” And so we are required to take a stand for some possible worlds and not others; we are required to begin to take responsibility for the ways in which we help to tie and retie our knotted multispecies worlds.” In other words, while the posthumanist perspective resists prescriptive interventions or rigid outcomes, it does not absolve us of the need to act. As van Dooren notes, responsibility involves taking a stand for certain possible worlds while recognizing the partiality and situatedness of our knowledge. A part of the answer to this tension lies in feminist approaches advocate for “tinkering” or experimental interventions that allow for small, situated acts of care rather than grand, totalizing solutions. Yet, no matter how small an action - or perhaphs even inaction—everything we do forecloses some possibilities at the cost of materializing others. In her book “What comes after entanglement” (2019), Eva Giraud describes a way to address this dilemma: acknowledge the limited and provisional nature of any particular stand we take, thereby making its limits or the exclusions it creates, visible, and therefore contestable. This third anchor I’d like to use therefore for rethinking responsibility is the practice of staging or making things public.

Material accountability

The worldmaking of devices is not only done through the knowledge they generate, but also through their material agency. Scholars are starting to grapple with how material accountability can be integrated into environmental media design. Acknowledgment of the material impacts of digital technologies is insufficient. Instead, environmental media designs must account for how these impacts are distributed across geographies and communities, often exacerbating existing inequalities. Material accountability, in this sense, entails rethinking the lifecycle of technologies, from production to disposal, and challenging the extractive logics underpinning their use.

While the Internet of Things (IoT) is frequently seen as promising to better understand environmental challenges, its direct environmental impacts across the life cycle of physical devices are often overlooked. There is an implicit assumption that the environmental burden of IoT devices is negligible compared to the positive impacts they are expected to generate. However, the significant economic and environmental costs associated with numerous interconnected devices that form the environmental media networks are increasingly not possible to ignore. These harms associated with them might include resource extraction for device production, energy consumption, electronic waste, and uneven global impacts of these practices.

The environmental footprint of IoT devices begins with their production. Manufacturing modern semiconductor devices involves highly energy- and resource-intensive nanoscale fabrication processes, generating substantial waste. Once deployed, each sensor in an IoT network requires energy to function. While the energy consumption of a single device may be minimal, the cumulative energy demands of an extensive sensor network can be significant. Furthermore, the data generated by these sensors must be processed and stored in large data centers, which are themselves very energy-intensive, requiring substantial computational and analytics capabilities. The environmental impacts of extraction of the materials for the production of media and waste processing falls disproportionally on populations who are not the primary users or consumers of these technologies and are not benefiting from them.

Given these implications, careful consideration of all aspects of the environmental media system life cycle is essential. However, addressing these concerns is far from straightforward. Reducing the footprint of electronics and computing devices requires equipping designers with tools to make informed decisions about sustainability early in the design process. Life-cycle assessment is one such critical tool for evaluating and mitigating environmental stress. Yet current methodologies are time-consuming and demand substantial expertise, particularly when applied to the numerous components, such as chips and sensors, that comprise the environmental media systems.

To ensure that those technologies contribute meaningfully to addressing environmental challenges without exacerbating ecological harm, the material and energy concerns must be prioritized in the design and deployment of environmental media. Scholars have been discussing these issues regarding the material footprints and asymmetries embedded in digital technologies, calling for “material accountability” in environmental media design (Kuntsman 2019; Parikka 2012; Starosielski and Walker 2016). They emphasize the need to address the socio-environmental costs of their production and use. Adi Kuntsman, critiques the pervasive reliance on digital technologies in environmental governance, highlighting the environmental harms associated with digital systems. Kuntsman argues that “digital solutionism”—the fact that each technical solution generates further technological advancements to solve its own limitations in addressing environmental issues—obscures the ecological footprints of these technologies. Kuntsman advocates for “materialist accountability,” which involves critically examining the lifecycle and global inequalities of digital technologies, advocating for engaging in forms of systemic “digital disengagement” (Kuntsman and Miyake 2022), exploring alternatives to digital technologies, in order to reduce reliance on them.

Practice of attentiveness

Attentiveness has been identified as a key ethical potential in shaping responsibilities in more-than-human worldings. Cultivating attentiveness is not without challenges. Scholars like Haraway (2016) and Latour (2004) emphasize that learning to be affected—an embodied process of attuning to the needs of others—requires sustained effort and reflexivity. This understanding challenges the dominant narrative surrounding environmental technologies, which often promise ease, efficiency, and a reduction of human effort. Many environmental media systems—sensors, databases, and monitoring platforms—are framed as tools for automating observation and analysis, offering a seamless, supposedly objective way to understand ecological processes. While these technologies are undeniably valuable, their promise of effortlessness risks sidelining the deeper ethical work required for cultivating attentiveness and care. In the context of environmental media, practice of attentiveness means designing systems that not only reveal ecological processes but also engage users in practices of care and responsibility.

To rethink environmental media in ways that foreground effort and reflexivity, it is essential to design systems that do not merely deliver information but actively engage users in the process of meaning-making. Jennifer Gabrys (2016a) discusses how citizen sensing projects can foster participatory practices that require users to interact directly with the environment, rather than simply consuming prepackaged data. By involving communities in the labor of data collection, interpretation, and contextualization, these projects can make the effort of attentiveness visible and shared, rather than hidden behind the interfaces of digital tools.

Environmental media can play a crucial role in fostering this form of attentiveness, but their design must move beyond simply representing ecological processes to actively engaging users in practices of care. Isabelle Stengers (2005) has emphasized the importance of "slowing down" in order to attend to the complexities of multispecies relationships and resist the rush to solutions imposed by dominant frameworks of efficiency and control. This slowing down can create space for users to not only perceive ecological processes but also reflect on their own participation within them. Attentiveness in this context becomes a practice of cultivating sensitivity to the liveliness and agency of the nonhuman world. For example, Deborah Bird Rose (2011) writes about the ethical potential of listening to the "stories" of other species—whether through their behaviors, their ecological roles, or their responses to environmental changes. This listening requires more than technological mediation; it necessitates an ethical and imaginative engagement that recognizes these stories as expressions of shared worlds rather than as data to be extracted.

From a design perspective, this suggests that environmental media should not be conceived as tools that replace attentiveness but as tools that *extend* it—foregrounding process over outcome, engagement over optimization. This could mean designing sensor-based media that require human interpretation, integrating storytelling elements into environmental data visualization to highlight complexity rather than certainty, or creating participatory installations that invite direct, multisensory encounters with ecological processes. Rather than positioning environmental media as instruments that extract knowledge from nature, they could function as relational infrastructures that help humans attune to the rhythms, needs, and agencies of nonhumans.

Making things public

As van Dooren writes (2014), we must take a stand for some worlds and not others. Every kind of action, including nonaction, results in materialization of some worlds at the expense of others. As Eva Giraud notes (2019), one way to address this tension is to acknowledge the limited and provisional nature of any particular stand we take—by making its limits or the exclusions it creates, visible, and therefore contestable. Making things public involves grappling with the limitations of representation and their worlding—by making those limitations publicly visible. Environmental media must be designed to acknowledge the partiality of its own perspective, as one of many voices in plurality of ways of knowing and relating to the world. Here is where environmental media and communities of practice developed around it can become platforms for staging of the stands we take and the worlds they realize, for dialogue around them and for their contestation. This can happen through various forms of making things public. For example, the DIY use of environmental media creates the potential to bring marginalized perspectives into public discourse. In another example, art projects, public installations, and educational interventions can serve to make these potential worlds visible, and engage diverse stakeholders in conversations about biodiversity and conservation.

Speculative visioning is one tool for making visible realities that might emerge through particular worldings. In one of *Mitwelten* workshops, Hira Sheikh, a multispecies ethnographies researcher based in Brisbane, discussed how she explored speculative models of relating to the land not through ownership but through obligation, as a way to investigate possible shifts of “smart” city governance (Sheikh, Mitchell, and Foth 2023; Sheikh, Foth, and Mitchell 2023). Sheikh’s speculative visioning project and its presentation during the *Mitwelten* workshop offer a vital example of how experimental and reflective practices can stage alternative realities, enabling dialogue and contestation. Sheikh’s project explored speculative models of relating to land not through the dominant framework of ownership but through the lens of obligation. This shift reframes governance practices in “smart” cities as opportunities to recognize and support multispecies justice, challenging anthropocentric priorities such as property rights and economic growth. Sheikh frames responsibility as an obligation embedded within cultural practices of reciprocity rather than as a top-down regulatory framework. This perspective shifts the focus from rights-based approaches to relational ethics, wherein humans and nonhumans are co-obligated to care for shared environments.

In her presentation, Sheikh critiqued how current technologies—such as biodiversity databases and urban planning maps—frequently reduce nonhuman species to abstract data points, stripping them of their relational and ecological roles. By introducing obligation as a guiding principle, her speculative scenarios resisted the notion of technology as a reductive tool and instead framed it as a means of fostering interspecies accountability and care. During the discussion, participants reflected on how these staged realities illuminate not only the exclusions embedded in current governance practices but also alternative modes of coexistence that could emerge if relational ethics were prioritized.

Sheikh’s workshop presentation exemplified how speculative visioning can function as a practice of "making things public." Sheikh’s speculative models, although provisional and limited, made visible the possibilities of worlds shaped by more-than-human obligations. This approach aligns with Eva Giraud’s (2019) argument that acknowledging the exclusions inherent in any intervention makes those exclusions contestable, the complexities of what multispecies justice might look like in urban contexts. In this sense, speculative visioning creates an opening for dialogue. Sheikh invited critical engagement and contestation, fostering a deeper understanding of "situational good" as opposed to universal or top-down prescriptions.

One key discussion point in Sheikh’s presentation—and one echoed in *Mitwelten*’s interventions—is the ethical tension inherent in using sensing technologies to "speak for" nonhumans. While these technologies can amplify the presence of nonhuman actors in governance and conservation, they also risk imposing human perspectives onto more-than-human worlds.

Through speculative models, participatory installations, and experimental tinkering, projects such as Sheikh and *Mitwelten* materialized alternative realities that invited critical reflection and dialogue. By foregrounding the relational and provisional nature of these interventions, they challenged dominant narratives of control and certainty, opening up possibilities for more inclusive and responsive ways of worlding. In doing so, they highlight the value of small, situated actions that, while limited in scope, can contribute to broader cultural and material shifts. Whether through speculative scenarios or tangible design interventions, these practices exemplify the potential of environmental media to foster relational attunement, ethical accountability, and participatory engagement

As we continue to navigate the uncertainties of the postnatural ecologies, the need for interdisciplinary and inclusive approaches to environmental governance becomes ever more urgent.

By embracing the relational obligations inherent in our entangled worlds, we can begin to take responsibility not just for the environments we inhabit but for the futures we collectively create.

Chapter 9 *Mitwelten* - Reflections and Propositions

Karolina Sobecka, Jan Torpus

9.1 Designing for relational worlding

Karolina Sobecka

The *Mitwelten* project explored how media technologies can support more-than-human, relational approaches to protecting living systems by foregrounding the entanglements between human and non-human agencies. In its experiments and design interventions, the project explored digitally-mediated encounters with postnatural environments. These encounters, where living beings, material elements, and technological infrastructures all participate in shaping shared worlds are the focus of the project's exploration of the processes of "worlding-with". The point of departure is to consider environmental media as not merely tools for human use but as part of a more-than-human assemblage that contributes to shaping together these worlds in common.

In contrast to conventional assumptions about how digital technologies are used in environmental management—for example, underlying "smart" approaches in cities or agriculture—this project represents a departure from technomodernist paradigms that frame environmental technologies as tools for control, optimization, and efficiency in managing landscapes. While environmental sensing technologies are typically employed to generate knowledge about aspects of ecosystems, their uses tend to indirectly support practices that implement human control over landscapes, even when the intent is restoration of natural processes. The *Mitwelten* project sought to challenge these often-unexamined biases that not only shape the design and application of environmental media in the way that reinforces those anthropocentric views but also vilifies the technology itself. While technologies have been shown to inherently contain unexamined biases of their makers, the questions environmental media are designed to answer and the data they collect primarily reflect the much more explicit priorities of their users. Furthermore, as scholars show, technologies can interact with their contexts in unexpected ways, becoming part of an assembly that has surprising or emergent capacities.

The *Mitwelten* project sought to interrogate the kinds of agency and worlding that environmental media systems are capable of producing or contributing to, recognizing that these technologies do not produce a singular, predetermined world. Instead, the *Mitwelten* project recognizes that the design of environmental media systems and the epistemic assumptions underpinning their use are key determinants of the realities these technologies co-create, and that they also become part of open-ended technoecological entanglement processes. By challenging the typical framing of environmental technologies as neutral tools for generating knowledge or producing overarching designs, *Mitwelten* reframes these systems as active participants in shaping diverse and relational worlds. The same sensors can be employed to either reinforce extractive or anthropocentric logics or, alternatively, to ask different kinds of questions that foreground the entanglement of humans, nonhumans, and ecosystems.

Important to the *Mitwelten* project is a shift where the notion of "responsibility" is reconfigured from acting from a position of "stewardship" - which remains hierarchical and rooted in notions of human exceptionalism - to continuous practice of care in multispecies cohabitation. The practice of care, long a grounding topic in feminist theory, means becoming sensitized to the agencies and capacities of different ecological actors. Care starts from “learning to be affected” (Latour 2004), an embodied process of attuning to the needs of others, oriented towards “rendering others capable” (Haraway 2016). Further, the openness and liveliness of ecologies means that it is not possible to know what kind of action is “good” for ecologies, or what they “should” look like. This is especially important to take into account in postnatural landscapes where disruptions and emergence are ever more visible.

When environmental media systems are designed and used within a feminist and posthumanist framework, grounded in an ethic of care and response-ability, their capacity to co-shape worlds changes fundamentally. Such an approach calls for attentiveness to the needs and agencies of more-than-human actors, acknowledging the co-constitutive relationships between humans, nonhumans, and their environments. These technologies, when reimagined through this lens, can shift from being instruments of control to becoming tools for attunement, fostering relational practices that make room for multispecies flourishing. By asking questions informed by these alternative worldviews—questions that prioritize care, mutuality, and shared responsibility—environmental media systems are enabled to create spaces where nonhuman agencies and ecological dynamics are recognized and valued. This perspective encourages a participatory and relational approach to environmental sensing, where the design and deployment of these technologies actively contribute to co-worlding practices that support diverse ways of being and knowing in the world.

The *Mitwelten* project aimed to apply this more-than-human ethic to practices of working with environmental sensor technologies. In this context, the care approach takes the form of careful and constrained experimentation. Since we can’t plan ahead of time, we should proceed with careful, small steps of modest “tinkering,” as it is only through such an experimental process that a relational ethic—a situational “good”—can emerge (Baan Hofman 2023).

Material considerations are critical to this process, ensuring that the design choices take into account energy consumption, local appropriateness of materials, and sustainability of data protocols, and tracing how their impact on humans and non-humans alike. By working with local, everyday objects and materials, and engaging with locally present species, the project aimed to develop interventions that are grounded in lived, entangled, multispecies ecologies already present at the chosen sites. These interventions are not designed to produce final products but rather constitute part of ongoing, evolving practices that respond to the contingencies of a shared world. The proposed media structures aim to create spaces where human actors can expand perceptive spheres, learning and experimenting what it means to co-exist more equitably in postnatural spaces.

We’ve learned from the project's interventions by drawing insights from both their successes and their failures. By embracing experimentation and learning from missteps, the project aims to open the process of building on the transformative potential of relational worlding.

9.2 Where design succeeds and fails

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The *Mitwelten* interventions were all small-scale, designed to engage special interest groups such as park rangers or students. They therefore are not examples of socio-cultural dynamics that might be present in other kinds of contexts, such as large-scale open to the public citizen science initiatives. The *Mitwelten* team departed from an assumption that organizing different opportunities through which the public or untrained participants can encounter situated materialities of techno-ecologies might lead to development of new kinds of knowledge practices that would support more sustainable approaches to biodiversity conservation. The *Mitwelten* experiments aimed to create a learner-led process of coming-to-knowledge that would enable a new kind of understanding of the postnatural condition and the techno-ecological entanglements. The *Mitwelten* team hoped this process would open the possibility of a relational approach to participant's understanding of their own positioning and agency in ecologies, and inspire ways of thinking anew about human entanglements with nonhumans.

In this section we focus on the lessons learned from the project. Were our assumptions correct? Which aspects of our experimental designs worked well and how can the other aspects be improved? Were there any unexpected results or side effects that might suggest an improvement to *Mitwelten* designs? Have the designs worked in a way that was unintended, creating undesirable outcomes or perhaps even reinforcing the very perspectives or behaviors we aimed to counter?

One of the most important aspects of the *Mitwelten* project has been its experimental nature, which allowed both successes and failures to serve as vital learning opportunities. By embracing the unpredictability of multispecies entanglements and acknowledging the complexities of more-than-human relations, the project has opened a space for reflection on how environmental design and environmental media can be structured to support both human and non-human inhabitants. Some of the most important insights emerged where the project seemed to fall short, often in areas where an anthropocentric bias inadvertently crept in. In retrospect, these failures illuminated the importance of consistently adopting a more-than-human lens throughout the design process.

Engaging with environmental media

The participants who took part in *Mitwelten* workshops and design interventions came from diverse fields and backgrounds, with varying levels of education, experience, and skills, including in the fields of ecology, technology, or design. While most of them were not considered "experts" in the specific applications of technology or biology being introduced, the terms "untrained participants" or "non-expert participants" would not be appropriate. The term "citizen scientists" on the other hand carries a strong association with large-scale, top-down initiatives where the public is often seen as data collectors rather than co-creators or collaborators in knowledge production. In the following discussion we therefore simply use the term "participant" to refer to the individuals taking part in *Mitwelten* interventions. This framing acknowledges critiques from Science and Technology Studies (STS) and related fields, which challenge the binary distinction between "expert" and "non-expert." By avoiding these labels, we aim to resist the devaluation of participants' knowledge and foreground the diverse perspectives and experiences they bring to the process. This approach aims to recognize the contributions of participants while also addressing the hierarchical assumptions around expertise and knowledge that often shape research practices.

The DIY assembly workshops brought together participants to assemble sensor technologies that would be used in the *Mitwelten* interventions. These sessions fostered teamwork and provided participants with hands-on experience, enhancing their familiarity with the hardware and software used in the given interventions, providing an opportunity to discuss the risks and opportunities of these specific technologies, such as acoustic sensors or machine learning analysis. These workshops were enjoyable and collaborative, but they required significant preparatory work by the *Mitwelten* team, and supervision during assembly, raising concerns about scalability and cost-effectiveness of such initiatives outside of research context.

Field setup and maintenance relied on participants to manage practical tasks, such as registering sensors using custom *Mitwelten* software, replacing batteries and storage media, and maintaining the in-situ installations. This reduced the workload on the *Mitwelten* team, but shifted the work to the volunteer participants. Learning from the shortcomings of this structure, the hardware components and software interfaces could be iteratively improved for the public use. For example, this experience underscored the need for solar power supply systems and online data transfer that would automate some of the tasks that proved unsustainably labor-intensive and led to gaps in data collection.

In data validation, participants played an important role in labeling audio and image files, for example assisting with validation tasks such as distinguishing wrongly identified target species from similarly looking objects. Data labeling process also provided an opportunity for exchange between participants and *Mitwelten* biologists and ecologists about specific species and their features. However, refining the machine learning models and drawing meaningful insights from them remained the responsibility of the *Mitwelten* team, showing the limitations of public involvement in advanced stages of data analysis.

The *Mitwelten* project aimed to also engage the public through interactive media platforms and installations. The public installation *Sensing with Trees*, for instance, signalled to passers-by the levels of soil moisture in the trees' planters, with the aim to presumably inspire them to consider the trees' well-being. The *WalkApp* allows participants to upload photos, building on the WildNeighbors reporting platform developed by the project partner Swild. We learned that features that required registration, such as ability to leave notes or observations, saw limited use, suggesting the need for more barrier-free and user-friendly designs. Long-term maintenance of such platforms, including fostering community engagement, emerged as a significant challenge requiring sustained effort, partnerships, and trust-building over a long period of time.

Involving public participation provides a valuable opportunity for participants to engage with new technologies, environmental monitoring strategies, and ecological challenges present in their environments. However, when viewed through the lens of more-than-human entanglements and land-based ways of coming-to-know, as articulated by thinkers like Leanne Simpson, this approach also exposes the limitations of expert-led frameworks. These limitations can obscure the broader relational and reciprocal dimensions of knowledge practices, constraining the potential for transformative environmental action. Conventional engagement of citizen science participants often positions them as supporting participants in a framework still primarily governed by expert knowledge and institutional scientific objectives. While participants gain hands-on experience and contribute to practical aspects of environmental sensing, their roles often stop short of meaningful involvement in knowledge generation. Tasks like assembling sensors, managing field maintenance, and validating data are presented as valuable forms of engagement, but they also risk reducing participants to low-cost labor within a system that remains hierarchical and technocratic. In order to involve participants in a truly transformative process, it is critical that they are given the opportunity to develop their own questions and their own experimental or research agenda, building on knowledge of technology and familiarity with the ecology at hand. It is through this process of worlding and contributing their unique perspectives to the collective worlding processes that a transformation can be accomplished.

While in the *Mitwelten* project we were able to identify many promising points of connection and collaboration which included participants in the process of generating knowledge—from sensor development to data evaluation and presentation, we believe a more radical shift, a much larger-scale reimagining of knowledge practices, which can lead to transformation of education institutions and practices, is also needed. An inspiring alternative would foreground ways of knowing that emerge from lived, land-based experiences and reciprocal relationships with more-than-human worlds. Land-based pedagogies, as Simpson writes, emphasize the process of "coming-to-know" through intimate, embodied, and reciprocal engagements with the land. This approach is fundamentally learner-led and relational, cultivating a deep sense of responsibility and interdependence with the natural world. It is therefore important for projects such as *Mitwelten* not only to analyze participation as part of the existing scientific paradigms, but also to empower participants as co-creators of new, relational forms of knowledge that go hand in hand with a critique of the logic of expert-based systems.

Expanding engagement with environmental media: toward relational worlding

While conventional frameworks for public participation in environmental monitoring are frequently valued for its cost-effectiveness and scalability—providing hands and eyes to assemble technologies, maintain field setups, validate data, and disseminate information—this perspective neglects the transformative potential of these interactions. By situating environmental sensing within a more-than-human and relational framework, inspired by principles of land-based pedagogy, we propose a re-categorization of benefits of engaging with environmental media.

Drawing on experiments detailed in Chapter 5, this section identifies three interconnected categories of benefits of engaging with environmental technologies: *Relational Attunement, Pluralizing Knowledge Practices*, and *Embodied Accountability*. These categories shift the focus from the utility of public participants' contributions to the generative possibilities of technoecological encounters, where human and non-human agencies co-constitute new ways of sensing, knowing, and being in the world.

The *Mitwelten* project embraces an experimental ethos, and further, building on the insights of land-based pedagogy, it reframes participation as a practice of fostering relational attunement, pluralizing knowledge practices, and cultivating embodied accountability. These approaches allow both successes and failures to become sites of vital learning, emphasizing the value of unpredictability in multispecies entanglements and the complexities of more-than-human relations.

Relational attunement

A recurring theme across the *Mitwelten* experiments is the role of environmental media in fostering relational attunement, or what Bruno Latour describes as "learning to be affected" (2004). This process entails becoming sensitized to the diverse entanglements of life and matter, cultivating an awareness that transcends the anthropocentric perspective.

The *CoCreate'23* teaching unit at FHNW became an opportunity to involve students in the Bachelor of Arts program in engaging with their surroundings in ways that foreground the interconnectedness of human and non-human inhabitants. Students' first concepts were radical—proposing to remove the concrete surfaces on the campus with pneumatic hammers to expose the soil and make room for ecological restoration. These ideas show the challenge of balancing ambitious ecological goals with the constraints of working within existing institutions, policies, and stakeholder frameworks. For students at FHNW, the possibilities for action were quickly revealed to be constrained to the ways that were acceptable in the local institutional and regulatory context. Students found they could only operate within perhaps the symbolic and communicative realm—creating interventions on a very small scale, or ones that could fit into existing avenues of expression sanctioned within the existing structures. These constraints underscore why world-making as a strategy is a crucial approach to environmental action. By focusing on reshaping collective imaginaries, knowledge practices, and community engagements, world-making interventions can lay the groundwork for future actions that work to transform the current worldviews and subsequently environmental governance systems based on them. Rather than merely working within existing structures, or protesting them, they aim to transform the underlying narratives and practices that shape how we understand and engage with the environment.

After tempering their initial ambitions, one student group explored how sculptures, as culturally familiar objects in public spaces, could serve as platforms for biodiversity. They created small, ephemeral sculptures from moldable fertile soil mixed with habitat-specific plant seeds. Over time, the sculptures disintegrated, transforming into flower beds that supported local biodiversity. This intervention not only symbolized the integration of plants into human-centric cultural practices but also demonstrated how non-human life forms could participate in creative processes. By designing sculptures that "disappeared" into the landscape, the project drew on long history of land art and engaging the temporal dimension in process art, inviting participants to reflect on the interdependence of human and non-human inhabitants over time. The intervention created a narrative and material presence that shifted how the site was perceived and engaged with, even as it disappeared.

Another group focused on the potential of the campus's paved railroad tracks to serve as a corridor for wildlife. Their intervention used ballast stones to signify an animal passageway, creating a physical obstacle that required human passers-by to cross with caution. This disruption generated awareness of the tracks as a shared space, prompting reflection on how urban infrastructure could be repurposed to support ecological connectivity. These visual cues were intended to inspire broader changes to campus planning, symbolizing a shift toward recognizing the ecological potential of urban spaces.

The students have learnt that art and design interventions, such as the sculptures and rail corridor designs, can reshape how people perceive and value their environment, creating a foundation for future ecological actions. Working within the limits of existing structures, they discussed how they can critically reflect on the systemic barriers to ecological restoration and advocate for their transformation.

Another course created and taught at the HGK and implemented on the campus in Brugg as part of the *Mitwelten* project, *SociaLandscapes*, encouraged students to shift their perspective beyond human-centered concerns and consider the needs and presence of other species during the ideation phase. Each working group was responsible for advocating for the needs of animals and plants in the encounter zones. In the prototyping phase, however, the interpersonal concepts dominated and hardly any new infrastructural interfaces between the species were developed. It was only during the semester project that installations endeavored further. They integrated well into the campus environment, drawing attention to biodiversity through their intentional use of situational topology and creating opportunities for visitors to engage with the more-than-human world. However, by making the last refuges for animals and plants accessible to humans, the interventions unintentionally put more pressure on these environments, reproducing the pattern seen on a larger scale in developed areas. Furthermore, it reinforced human dominance by master planned decision-making. This reflected a key learning moment: while the intention was to create awareness around the presence and complexity of nature, true multispecies coexistence was compromised by privileging human access and visibility over non-human autonomy.

These learning moments underscore how essential it is to not only include but center more-than-human considerations from the outset. One student project, for instance, drew attention to small, inconspicuous organisms that play critical roles in ecosystems. The students used the zoo metaphor, humorously elevating the small soil organisms to the level of the elephant, lion and zebra by erecting a large fence and information boards about the creatures. It is helpful to create an understanding of these organisms, but the approach of exhibiting them and reporting on them from a distance disregards their autonomy and agency.

This example showed how, even when intentionally trying to shift our perception and conceptual approach, we naturally tend to fall back on habitual ways of thinking - ingrained human-centered concepts. The installations' unintentional reinforcement of human dominance serves as a key learning moment: relational attunement is not a one-time achievement but an ongoing commitment. The work of fostering multispecies coexistence is not only about individual interventions or one time design choices but also about ongoing practices of shaping and sustaining world-making practices that continually reconfigure underlying narratives and change how humans engage with the more-than-human world.

Relational attunement involves recognizing that every act of design, engagement, or intervention participates in the construction of realities— what Donna Haraway and other feminist STS scholars describe as material-semiotic world-making. These realities are not neutral or given but are actively shaped by underlying imaginaries—shared ideas, values, and narratives about what the world is and should be. In this sense, relational attunement is about transforming the imaginaries that guide human interactions with more-than-human life, shifting from anthropocentric notions of mastery and utility to an ethic of care, reciprocity, and cohabitation.

World-making through relational attunement extends beyond individual actions to encompass community-building and knowledge-sharing practices. Communities play a crucial role in maintaining the cultural and epistemic infrastructures that support specific ways of knowing and relating to the world. For instance, the students' attempts to design biodiversity-focused interventions on the Dreispitz campus revealed how difficult it is to sustain more-than-human considerations when existing institutional and societal frameworks—such as property ownership, economic imperatives, and aesthetic norms—privilege human-centered priorities.

Relational attunement depends on challenging and reshaping dominant imaginaries. In the case of Dreispitz, the dominant imaginaries are those of urban development as a human-centered activity, where biodiversity is often an afterthought or an aesthetic addition rather than a central consideration. To create enduring change, these imaginaries must be expanded to include the agency, autonomy, and needs of non-human life forms. For example, the project's use of symbolic interventions, such as the "zoo metaphor" for soil organisms, utilized the power of storytelling and cultural narratives to shape how people perceive and value more-than-human life. The same power of narratives can be mobilized to instill more-than-human values and disrupt underlying imaginaries. Elevating soil organisms to the status of charismatic megafauna, while well-intentioned, inadvertently reinforced anthropocentric patterns of exhibition and control. After careful rethinking, a different narrative could be staged instead that might involve fostering multispecies engagements that challenge visitors to experience the world from perspectives beyond their own. Embodied practices are especially relevant here. For example, by simply inviting participants to touch the soil, and learn about measures to enhance soil health, such practices could shift imaginaries away from control and spectacle toward reciprocity and care.

The ongoing nature of relational attunement underscores that world-making is not a finished product but a continuous process of negotiation, adaptation, and reimagining. Just as ecosystems are dynamic and constantly changing, so too must the imaginaries, communities, and practices that support relational attunement be flexible and open to transformation. This means recognizing that failures and unintended consequences—such as the increased pressure on animal refuges caused by human access—are not endpoints but opportunities for reflection, transformation and careful next steps towards a newly-realized "situational good".

Pluralizing knowledge practices

The *Mitwelten* project's emphasis on DIY sensing and public participation challenges the frameworks of Western scientific expertise and education, experimenting with opening space for pluralizing knowledge practices. It departs from the assumption of agency of devices - an understanding that environmental sensing devices, often perceived as tools of scientific objectivity, can be also recognized as instruments of situated and partial perspectives, shaped by their technical configurations, contexts of use, and interpretive frameworks.

The design and use of digital technologies for engaging with environments can involve pluralistic approaches that reflect an ethos of "land-based coming-to-knowledge," where learning is learner-led and grounded in reciprocal relationships with the land and its inhabitants. This contrasts sharply with the disembodied, top-down knowledge production of conventional science, offering a model for more inclusive and context-sensitive ecological inquiry.

The pluralizing effects of DIY environmental media are not primarily about generating knowledge that confirms the existing scientific paradigms; they are about ability to ask different questions, extending to shaping imaginaries and practices of world-making. Technologies of mediation actively participate in the construction of socio-material realities. A different type of "environmental media" can play a role in this process. *WalkApp* and *Panorama* App developed within the *Mitwelten* project, are screen-based applications that mediate encounters with nonhumans and their habitats. These apps can provide users with access to diverse perspectives, facilitating reflection and discussion around ecological entanglements.

The *WalkApp*, implemented in Reinacher Heide, presented diverse perspectives on the environmental management of a protected area. As Turnbull et al. (2023) note, digitization can both mediate and disrupt ecological relationships, creating spaces where political and ethical stakes are reshaped. The *WalkApp*'s potential to make visible such spaces shows how digital technologies can cultivate awareness of more-than-human concerns and epistemological diversity. The app's “Point of View” feature brought together voices from various stakeholders, such as rangers responsible for enforcing conservation rules, local residents advocating for recreational use, and other stakeholders grappling with overlapping demands on the land. This feature introduced participants to the multiplicity of viewpoints. Revealing these viewpoints is already useful, however the learning lesson here is that this step should be followed by creating a participatory process that could bridge these divides and foster mutual understanding.

This example shows a challenge inherent in approaching ‘wicked problems’ such as biodiversity conservation: the need to not only make visible the diverse perspectives but to create conditions for a dialogue and a process of worlding together. Acknowledging the partiality of any perspective is critical for countering universalizing claims and embracing epistemological plurality. But without active processes to weave these perspectives into a shared narrative, shared vision of how they are all accommodate in a common future, there is a risk of reinforcing entrenched positions rather than building a collective sense of care that includes nonhuman actors. To address these challenges, future iterations of such projects could draw on speculative practices that imagine alternative ways of cohabiting the space. By inviting stakeholders into intentional visioning exercises—where they collectively speculate on how human and nonhuman actors might thrive together—these tools could transcend the “not-in-my-backyard” mentality. Such a process could help participants not only understand but care for other perspectives, including those of the flora, fauna, and ecological processes often marginalized in human-centric debates.

The *Panorama* App, tested in the Merian Gardens, aimed to employ the potential of digital media to foster imaginative and experiential engagements with ecological systems. Screen technologies have been linked by scholars to both producing and reflecting ecological disengagement. The criticisms of "extinction of experience" (Pyle 1993) and "nature deficit disorder" (Louv 2008) describe how digitization often replaces direct encounters with mediated representations, potentially severing people from the lived, embodied connections that sustain care for the environment. *Panorama* used a technique of role-playing to try to overcome this. By enabling users to adopt the perspectives of human, nonhuman, and material actors in the ecosystem, the app encouraged ‘stepping into the shoes’ of another entity that encouraged reflection on interspecies relationships and dependencies. This playful approach draws on the potential of the more-than-human ethic of acknowledging partial perspectives and valuing diverse ways of knowing, and builds on the potential of digital encounters to reorient users’ sensory and cognitive relationships with more-than-human worlds. However, the app also revealed the challenges of abstraction and partiality inherent in digital mediations. By abstracting actors and their interactions into simplified graphic representations, it lost the specificity, multidimensionality and ‘messiness’ inherent in material encounters.

Screen media frequently repackage nature into idealized forms. Representations of "pristine" nature—replete with charismatic species and picturesque landscapes—omit the messy, mundane, or seemingly "unnatural" aspects of ecosystems that are often integral to their functioning or representative of the entanglements of naturecultures. These curated visions reinforce human-centric ideals, presenting nature as a backdrop for human awe or utility while erasing less photogenic elements like decaying matter, invasive species, or industrially altered landscapes. The lens of postnatural technoecological entanglements can help us understand how by privileging aestheticized representations, apps may perpetuate reductive narratives of nature, presenting it as static, bounded, and decoupled from human actions.

To counter these tendencies, designs can emphasize relational storytelling and participatory modes of engagement - as suggested by the role-playing technique. By allowing users to explore ecosystems from the "point of view" of soil organisms or pollinators, the app could further challenge anthropocentric assumptions and encourage an appreciation for the interdependencies that sustain life. Extending this approach might involve making the mediation itself visible - the apps could foreground their situatedness by for example embedding contextual narratives that illuminate the histories and power dynamics behind the assembled elements from history of representation of technology. A focus on multispecies narratives would also provide an opportunity to address the systemic erasures perpetuated by conventional conservation frameworks, which often overlook the contributions of non-charismatic species.

Ensuring that digital media tools genuinely amplify marginalized voices—both human and nonhuman—requires careful attention to the socio-technical arrangements they embody and the contexts in which they are deployed. The process of pluralizing knowledge by engaging with DIY media must go beyond data collection or reading of ecological information, to facilitate meaningful, reciprocal relationships with the land and its inhabitants. This involves creating spaces for collective inquiry, for learner-led learning, and for care that honors the agency and autonomy of humans and nonhumans alike.

By making environmental media tools accessible to non-experts, DIY initiatives democratize environmental observation, allowing diverse communities to contribute their localized, embodied insights. This aligns with Donna Haraway's concept of “situated knowledges,” which emphasizes the importance of acknowledging the partiality and positionality of all perspectives. In this way, DIY environmental media can potentially become tools for appreciating diverse ways of seeing and experiencing the world.

DIY environmental media projects encourage an epistemological plurality that can challenge the reductive frameworks often associated with conventional environmental monitoring. While these tools facilitate encounters with ecological phenomena that might otherwise remain inaccessible, such as the ultrasonic calls of bats or the microbial dynamics of soil, learning how technology mediates and shapes access to these material realities also enables participants to recognize the vastness of aspects of environments that will never be captured. However, by enabling individuals to engage with these “invisible” aspects of the environment, new sensitivities and understandings can complement and expand traditional scientific perspectives.

Embodied accountability

Embodied accountability as a question of responsibility in conservation is an inquiry into how we become attuned to more-than-human entanglements and what it means to design with care. A reflection emerging from the *Mitwelten* project is that environmental media might be best considered not just tools for passive observation but instruments of attunement —mechanisms through which participants learn to register and respond to multispecies entanglements. Following Latour's (2004) and Haraway's (2016) insights that learning to be affected is an embodied and situated process, we consider how environmental media—and the practices surrounding them—can shape and extend the capacities of those who use them, making them more sensitive to the complex, layered agencies of the worlds they inhabit. While environmental media is usually portrayed as technology that makes ecological processes visible, less has been said about how these technologies mediate the bodily and affective dimensions of environmental knowledge. This perspective shifts the conversation from *knowing* the environment to *learning* with and being *transformed* by it.

One of the shifts in approach to biodiversity conservation that the *Mitwelten* project inspires is that DIY participation in environmental media-making does not simply increase public involvement in biodiversity monitoring; it transforms the way participants relate to their environments. The process of developing, installing, and maintaining sensing infrastructures or experimental interventions, beyond being a technical exercise, was also a means of becoming sensitive to the fragile interdependencies at play in urban ecologies. The *WalkApp's* Point of View feature, for instance, does not merely provide factual information about Reinacher Heide but instead stages a space of ecological negotiation. By juxtaposing perspectives from conservationists, recreational users, and local policy makers, it forces a confrontation with the tensions of coexistence in postnatural ecologies—exposing how different ways of valuing the landscape produce different material realities. The *Panorama* App installation at the Merian Gardens, which invited users to experience the garden from the perspectives of various nonhuman species functioned as an educational interface, but it could be argued that it also worked on a more affective level, encouraging users to linger, to look at the garden and its entangled ecologies of natural entities and human infrastructures differently, and to imagine their own bodily presence as only one among many coexisting forms of life. Another example are the Stepping Stone Habitats, designed to function as biodiversity corridors for insects and birds, but that also shaped human awareness of the difficulty of movement for nonhuman inhabitants. As Maria Puig de la Bellacasa notes, attentiveness is cultivated through ongoing engagement (2017), not a one-time action, and embodied accountability arises when through this continuous attention humans begin to be sensitive to, even in small ways, the constraints and possibilities of more-than-human experience in a given environments. Following Giraud (2019), one of the key lessons from *Mitwelten* is that the exclusions produced by environmental media—what they render visible and what they obscure—should not be treated as incidental limitations but as inherent aspects of their worlding. Rather than presenting technology as a neutral tool for biodiversity monitoring, *Mitwelten* positioned it as a site of ethical engagement—one that demands critical reflection on how and why certain forms of environmental knowledge are privileged over others.

The process of becoming sensitive or learning to be affected is a process of bodily transformation. As Kiseleva and Kuznetsov (2024) argue, bodies—including those of designers, researchers, and citizen scientists—become "learning trajectories" that register more and more environmental differences as they learn to work with the sensing and mediating technology. Becoming response-able is not just an abstract ethical principle or a practical skill, rather it is a process of bodily transformation, an ongoing engagement through action and ecological response. The DIY nature of interventions in the *Mitwelten* project made this process evident: rather than acquiring top-down learning following pre-established protocols, participants learned by having to adapt, modify, and respond. This echoes both learning from the land practices discussed by Leanne Simon and Anna Tsing's (2015) concept of collaborative survival, where the goal is not to impose control over an environment but to coexist with its indeterminacies. The *Mitwelten* experiments highlight the value of working with ecological uncertainties rather than trying to eliminate them. By engaging in hands-on, situated tinkering, participants could get closer to cultivating situational good (de la Bellacasa 2017; Baan Hofman 2023)—an ethical practice that is neither prescriptive nor universal but emerges from attentive responsiveness to specific multispecies entanglements.

Another dimension of embodied accountability is material accountability—the recognition that digital environmental media are not immaterial representations but infrastructures that have material and energy impact. Digital monitoring technologies employed in conservation are not inherently "green" - the production, deployment, and maintenance of these devices all entail material and ecological costs. *Mitwelten*'s approach sought to integrate these concerns into the design process. The team experimented with low-power solutions and edge computing (where computation is performed at the node without having to send data for processing to the main data center), and made its media reusable. Most of the IoT nodes were disassembled into their basic components after the project expired and made available to students on a FHNW platform. Making all the outputs of the project open source was another aspect of this consideration.

While reducing environmental impact of technologies is a systemic challenge that is relevant for the entire industries involved, it is also the role of projects like *Mitwelten* to make these impacts visible and to challenge tendencies such as "digital solutionism" of circular logic: when concerns arise about the environmental harms of digital infrastructures (such as e-waste, energy consumption, and resource extraction), the proposed solutions tend to involve even more digital technologies, reinforcing a cycle of technological dependency.

9.3 Outlook

Karolina Sobecka

The *Mitwelten* project and this book have explored the potential of environmental media as tools for relational worlding, aiming to reconfigure how designers and conservationists can engage with more-than-human environments. By integrating feminist STS, posthumanist, and more-than-human design perspectives, the project has approached examining how DIY environmental media, digital sensing, and participatory platforms can move beyond extractive, anthropocentric paradigms and foster multispecies attunement, care, and cohabitation. However, this work does not—and cannot—offer one-time finalizing solutions. Instead, it raises new questions, methodological possibilities, and conceptual directions for the future of environmental media and more-than-human design.

One critical avenue for future research and practice lies in deepening the integration of multispecies justice into environmental media design. While this book has argued for environmental media that recognize and respond to nonhuman agency, many challenges are just starting to become visible: How can design processes meaningfully include the needs and ways of knowing of the nonhuman actors? How can sensing technologies avoid reinforcing existing governance regimes that privilege human priorities? Future work must explore more nuanced ways of designing with and for nonhumans, engaging speculative and participatory approaches that allow for reciprocal, evolving relations rather than static, imposed structures.

A second key direction involves expanding the role of participatory and citizen-led environmental media practices. The *Mitwelten* project demonstrated the value of DIY engagement with sensing technologies, showing how these practices can cultivate new forms of ecological attention, material accountability, and worlding. However, further research is needed to understand how such participatory models can scale, sustain themselves over time, and contribute to systemic change in environmental governance. How might grassroots initiatives leverage environmental media to contest dominant conservation narratives, design and implement studies of their local ecologies, or propose alternative models of ecological care? How can communities develop long-term infrastructures for knowledge-sharing that do not fall into the traps of institutional co-optation, extractive labor dynamics, or technical solutionism?

A third area for development concerns the fact that any action means taking a stand for some possible futures over others. This book has argued that engagement with environmental media should not only be about collecting data and representing ecological processes, but also be a process that reveals the exclusions, assumptions, and power relations embedded in the design and technology choices in any initiative, and more broadly in practices of ecological management. Future work must further investigate how environmental media can be designed to facilitate "situational good"—an ethics of ongoing, experimental engagement that resists universalizing prescriptions and instead facilitates collective negotiation of environmental futures. What kinds of media infrastructures best support this kind of contestation? How might environmental technologies be designed not to impose singular solutions but to open up space for plurality, uncertainty, and deliberation?

Finally, the material and ethical implications of environmental media production itself must be further examined. The concerns around material footprint of digital sensing infrastructures call for a shift toward material accountability in design. Future research could explore alternative materialities for environmental sensing, low-impact media infrastructures, and approaches that explicitly address the colonial and capitalist histories of technology production and use. How can designers, researchers, and practitioners work toward environmental media that do not reproduce the very problems they aim to address? What possibilities exist for low-tech, biodegradable, or repairable alternatives to mainstream digital infrastructures?

The *Mitwelten* project has opened pathways for reimagining environmental media as entangled in the co-making of multispecies worlds. As digital ecologies continue to shape conservation, urban governance, and public engagement, the question is not whether environmental media should be used, but how they can be designed and employed in ways that foster attentiveness, care, and response-ability. The work presented in this book is therefore not a conclusion but an invitation—to experiment, to reimagine, and to continue building practices that make space for diverse, more-than-human ways of living together.

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