PERCEIVING PLANETARITY: COMPUTATION, CLIMATE AND THE EMERGENCE OF ENVIROGRAPHIC ART

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Abstract

This dissertation proposes the term *envirographic art* to denote a new branch of data-driven digital media that utilizes environmental data as an artistic medium to interrogate and communicate the complex realities of planetary ecologies and the climate crisis. Whereas the history of digital media has often overlooked environmental imperatives, envirographic art transforms imperceptible ecological phenomena into sensory experiences, making them accessible to a broader audience. Grounded in the historical evolution of climatology and computational media, and informed by theoretical frameworks such as planetarity and the holobiont concept (which both emphasize the interconnectedness of organisms and ecosystems), this research-creation inquiry outlines three core methodologies: (1) translating raw environmental data into visual, auditory, and tactile forms; (2) engaging the public through citizen science and participatory practices; and (3) fostering transdisciplinary collaborations between artists, scientists, and creative technologists. The proposed approach is exemplified through the presentation and analysis of six artworks developed by the author between 2021 and 2025, which demonstrate how digital mediation can render complex ecological processes both visible and experientially engaging. The findings underscore envirographic art as a replicable framework for generating environmental dialogue and advocacy. Future research will extend these methods to projects addressing air pollution, interspecies communication, and soil health visualization, further exploring the potential of art to serve as an empirical interface for understanding and responding to planetary-scale challenges.

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Introduction

Chapter 1

Introduction

1.1 Envirographic Art: A proposition

In the domain of digital media, environmental concerns are present but do not typically occupy a central position. However, for artists whose practice involves creating new media artworks focused on the climate crisis and care for the living world, this theme often becomes a serious, if not exclusive, focus of their work.[1]

I propose the term "envirographic art", or "envirographics", as a specific type of data-driven computational art intersecting with the broader histories of eco art movements. From this perspective, envirographics describes a domain of research-creation inquiry that utilizes ecological or environmental data, often in conjunction with information technology and data visualization techniques. Envirographics involves the use of digital tools and data-driven methods to create artworks that explore and communicate complex environmental issues, such as climate change, biodiversity loss, pollution, and sustainability. Envirographic artists frequently use climate measurements, pollution levels, biodiversity statistics, satellite imagery, scientific reports, and other environmental data sources to create artworks. Environmentally focused digital media practices overlap with other defined movements of art, such as eco art, bio art, or data art, while still remaining distinct from— or at times oppositional in aim— to the dominant threads of discussion in those fields of inquiry. For example, in distinction from data art, envirographic work specifically focuses on the impact of climate change and environmental degradation.

Examples of artists whose work may be considered to be envirographic include Terike Häppöjä, whose installations often address environmental themes and use scientific data and electronics, and Natalie Jeremijenko, known for her environmental interventions and collaborative projects that combine art, science, and technology to engage with ecological issues.[2][3] My own practice contributes similarly to this dialogue, and its trajectory, inspirations, and recent works are examined in the chapters that follow.

My proposition of envirographic art emerged organically while writing about recent artworks - *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eaters* (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024). I sought language to describe their use of real-time sensor-driven data for environmental inquiry aimed at heightening public awareness of ecological processes and concerns. I realized that the existing terms, such as "eco art", "data art", or "art-science collaboration", did not encompass my own research-creation practice or that of many others along the history of new media art.

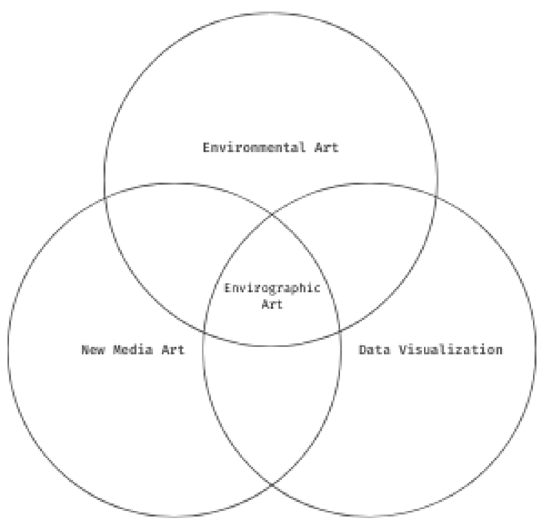


Figure 1.1: Diagram situating the proposed term, envirographic art. (Image created by the author).

Artists like Terike Häppöjä and Beatriz da Costa, for example, integrated environmental metrics with digital interfaces. However, scholarship on these practices appeared to indicate a gap: art theorists writing about environmental artists such as Linda Weintraub and Lucy Lippard seldom highlight computational practitioners, and computational art historians writing about computational or new media practices like Noah Wardrip-Fruin, Stephen Wilson, and Edward Shanken rarely foreground environmentally focused projects.

Occasionally, artists working in this manner have introduced terms for their own practices: Tiffany Holmes described hers as “eco-visualization,” the Manifest Data Project collaborators coined “data manifestations,” and David Green spoke of “scientific reification.” However, none provided a more encompassing umbrella for other artists working in this domain. Through my own iterative art-making process, combined with researching the history of related artistic practices, I have come to believe that a new term is needed. One that can encompass the shared motivations, forms, and functions of digital media practices addressing environmental issues and concerns.

1.2 Defining Envirographic Art

A challenge for all definitional projects is to arrive at a description of core concepts that are inclusive of the genre while sufficiently open enough to contend with the vibrancy of the field of inquiry.[4] Envirographic art, abbreviated envirographics, is intended only as an inclusive articulation verbalizing a long-standing research-creation area and not as a rigid disciplinary boundary. As such, the following is an attempt to describe shared forms and methods.

Key aspects of envirographics include:

- *Data Visualization/Physicalization/Sonification*: Artists use data translation techniques to represent abstract ecological data sets in forms such as animations, sculptures, sound art, and multimodal interactive installations. This helps viewers understand environmental trends, patterns, and relationships.
- *Interdisciplinary Collaboration*: Envirographic art often involves collaboration among artists, scientists, ecologists, environmental researchers, and more. This interdisciplinary approach allows for the integration of scientific knowledge and artistic creativity to address environmental challenges.
- *Technology Integration*: Artists may employ technologies such as geographic information systems (GIS), remote sensing, real-time sensors, and digital mapping tools to collect, process, and visualize environmental data in their artwork.
- *Environmental Advocacy*: Envirographic art aims to raise awareness in communities and societies about environmental issues, provoke thought and discussion, and inspire action toward ecological sustainability and conservation.

- *Critical Engagement*: Artists may critique human impacts on the environment, explore socio-ecological relationships, and envision alternative futures through their artworks.

Many envirographic artworks integrate several of these key aspects. For example, my own project, *We Are Air Aware: AtmoSpheres* (discussed in Chapter 17), is an interdisciplinary collaboration between digital art, atmospheric science, and microelectronics engineering, incorporating real-time environmental sensing and data visualization to advocate for cleaner air in urban environments.

1.3 Related Art and Research-Creation

Envirographic art intersects with movements such as computer art, data art, eco art, bio art, post-naturalism, and SciArt, but it is not synonymous with any of them. Boundaries between areas of inquiry are neither distinct nor clear-cut, mirroring the interconnected and fluid nature of the ecosystems these genres engage with and examine. Both eco art and data art are incontestably foundational for envirographic art, providing important ideas and methods used in envirographics without being synonymous with or adequately defining it. In the following chapters, I will describe the distinct objectives, theoretical frameworks, and methodologies employed by envirographic artists. Naming these collective efforts as an art movement in its own right highlights how artists are using computationally enabled methods to transform environmental data into aesthetic experiences, often with explicit goals such as generating fresh ecological insights or motivations for collective action.

Below is a non-summative list of art movements and genres that intersect with envirographics, while acknowledging that envirographic art describes a living area of accumulating concepts and aspirations, not a stationary pursuit.

- *Digital Media, New Media, or Computational Art*: Computational art is a creative practice that uses computer algorithms, code, or machine learning to generate or assist in creating visual, auditory, or interactive works. It often blends technology and traditional art forms, allowing artists to explore complex patterns, randomness, and interactivity in ways that would be challenging to achieve manually. This genre ranges from digital paintings and animations to immersive installations and responsive environments.[5]

- *Data Art or Data-Driven Art*: Data art encompasses artworks that use data as a primary material or inspiration. Data-driven art transforms raw data into visual or interactive experiences, often blending aesthetics with information to communicate complex insights or narratives. Artists like Refik Anadol use vast datasets and algorithms to create compelling abstractions.[6]

- *Ecological Art, or Eco Art*: Artworks that engage with ecological themes and sustainability. Covers a broad range of art forms that address environmental themes. Often, this involves collaborative efforts with scientists, activists, and communities to address ecological issues through artistic expression. Does not refer to data-driven art. Sometimes also called Environmental Art.[7]

- *Eco-Critical Art*: Eco-critical art examines environmental issues through a critical lens, often using visual arts to provoke discussion and reflection on ecological themes. Artists like Mark Dion and Agnes Denes are known for their eco-critical artworks that challenge societal perspectives on nature and the environment.[8][9]

- *Bio Art*: explores the intersection of biological data and artistic expression, often using computational tools and visualization techniques to create artworks based on genetic sequences, biodiversity data, and biological processes. Artists such as Eduardo Kac and Marta de Menezes engage with bioinformatics to explore ecological and ethical implications through their art.[10][11][12]

- *Post-Naturalism*: Post-naturalism in art challenges traditional notions of nature and the natural world in the Anthropocene era, where human activity profoundly influences ecosystems. Artists like Natalie Jeremijenko and Tomàs Saraceno investigate post-natural landscapes and species interactions through their artworks, often incorporating ecological data and biotechnological interventions.[13][14]

- SciArt or ArtScience: a broad research area that refers to interdisciplinary collaborations between artists and scientists to explore complex issues through creative expression and scientific inquiry. Organizations like Ars Electronica and artists like Heather Dewey-Hagborg engage in SciArt practices to develop work that sits between art and science in innovative ways, often using cutting edge technology and engineering.[15][16][17]

1.4 Environmental Data: Both quantitative and qualitative

Envirographic artists often visualize environmental data in creative ways with specific outcomes in mind. For example, to raise awareness about environmental issues or to explore relationships between humans and the environment. The use of data is not only quantitative, as used in scientific fields of inquiry, but is also qualitatively used to deepen the emotional resonance of an artwork, as described below.

> . . . art can provide people with visualizations of the problem and give them a personal experience with the subject matter, which is especially important regarding climate change as many people still see it as an abstract issue that poses no direct threat.[18]

From this perspective, the affective dimension, or aesthetic surplus, is key. The powerful potential of envirographic art is not located in the mere visualization of environmental realities, such as a graph of rising CO2 levels, but through the generation of "unexpected aesthetic experiences with our co-beings", both human and other living beings.[19] Such perspective shifts help viewers connect better to one another and other species, ultimately perhaps imagining alternate more liveable and thriving planetary futures for all.

In summary, envirographic art merges art, science, and technology to create impactful visual representations of ecological data, fostering a deeper understanding of our relationship with the natural world and advocating for greater environmental stewardship. It emerges organically from the intersection of ecological concerns, computationally driven methods, and artistic expression in contemporary art.

1.5 Envirographic Art and Activism

Beyond ecological connection, envirographic artworks can also be activist in nature, leveraging data-driven aesthetics to provoke new ways of conceptualizing environmental issues. Such public art projects foster emotional resonance that may motivate changes in attitudes or behaviour, and may also lead to micropolitical engagement— thereby constituting a form of cultural activism. Data alone often fail to alter public sentiment, while emotional connection and aesthetic imagination open the door to a level of engagement with the audience that is transformative. Cultural activism is the production of creative events and objects designed to mobilize through affect, and political activism is the production of interactions designed to ignite political change. Artists/activists, creative technologists/hacktivists, and designers may work on both cultural and political activist expressions, and on occasion certain actions may be both one and the other. To further complicate matters, either type of activism is engagement that happens along a continuum. Some expressions are subtle micropolitical engagements, "art with an activist pulse," while others are broadly confrontational and revolutionary in nature.[20]

In the context of cultural activism, certain engagements aim to passively document and witness, while others emphasize consciousness raising, education, agitation, or active intervention.[21] Without evolving coherences that are reductive, cultural activism generally mobilizes for social justice through pathos or engagement of the emotive nature of the subject at hand, and political activism engages more so through logos, the logic of it. However, ethos, or ethical arguments, arise in relation to both logos and pathos.

Significantly, in the context of the climate crisis, activists have long found that facts alone do not sway many. An emotional connection must be made, and this is precisely where envirographic art becomes especially powerful. Art is uniquely able to evoke strong emotional responses from viewers and participants.[22] Art can intersect with activism toward the envisioning of a different way of doing things: speculative framings of potentially alternate futures. Realizing change begins with our capacity to envision a different future, then rallying energy behind that vision. In my own envirographic practice, I do not perceive this type of aesthetic activism to be a substitution for other more direct forms of political activism. Rather, in my view, cultural and political activism are complementary.

In this way, art must not be seen as a surplus, but rather as a vital part of changing societies, and indeed everyday life.[23] Its creation is a generative process capable of making unexpected connections and revealing oft-overlooked viewpoints: helping us to see our planet and ourselves differently. It is as Micaela Martegani beautifully and simply states, "art as it acts on one person ultimately acts on the world at large, and vice versa."[24] From her perspective, engendering political engagement falls very much in the realm of the cultural role of art and artists. As such, envirographic artworks are well suited towards engendering affective responses in viewers, and therefore hold the potential for consciousness raising, reimagining our role in the world through empathy across and between different groups of people and perceived borders.

Through the envirographic artworks discussed in this paper, I will outline investigations of varying success of the intersections and divergences between artistic and activist practices in the pursuit of sustainable planetary systems. This process has generated more questions than answers. However, I maintain one conviction: artistic thinking, along with activism and education, forms a vital part of a collaborative, transdisciplinary effort necessary to meet the profound societal challenges of this century.

Environmental discourse is often one framed by the sciences, by data, and by politics, but frequently these have been overly clung to the idea of utility: nature as a resource for human evaluation/consumption; nature as seen through the human lenses of value. What we need, and have always needed, is imagination, to go beyond utility. The arts and humanities have necessarily always been part of environmental movements. Twenty-first century problems are complex and thorny global and local issues, not solved with simple solutions. From my perspective, these problems are both bigger and more localized than any one discipline can address alone, and therefore are best met in a transdisciplinary manner— transcending discipline, and in fact the academy altogether. What is required is radical teamwork across systems and holistic framing inclusive of pluralistic perspectives.

1.6 Envirographic Art and Environmental Impact

Even as art (envirographic art, eco art, or other) discusses and embodies information about climate change, it also exists within climate change itself. In other words, art simultaneously participates in and contributes to the very environmental conditions it addresses. Like all human activity, it is inherently consumptive. Therefore, it must undergo the same systemic changes climate concerned citizens now seek in all sectors as we strive to balance anthropic demands on Earth with its capacity for renewal, replacing extractive behaviours with transformative climate justice for all terrestrial life. Art, then, carries a responsibility. This is inherent in its position as both a communicator about ecological crises and a participant in them. Although art alone cannot resolve ecological emergencies, envirographic art— when aligned with activism, education, and policy— can support a holistic strategy for confronting planetary-scale challenges.

1.7 Outline of the Dissertation

In the chapters that follow, I pursue three interconnected aims. First, I investigate the cultural and environmental histories underpinning the emergence of envirographic art. Second, I outline the primary theoretical and methodological frameworks, which encompass social practice, interdisciplinary collaboration, and sensory data translation strategies. Third, I present and critically reflect upon six envirographic artworks developed throughout my Ph.D. studies, demonstrating how computational mediation can render ecological processes both visible and experientially engaging. Lastly, I conclude with a brief reflection on envirographic art as a movement and an outline of potential future directions for my own practice.

Section II: Historical and Art Historical Context

This section positions envirographic art within broader historical trajectories, mapping the co-evolution of climatology and computational art practices across the twentieth and twenty-first centuries. It highlights how computational advancements, historical figures, and artistic responses have shaped contemporary understandings of the climate crisis and our interdependencies within planetary systems.

- Chapter 1: Learning Planetarity Through Computation

  Establishes foundational links between the history of climate discovery and computational technologies, introducing the concept of planetarity— drawing on Gayatri Spivak, Jennifer Gabrys, Dipesh Chakrabarty, and others— as a framework for recognizing human agency and responsibility on a planetary scale.

- Chapter 2: From the Origins of Climate Change Through the Twentieth Century

  Traces early milestones in climate science and computational modelling, situating pioneering research and artistic experiments within a broader context of global scientific collaboration, Cold War politics, and technological advancement.

- Chapter 3: The 1990s, Climate Certainty, and the Millennium

  Explores the era marked by the growing consensus around climate change and the proliferation of digital networks and media. It examines how artists combined environmental data and activism, amplifying climate issues through computational and participatory art practices.

- Chapter 5: The Twenty-First Century and The Great Transition

  Examines how contemporary artists leverage digital media, speculative design, and data-driven methods to advocate active remediation and planetary care. This period reflects a significant transition toward art as both an investigative tool and a medium for ecological communication.

Section III: Theoretical and Methodological Frameworks

This section articulates the theoretical foundations and practical methodologies of envirographic art, emphasizing participatory, interdisciplinary, and experiential approaches to ecological data.

- Chapter 6: Introduction

- Chapter 7: Citizen Science, Participatory Action Research, and Co-creation

  Analyzes methodologies that challenge hierarchical knowledge structures, democratize scientific inquiry, and situate public communities as active co-creators of environmental knowledge.

- Chapter 8: Interdisciplinary Collaboration as a Methodology

  Examines historical and contemporary intersections between artistic and scientific inquiry, arguing for interdisciplinary collaboration as a methodological cornerstone of envirographic art practices.

- Chapter 9: Rendering Data Experienceable

  Discusses how envirographic artists employ data visualization, physicalization, sonification, and embodied interaction strategies to translate abstract environmental data into tangible sensory experiences.

- Chapter 10: In the Field, In the Code, In the Image: Reflections on my own Research-Creation Methodologies

  Provides a reflective account of my own envirographic research-creation methodologies, detailing the iterative processes, computational experiments, and site-specific interventions that inform the artworks presented in subsequent chapters.

Section IV: Artworks (2021-2025)

Each artwork examined in this section (Chapters 11-17) operationalizes the theoretical insights and methodological practices outlined earlier. Spanning interactive installations, wearable technologies, and public art, these projects render environmental processes— such as air pollution, climate conditions, plant bioelectric rhythms, and ecosystem data— sensory and experiential. The works discussed include *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eaters* (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024), each reflecting my iterative, interdisciplinary, and participatory approach to research-creation.

Figure 1.2: Working on one of the branches for art installation *Sun Eaters* in the Transmedia Lab at York University in 2023. (Photo by Alomar Kocur).

Section V: Conclusion and Future Directions

In the final chapter 18, I reflect on the overarching potential of envirographic art as an integrative practice at the intersection of computation, environmental data, art, and activism. Looking ahead, my research will expand on current methodological frameworks to investigate areas such as air quality, interspecies communication, and soil health, further exploring the transformative potential of art as an empirical interface for understanding and responding to our shared planetary future.

Part II

Historical Context

Chapter 2

Learning Planetarity Through Computation

> . . . Our future as a species depends on the politics of planetary entanglement defeating the politics of borders and separation. How could that happen? What should planetary politics look like?
>
> –Achille Mbembe

2.1 Introduction

This section traces the historical context that gave rise to envirographic art, which is predicated on the discovery of climate change. It is less concerned with pinpointing the inception of the human activity that induced the climate crisis than it is in focusing on the trajectory of our realisation that it is happening.[1] That is to say that the following three chapters describe our dawning awareness of climate as opposed to weather, of planetary systems writ large, and human entanglement with other species. This was theorized shortly after the birth of the Industrial Revolution by pioneering researchers such as Eunice Newton Foote and John Tyndall. However, it remained impossible to ascertain or characterize until the advent of computational modelling in the mid-twentieth century, beginning with the first general circulation model developed by Norman Phillips in 1956.[2][3][4] The field of climatology was solidified as a domain of research on a parallel with the emergence and formal establishment of computational art and early envirographic artworks and experiments.[5][6] These chapters will trace their co-development in three parts. First, their twentieth-century emergence. Second, the maturation of both fields, coinciding with the resolution of doubt about climate change and renewed fears of planetary systems collapse, including Y2K. Third, twenty-first century shifts away from discovery towards defining what modes of remediation and planetary care are needed—i.e., from the Great Acceleration to the Great Transition. The selection of events and artworks presented here primarily aligns with their acknowledged significance within historical developments, as documented and cross-referenced in the most frequently cited literature on the subject. Nevertheless, it must be acknowledged that any historical selection inherently involves acts of curation by the author. My choices reflect this inevitable subjectivity in primarily two ways. Firstly, I have deliberately endeavoured to uncover and foreground perspectives from key individuals— often women— whose contributions, in my view, have historically been undervalued due to prevailing social structures in the regions where my research has been conducted and focused. Secondly, I have at times emphasized lesser-known artworks precisely because they have significantly influenced my own research-creation practice, the subject explicitly examined in this paper.

2.2 Defining Planetarity

Before proceeding to a discussion of context, further clarification is required regarding my use of the term *planetarity*. In this section, I frequently engage with the concept of planetarity, defined here as "a framework that recognizes humankind as embedded in scalar multiplicities that bridge geologic, social and atmospheric phenomena."[7]

My use of the term planetarity is informed by views outlined in the writings of media theorists Jennifer Gabrys (*Program Earth: Environmental Sensing Technology and the Making of a Computational Planet*), Benjamin Bratton (*The Stack: On Software and Sovereignty*), and Timothy Morton (*Hyperobjects: Philosophy and Ecology after the End of the World*).[8][9][10] These thinkers, in turn, draw from the precedent set forth by theorist Gayatri Spivak, who coined the term in her seminal work *Death of a Discipline*.[11] In this work, Spivak critiques the homogenizing tendencies of globalization, which often reduce cultural and ecological complexities to commodifiable units. Furthermore, globalization, a driving force of modernist thought, functions as a conceptual framework through which the industrial application of technology seeks to neutralize or instrumentalize natural systems for capitalist gain. This dynamic has effectively contributed to an increasing separation between human systems, particularly urban environments, and the living ecologies upon which they depend.

Similarly, the writing of Dipesh Chakrabarty, whose influential essay “The Climate of History: Four Theses” explores how climate change necessitates a rethinking of history and human agency on a planetary scale, aligning with Spivak’s vision, although he does not use the word planetarity itself.[12] The writings of both Spivak and Chakrabarty adopt an alarm-raising tone, serving as early exemplars of the shift in critical discourse from globalization toward planetarity. Their foundational insights anticipate themes that have subsequently been explored in greater depth in the more recent scholarship of Timothy Morton, Jennifer Gabrys and Benjamin Bratton. Gabrys and Bratton, both media theorists, focus more on technical specifics— planetary computation— and given that methodological alignment are greater influences on my point of view.

As I see it, planetarity stands in direct contrast to the projects of modernity and globalization, which seek to supersede natural systems; instead, planetarity attempts to reconnect with and celebrate ecological systems. It emphasizes interdependence and shared vulnerability between humans and other species, encouraging perspectives on our relationships with the living planet that honour its diversity and interconnectedness. It also seeks to resist the commodification of knowledge and culture that globalization frequently promotes. Planetarity is a project of our current historical period, an intensifying time of complex grappling with the multiple systems crises that modernity wrought. This defining of planetarity owes significantly to Achille Mbembe’s work, particularly his most recent text *La communaute terrestre*, which examines the intersections of colonialism, globalization, and planetary consciousness, and underscores the need for a more inclusive and interconnected understanding of the world through rights that do not depend on the nation-state.[13]

Importantly, I am also attempting to bridge humanities planetarity discourse as well as expressly drawing from a range of scientific theory about planetary systems, most notably the writings about the Gaia theory that the Earth functions as a single organism, both from the perspective of James Lovelock (*Gaia: A New Look at Life on Earth*), and Lynn Margulis (*Symbiotic Planet: A New Look at Evolution*).[14][15] I am also shaping my perspective from reading across scientific fields of research that study global biosphere and atmospheric interactions, chiefly bioclimatology and biometeorology, as well as bioelectrical signalling in plants and microbiology.[16][17]

2.3 Planetarity in Relation to Technology

Having introduced the concept of planetarity, it is now essential to consider how technological advancement has fundamentally shaped our understanding of the term, as the two are, in fact, inextricably linked. At first glance, the conceptualization of interscalar relationships among local environments and living beings— extending to planetary and even cosmic levels— might appear separate from technological developments. However, our capacity to comprehend phenomena at planetary scales is indebted to the perceptual affordances of our tools, particularly latent developments such as sensors, satellites, and the computational systems that operate them. The evolution of technological tools and humanity's pursuit of self-understanding and environmental exploration are profoundly symbiotic; we apprehend our world, ourselves, and our place within it through the apparatuses we devise. With the advent of computers, we gained an unprecedented ability to apprehend the living planet at scales— both macro and micro— that transcend ordinary human perception. Consequently, the history of computing technology is intricately interwoven with the evolution of our understanding of humanity's relationship to planetary systems. Through these tools, we have come to recognize ourselves as a global geological force, capable of having induced climate change and to be able to measure and forecast it.

This section seeks to illuminate the profound influence of rapid cultural and technological transformations on the emergence of planetary consciousness, tracing this trajectory into the present. The aim is to elucidate the evolution of digital media and data visualization— across both artistic and scientific domains— and their contributions to our understanding of the escalating global climate crisis. I focus on experimental practices that not only explored but also significantly advanced our grasp of planetary systems and their inherent fragility in the face of human impact.

Finally, it is important to note that computational technologies have not merely enhanced precision and accuracy in environmental understanding; they have also ushered in entirely new modalities of knowledge production and creative expression. Envirographic artists employing digital media— including myself— have been enabled through computation to explore existential questions regarding our relationships with the environment and have over time invented a multitude of techniques and methods by which they do so. These will be discussed in depth, including the use of remote sensors to record environmental phenomena, and the visualization, or sonification of resulting environmental datasets.

Such methods have heightened cultural awareness of climate change, extending the role of art beyond traditional pictorial representation to that of a strategic instrument or autonomous system. Envirographic art, as both a vehicle for public engagement and a catalyst for critical reflection and tangible action, now occupies a pivotal position in the landscape of climate communication. As the climate crisis intensifies and this medium matures, digital art has enabled more comprehensive explorations of planetary ecological understanding and facilitates the envisioning of speculative global futures.

Chapter 3

From the Origins of Climate Change Through the Twentieth Century

> It was an extraordinary novelty (in the development of human societies) that (climate change) became a political question at all. Global warming was invisible, no more than a possibility, and not even a current possibility, but something predicted to emerge only after decades or more. The prediction was based on complex reasoning and data that only a scientist (or artist) could understand. It was a remarkable advance for humanity that such a thing could be a subject of widespread discussion.
>
> *–Spencer Weart*

3.1 From Observation to Calculation

The widespread adoption of computing in research during the 1960s marked the beginning of a critical era, one that ultimately led to the recognition that Earth's climate was warming. However, it is imperative to first acknowledge the antecedent milestones that laid the foundation for this transformative period. The foundations of climatology date back over a century prior.

Eunice Newton Foote is recognized as the first woman in climate science, as she theorized in 1856 that changes in atmospheric carbon dioxide could influence Earth's temperature. She published her findings in a paper, "Circumstances Affecting the Heat of Sun's Rays" which was presented at the American Association for the Advancement of Science.[2] Three years later, in 1859, John Tyndall published a similar study building upon Foote's foundations, likely influenced by the presentation of her paper. His work demonstrated that variations in atmospheric carbon dioxide levels could impact Earth's climate.[3] Their work enabled Svante Arrhenius to predict a few years later, in 1896, that the combustion of fossil fuel specifically, may lead to global temperature increases.[4] However, despite these researchers' early efforts and those of many others, it would not be until the advent of early computers in major research institutions that what would become known as the greenhouse effect would be calculated with precision.[5][6] This would not be achieved until 1955, when Norman Phillips at Princeton, using one of the earliest computers invented, created the first global atmospheric circulation model, a feat quickly iterated upon by others.[7]

3.2 From Calculation to Computation

In the intervening years between the efforts of Foote and Phillips, Tyndall and Arrhenius, more research was undertaken via manual computation. Notably by Lewis Fry Richardson in 1922, through his proposed numerical system for weather prediction, described below:

> His idea was to divide up a territory into a grid of cells, each with a set of numbers for air pressure, temperature, and so forth, as measured at a given hour. He could calculate, for example, a wind speed and direction according to the difference in pressure between two adjacent cells. This would give the pressures and temperatures in the grid cells an hour later, which would serve for the next round of computations, and so forth.[8]

What was essentially a precursor to the contemporary Excel spreadsheet, unfortunately ended in failure. For the speed of the mechanical calculators at the time, even if deployed by a large team, or a "forecast-factory," could not predict weather conditions more quickly than it could unfold in real-time.[9] Therefore, for the next few decades, meteorologists largely gave up hope of weather prediction due to the inadequacy of current-day tools. Scientific interest nonetheless persisted. In 1938, Guy Stewart Callendar presented to the Royal Meteorological Society that atmospheric CO2 had increased from older 19th century publications, but astonishingly his findings were dismissed as unconvincing, possibly erroneous, and either way, totally unimportant.[10]

It would take climate models produced by early laboratory computers to solve the puzzle. Little advances were made until governmental defence research, driven by an attempt to gain an advantage over other nations'armies, drove a resurgence in interest and funding to develop the tools. In the mid-1940s, the United States military chose to continue funding scientific experimentation, through public and private universities. They recognized that their previously top-secret investments in innovations like radar and atomic weaponry had not only contributed to but to an extent determined the outcome of the Second World War.

> Who could guess what basic research would turn up next? Ready access to skilled brains might be vital in some future emergency. Meanwhile, scientists who made famous discoveries would bring prestige to the nation in the global competition with the Soviet Union.[11]

Then in 1946, Princeton mathematician John von Neumann and a cybernetician, began to advocate for the use of computers for numerical weather prediction, and Norman Phillip's breakthrough soon followed in 1955.[12] With the shift from paper calculations to punch cards, the transition from manual calculations to computer-based models represented a significant advancement in climate science. Ultimately it was military funding that drove this proliferation in computing.

It is also worth noting that intra-university disparities between certain science, technology, engineering, and mathematics (STEM) fields and the humanities were set-up, or at least exacerbated, at this time through the hand-picked governmental funding of some types research but not others. Fields such as physical geoscience and meteorology were able to secure backing for their latest research questions much more easily than humanities disciplines such as writing, history, other STEM fields such as botanical science, and the arts. This growing disciplinary divide is described more in depth in the seminal essay "The Two Cultures" by C.P. Snow.[14]

However, in contrast, there was a sudden growth of governmental support for creating international connections between research laboratories at this time. This was a period in which the United Nations was created, the Bretton Woods financial institution, and many other multinational efforts. Governing bodies, after witnessing the atrocities against humanity wrought by Germany and others during the Second World War, desired "to bind peoples together with interests that transcended the self-serving nationalism that had brought so much horror and death."[15] Competition nonetheless continued between countries to reach technological milestones faster than researchers elsewhere, but with the acknowledgement that information sharing between them, at least in some ways, was vital.

3.3 The First General Circulation Models

From the mid 1950s to the mid 1970s, computing power increased literally exponentially, by a factor of several thousand, and this rapid expansion enabled predictive models to improve exponentially as well, from the US to Australia.[16] Increased computing power made possible the representation of a greater number of variables and extended periods of time. Early climate modelling efforts by John Sawyer (1973), Wally Broecker (1975), and James Hansen (1981) demonstrated remarkable accuracy in retrospect, and although some models slightly underestimated or overestimated planetary warming, all closely aligned with official temperature records for the period between 1970 and 2016.[17]

The military funding driving the proliferation of computing was also fuelling increasingly sophisticated global satellite technology. Prior to their invention, the provision of weather data used in computational climate and weather modelling was provided by military weather balloons. However, the invention of satellite data transmission, occurring alongside advancements in computing, provided accurate and rapid worldwide weather data for the first time in human history.

3.4 Thinking in Systems Across Science, Engineering and Art

As computation increasingly swept through university labs from the mid-1950s onwards, it revolutionized the way researchers across various disciplines, including scientists, engineers, and artists, explored and comprehended our planet. This transformative time was marked by the advent of cybernetics theory, as initially described by Norbert Wiener in 1948, in which we witness the emergence of a transdisciplinary framework that aimed to comprehend the intricate behaviours of dynamic biological and technical systems. Wiener was a mathematician employed by the United States military to improve machine gun accuracy. His work on improving automatic self-correction mechanics to reduce gun wobble likely set-up some of his early cybernetics theories.This context is significant, as it highlights how early computational tools and modes of thought were fundamentally shaped by the priorities and perspectives of American military research. Ultimately, cybernetics cast a wide net of influence, permeating diverse fields, ranging from governance, and engineering to the arts.

Interestingly, significant shifts in art come to the foreground in this contextual mileau, marking a transition from process-oriented explorations towards often more structured, systems-oriented procedures and procedural thinking. Interests moved from passive observation to active engagement and from static representations through object making to dynamic forms of expression via installations and happenings. This profound transformation in artistic representations of human experiences extended from individual observations to collective consciousness, from everyday experiences to deep geological timescales, and from localized impacts to a global understanding of planetary geopolitics. Pertinent questions were raised regarding the roles of both creators and viewers in this evolving artistic landscape.

3.5 Chaos and The Great Acceleration

The beginnings of chaos and complexity theories were also developing due to these early weather and climate computational modeling efforts, giving rise to a great understanding of the intricacies of exosystemic interrelations. In the words of Weart:

> A few scientists began to wonder whether the exquisite sensitivity of computer models might be saying something about the real world. Start two computations with exactly the same initial conditions and they must always come to precisely the same conclusion. But make the slightest change in the fifth decimal place of some initial number, and as the machine cycled through thousands of arithmetic operations, the difference might grow and grow, in the end giving a seriously different result.[18]

It was discovered that there were underlying systems of patterns such as feedback loops, repetition, self-similarity, fractals and self-organization. Mathematically described, some of these, such as feedback loops, mirrored newly invented programming control structures used in the laboratory computers. Fields such as bioclimatology and microbiology were significantly influenced, and equally visual exploration of the same realizations through art.

Meanwhile, population and industrialization were exploding in growth worldwide in both disruptive and generative ways. Global population quadrupled during the twentieth century. This period would later would be described as the Great Acceleration.[19] Mirroring the growing interest in chaos and complexity research, the Great Acceleration period - driven by complex computational systems and ever-expanding datasets - introduced fragmentation and seeming disorder. Simultaneous inventions took place in diverse geographies and cracks appeared in and between the newly formed international research and governmental organizations. In addressment, novel methods of sharing climate data sets and ideas were developed such as interdisciplinary research groups and conferences. Early meteorological papers were usually published by a single researcher. Yet after the advent of computing, group publishing became the norm, and together these specialists grew in their understanding. They were beginning to see patterns in the noise and believe there existed a single Earth climate system comprised of the varied more localized climates once studied. Maverick scientist James Lovelock, working together with Lynn Margulis, would soon come to give a name to this system, “Gaia.”[20]

Furthermore, awareness was dawning about what these climate models might mean to humanity writ large. In 1957, Revelle and Suess published findings on ocean absorption of CO_2 and presciently wrote, “human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future.”[21] Overall, this feverish time was instrumental - it saw the creation and early defining of the fields of computer science, digital art and climatology, departing from antecedent linear and static art forms and the fields. It was also the era in which visionary J. C. R. Licklider proposed the Internet, Joseph Weizenbaum invented the first chatbot, and Theodor Nelson coined the term “hypermedia.”[22] These were the years in which artist Hans Haacke exhibited living systems as artworks for the first time, artists and engineers came together revolutionarily to create ambitious projects through Experiments in Art and Technology (E.A.T.), and art critic Jack Burnham gave voice to it all through his seminal essay “System Esthetics”.[23]

3.6 System Esthetics

Burnham's "System Esthetics," effectively condensed into words the pivotal atmosphere of the times, encapsulating the zeitgeist. He critically examined the contemporary developments in art, science, and economics, advocating for a shift from the traditional focus on objects to the embrace of the "unobject." He argued that objects were becoming increasingly disconnected from societal relevance, that art had become post-formalist, and should "act as the bridges or prosthetic joins between . . . artificial and natural environments."[24]

Burnham contended that the sixties was transitioning from an object-oriented to a systems-oriented culture in which "a different set of needs" was arising: "maintaining the biological livability of the Earth, producing more accurate models of social interaction (and) understanding the growing symbiosis in man-made relationships."[25] Artist and educator Gyorgy Kepes at MIT also remarked on this change, describing it as dematerialization, similar to Burnham's "unobject." He wrote:

> . . . there is a steadily increasing movement in science and in art toward processes and systems that dematerialize the object world and discredit physical possessions. What scientists considered before as substance shaped into forms, and consequently understood as tangible objects, is now recognized as energies and their dynamic organization. In the visual arts painters and sculptors have arrived at conclusions not unlike those of the scientists. Artists have liberated their images and forms from the inhibiting world of object. Painting has become the capture and arrangement of visual energies. Through the innovations of a number of contemporary architects and engineers, buildings are also losing their object solidity and opacity to become light and transparent, "thingless" events.[26]

Both Burnham's and Kepes' articulations of this shift towards a systems-oriented perspective underscored its prevalence across the arts and culture and research more generally.[27] The same attempts at dematerialization can be seen even in the field of architecture. Buckminster Fuller's airy Dymaxion structures are one example, and the Pepsi pavilion created for Expo 1970 is another.

This ambitious work aimed to dissolve the perceived boundaries between the built and natural environments, using artificial fog to merge the pavilion with the surrounding sky. "Scientific measurements of the Fog and

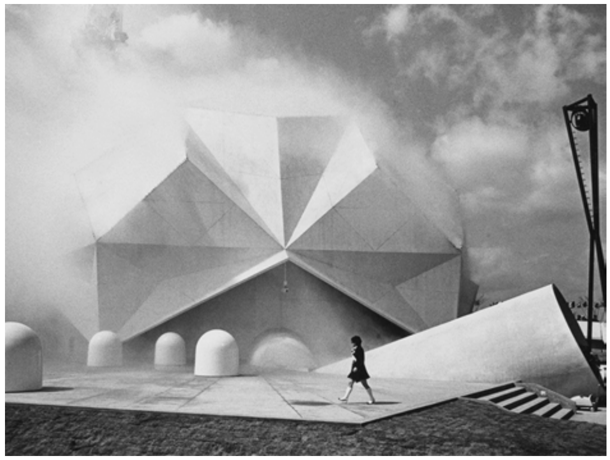


Figure 3.1: Artificial fog enshrouds the Pepsi Pavilion at Expo 1970 in Japan. (Photo by Shunk-Kender from https://spectrum.ieee.org/when-artists-engineers-and-pepsico-collaborated-then-clashed-at-the-1970-worlds-fair).

its reaction to the weather were being made daily," wrote E.A.T. collaborator Billy Klüver in his production notes.[28] The fog emission levels, generated by 2,520 jet spray nozzles capable of spraying 40 tons of tiny water droplets per hour, were reduced or increased based on computations from measurements of the site's meteorological conditions via anemometers, humidity gauges, and thermometers from the pavilion's control room.[29]

3.7 Earthrise and Thinking Planetarily

The year 1968 stood out as a pivotal year for thinking planetarily, even as it was set within a decade of remarkable developments. There was a momentous call to perceive life on Earth as an integrated planetary system, emphasizing the interconnectedness between "natural" and human subsystems. This perspective was notably accelerated by humanity's initial encounters with photographs of the Earth from space.

Bill Anders'iconic "Earthrise" photograph was taken during the Apollo 8 mission and widely published, giving us our first full-colour photograph of Earth taken from lunar orbit. This image revealed swirling white cloud formations over a blue marble of the Earth suspended in the vastness of space revealed to us how small and fragile our world is. This image, and others like it, helped culture shift its scale and recognize the world as a connected, holistic system. Buckminster Fuller, inspired by it, would come to describe our world as Spaceship Earth - our only home - and advocate for greater stewardship of it.[30]

Figure 3.2: The iconic Earthrise image. (Photo by Bill Anders, NASA, from https://www.nasa.gov/image-article/earthrise-3/).

Fuller developed an alternative map of the world, "the Dymaxion Map", showing all of Earth's landmasses connected. Fuller's perspective was that we have been ignoring humanity's responsibility to care for the Earth, which he viewed as a fragile and unique life-affording bubble, making its way along in an indifferent universe.

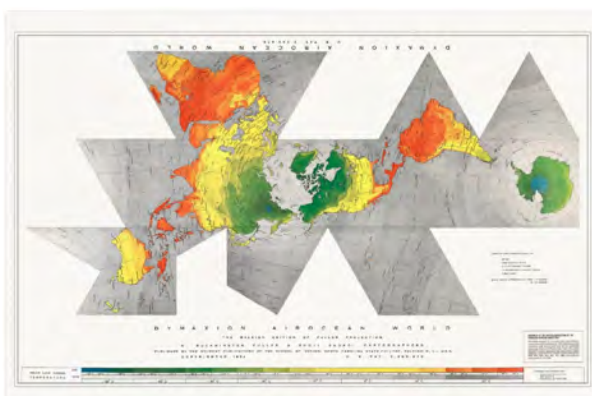


Figure 3.3: Buckminster Fuller's *Dymaxion Map*. (Image from https://www.bfi.org/).

New perspectives on environmentalism were born of this realization. Naomi Kline writes:

> Before those pictures, environmentalism had mostly been intensely local- an earthy thing, not an Earth thing. When environmentalism went into outer space, it adopted the perspective of the omniscient outsider.[31]

Around this time the term "Earth System" gained prominence for the first time.[32] NASA launched Earth

System Science as a theoretical framework for its future research activities. There was a new cultural understanding that there were interactions of physical, chemical, and biological cycles and energy fluxes which gave rise to the conditions necessary for life on Earth, and these could be influenced by human activity. Our planet was small and living conditions more fragile than previously realized.

Figure 3.4: Colour photograph of the whole Earth (western Hemisphere), shot from the ATS-3 satellite on 10 November 1967. (Image from https://en.wikipedia.org/wiki/ATS-3#/media/File:ATSIII_10NOV67_153107.jpg).

Soon more photos began circulating, including this ATS-3 satellite image of the western hemisphere. Like the Earthrise image, it was rapidly distributed. Public interest in space exploration was at an all-time high. This image was used the same year it was released by both Stewart Brand on the cover of the Whole Earth Catalogue and by artist Robert Morris in the infamous Xerox Book produced by New York City experimental gallerist Seth Siegelaub.

Both Stewart Brand and Robert Morris employed the image as emblematic of the prevailing Earth-centric politics of the era. Morris's use of the photo sought to disorient and redefine our collective perception of the planet. He rotated the image by ninety degrees and reproduced it twenty-five times, each iteration less distinct than the last. Morris aimed to dissolve the earth's "object quality" instead offering "an alternate view of ecology that would take the dynamics of energy flow as their founding principle rather than the monumental object."[33] This was a departure from the prevailing materiality-focused environmental awareness of the time. These seminal events collectively encapsulate the spirit of the period and its profound impact our evolving understanding of the planet.

Figure 3.5: *25 plates* from *Untitled (Xerox Book)* by artist Robert Morris, 1968. (Image from https://miacooperferm.com/copy-art-an-overview-of-process-and-techniques/).

3.8 Twentieth Century Environmentalism

The first Earth Day was held in 1970 in the United States, marking the mainstreaming of environmentalism into full public awareness and engagement. By this year, the essential facts of atmospheric warming due to CO2 were at least largely understood, though nowhere near settled. Attention began shifting towards refining predictive models, investigating the global consequences of unchecked CO2 emissions, and activist calls for regulation and cessation.

Despite public awareness, significant barriers to environmental activism persisted, with such work often facing resistance.[34] One notable environmental activist during this period was artist Hans Haacke, who was building artfully arranged "real-time systems" both technical and biological, within which "energy flows and materials respond to each other within actual life contexts." His iconic artwork *Rhine Water Purification Plant* from 1972, deployed a mechanical system to bring polluted water from the Rhine River into a museum in Germany, presenting river sludge as art, alongside a filtration system, live goldfish, and an outdoor garden. In the artwork, the toxic water was displayed on a table in large glass bottles next to a tank of circulating water adjacent to a window overlooking an outdoor garden plot, and beyond it the Rhine. The installation was effectively a water remediation project, with success made evident by healthy plants in the grey water filtration garden and live goldfish in the indoor tank. Public response was positive. However, rather than garner the response desired by Haacke, which was immediate reappraisal of the nearby Sewage Plant's operations, his artwork was removed and museum staffers fired for showing it.

Figure 3.6: *Rhine Water Purification Plant* by Hans Haacke, 1972, in the museum Haus Lange in Krefeld, Germany. (Photo from https://www.wikiart.org/en/hans-haacke/rhinewater-purification-plant-1972).

Many other remarkable environmental artists were also working in a manner similar to Haacke, such as Helen Mayer and Newton Harrison. Operating jointly as The Harrison Studio they created "The Lagoon Cycle" between 1974 and 1984. It was a significant work that combines art and environmental science. As Stupples writes of the Harrisons work on The Lagoon Cycle: "they quickly understood climate change as a problem of systems, drawing on Jack Burnham's proposal that artists should engage with systems rather than produce discrete objects."[35]

Figure 3.7: Image from *The First Lagoon* by The Harrison Studio. (Photo from https://www.theharrisonstudio.net/the-lagoon-cycle-1974-1984-2).

It consists of a 360-foot long and eight-foot tall mural, divided into over 50 parts, and includes images and text. The work features two characters, a "Lagoon Maker" and a "Witness," who explore the ecological and philosophical aspects of lagoons. The cycle is organized into seven numbered lagoons, each detailing different aspects of the project storyline and environmental issues. Through them they depicted a story of two opposing groups, the "haves" and the "have-nots" who have to learn to work together when in the future ocean levels rose.

3.9 Climate Science and Industrial Regulation in North America

The 1970s saw a broad wave of government regulation on industry in response to early climate science research and environmental activism. Problems with smog and acid rain plagued cities and revolutionary activists such as Rachel Carson helped the public to see them as issues too large to ignore. Carson's book Silent Spring and the 1969 Santa Barbara oil spill were among a series of tipping points that launched a "new kind of North American environmentalism, one far more confrontational than the gentlemen's conservationism of the past."[36] In the United States legislation was created to regulate businesses and protect the environment at a scale never accomplished before. A non-summative list includes: the Clean Air Act (1963), the Wilderness Act (1964), the Water Quality Act (1965), the Air Quality Act (1967), the Wild and Scenic Rivers Act (1968), the National Environmental Policy Act (1970), the revised Clean Air Act (1970), the Occupational Safety and Health Act (1970), the Clean Water Act (1972), the Marine Mammal Protection Act (1972), the Endangered Species Act (1973), the Safe Drinking Water Act (1974), the Toxic Substances Control Act (1976), the Resource Conservation and Recovery Act (1976).[37] In Canada, similar changes were taking place through legislative actions including the Water Act (1970) and Clean Air Act (1971), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973), and the Convention on Long-Range Transboundary Air Pollution (1979).[38] At this time, North America was leading the world in legalizing environmental protection, though that would soon be eroded and then surpassed by European countries in the decades to follow.

3.10 The Success Story of Ozone Hole Correction

The idea that the planet's ozone layer could be deteriorated by the emission of chlorofluorocarbons (CFCs) took time to be discovered and accepted, but once it was, decisive correction measures took place swiftly. This timeline provides a stark contrast to governmental responses to the discovery that CO2 and other greenhouse gas emissions were rapidly changing Earth's climate.

A group of nearly 1000 atmospheric scientists, led by chemist Harold Johnston, found that proposed supersonic transport planes (SSTs) in development by aerospace engineering company Boeing, were likely to erode the ozone layer by 10-20 percent and published their findings through a Climate Impact Assessment Program funded by the United States Congress. However, the US Department of Transportation undermined their findings, followed by press journalists who denounced the work as alarmist. Newspapers further hindered their efforts by refusing to publish letters to the editor submitted in response by Harold Johnston and other leading scientists of the time.[39] Meanwhile, NASA began to worry about the impact of space shuttle emissions of chlorine on the ozone but given the climate on capitol hill, wouldn't publish their scientists' findings.

Scientists bravely persevered through different channels. The same NASA scientists stifled by the agency and others, instead published about the effects of chlorine emissions from volcanoes (Cicerone and Stolarski - 1974) (Paul Crutzen - 1974) and about the pathways by which CFCs degraded into chlorine (Rowland and Molina - 1974).[40] CFC use was widespread in industrial manufacturing at this time, emitting billions of points per year. Scientist James Anderson developed a sensor that proved the presence of chlorine monoxide in the stratosphere and this, in conjunction with the US National Academy of Science funding and then publishing conclusively in 1976 linking ozone depletion with CFC emissions, finally shifted public opinion. The EPA and FDA called for regulatory correction within a month of their report.[41] By 1979, after some delay in industry adjustments, the use of CFC propellants was banned, and Congress directed NASA to undertake ongoing and active ozone monitoring.

In direct contrast, when in 1979, a historic US Environmental Protection Agency (EPA) report on coal warned that the use of fossil fuels might bring about "significant and damaging changes to the global atmosphere," within the span of only two to three decades, official response was only a call for more research and no regulation. Environmentalist Rafe Pomerance was instrumental in bringing this important EPA report to the forefront of political discourse, and at first it seemed promising that corrective measures would be put in place. Yet, action remained delayed for several years as oil companies such as Exxon initiated counteractive measures.[42] In an internal memo by Exxon staffer Henry Shaw to his superior: "It behooves us to start a very aggressive defensive program because there is a good probability that legislation affecting our business will be passed."[43] From this year forward an extraordinary amount of time and money invested in lobbying against environmental interests, a number that would eventually soar into the trillions.[44]

3.11 Technophilia, Technophobia, and Land Art

In the same year as "System Esthetics" was published by Jack Burnham, Leonardo Journal was launched by kinetic artist and astronautical scientist Frank Malina championing experimental art at its intersection with science and engineering. Also, the inaugural issue of the "Whole Earth Catalog" was published by Stewart Brand. Brand's "Whole Earth Catalog", offered a heady mix of text, instructions and items for would-be commune dwellers desiring to return-to-the-land alongside cybernetics theories, tools, and computers:

> The catalogue brought together the motley assortment of gardening supplies, architectural plans, and psychedelia that one required to drop out, while supplying the counterculture with the theoretical texts, diagrams, and computing gear that corporate and scientific interests were using to create a powerful administrative state in the aftermath of the second World War.[45]

During the late 1960s and early 1970s, attitudes toward computing split into two starkly opposed camps, creating a dialectical tension that still shapes technological discourse. On one side stood the technosolutionists—engineers, entrepreneurs, and counter-culture "tool freaks" clustered around the San Francisco Bay Area just as it acquired the nickname Silicon Valley (a nod to the silicon-wafer fabrication driving its semiconductor boom). Figures such as Human-Computer Interaction engineer Douglas Engelbart, computer scientist John McCarthy who co-coined the term artificial intelligence, as well as Brand hailed computers as amplifiers of human intellect and catalysts of social progress. Their optimism echoed the era's faith in space exploration and systems theory: if technology could put humans on the Moon, it could surely heal social ills. Brand's Catalog embodied this ethos by placing microchips and satellite imagery alongside communal-living guides, suggesting that computation might be the ultimate tool for building an enlightened society.

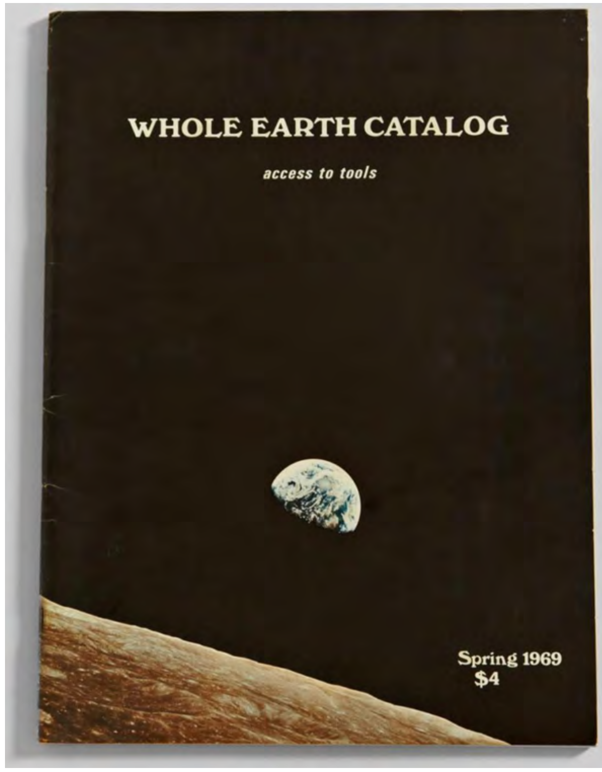


Figure 3.8: Whole Earth Catalog: access to tools by Stewart Brand. (Photo from https://doorofperception.com/2014/06/stewart-brand-the-whole-earth-catalog/).

Opposing voices, however, warned that these same machines— born of Cold-War militarism and cybernetic thinking— encoded logics of surveillance, control, and hierarchy. Thinkers such as Theodore Roszak, the author of *The Making of a Counter Culture,* traced computers to Pentagon-funded projects, such as SAGE early-warning radar and ARPANET, arguing that such origins predisposed digital systems toward systemic coercion. Some cultural radicals rejected industrial modernity altogether, retreating to back-to-the-land communes where hand tools replaced mainframes and self-sufficiency trumped data as the measure of empowerment. For example, widespread adoption of laptops and smartphones reignited these debates, because although ubiquitous computing offered remarkable conveniences, it also enabled unprecedented levels of opaque data extraction and algorithmic influence, even control.

The Catalog thus functioned as both a celebration and a critique of prevailing narratives, profoundly influencing artists grappling with the broader Postmodernist crisis of belief in society, its cultural artifacts, and “the great human meta-narratives.”[46] It seemed to offer potential alternative ways of operating in the world, much like the works of artists such as Haacke and Morris, and the projects of Experiments in Art and Technology (E.A.T.).

Art itself came to be viewed as part of the solution to countering dominant cultural narratives and mounting environmental concerns. Influential artist and educator Gyorgy Kepes optimistically wrote in *Arts of the Environment*:

> Environmental homeostasis on a global scale is now necessary to survival. Creative imagination, artistic sensibility, can [serve] as one of our basic, collective, self-regulating devices that can help us register and reject what is toxic in our lives.[47]

Yet consensus on how art might achieve this was elusive. Against the varied techno-optimistic environmental perspectives of Brand and Kepes stood a growing public unease: “To many environmentalists, almost any new technology looked dangerous.”[48] The spectre of nuclear weapons and the visible ecological damage wrought by industrialisation fuelled scepticism. In this climate, Land Art emerged. Also known as earth art or earthworks, it was form of art created directly in the landscape using natural materials. Land art emerged in the 1960s and gained momentum in the United States and in Great Britain. It often involved large-scale, site-specific interventions in natural environments such as Robert Smithson’s *Spiral Jetty* (1970) and Jean-Claude and Christo”s Surround Island (1983). Both works altered the landscape, treating it as a canvas.[49][50] Although pioneering, sometimes Land Artworks, such as Spiral Jetty, which was carved into a shoreline via bulldozer, had very real negative environmental impacts themselves. Others such as Agnes Denes’s *Wheatfield - A Confrontation* (1982), in which Denes planted and harvested two acres of wheat in downtown Manhattan, were remedial acts that foregrounded care for both land and people.[51] *Wheatfield* and others like it celebrated and offered acts of care for environments and often people in them.

Scepticism toward new media is essential and serves crucial roles. Critical dialogue establishes checks and balances aimed at curbing potential abuses of the tools. As digital humanities scholar Janet H. Murray has astutely noted, these anxieties play a vital role in safeguarding society, when she posited, “Prometheus is a hero to some and a transgressor to others... both are right.”[52] Unequal access to computational tools and knowledge, especially among under-resourced and marginalized communities, and the weaponization

Figure 3.9: *Wheatfield - A Confrontation* by Agnes Denes, 1982, two acres of wheat planted and harvested by the artist on the Battery Park landfill in Manhattan. (Photo taken by John McGrall from http://www.agnesdenesstudio.com/).

of technology for surveillance and social control remain stark reminders of dangerous potentials embedded in each new wave of innovation. Concern and counteractive measures remain vital, for— as Murray's adaptation of the Prometheus myth suggests— every technological fire illuminates possibility even as it risks burning the society that wields it.

3.12 Neoliberalism and Ronald Reagan

When Ronald Reagan took office, his administration ushered in a dramatic shift in environmental policy, framing regulations as a threat to jobs and economic growth and environmental scientists and activists as dangerous. James Watt, Reagan's controversial Interior Secretary, accused environmentalists of advancing centralized control over society under the guise of ecological concerns, likening it to the rise of oppressive regimes in the 20th century. This rhetoric, dubbed "ecofascism," became a cornerstone of the administration's strategy to undermine environmental initiatives.[53] Reagan's neoliberal ideology, which favoured market-based solutions over regulatory measures, dismantled key environmental protections and set the tone for the decades that followed.

Despite this hostility, resistance emerged, particularly from Black communities in the United States disproportionately affected by toxic waste dumping.[54] Their health-based struggles culminated in the environmental justice movement, marked by the First National People of Color Environmental Leadership Summit in 1991.[55] This historic gathering adopted principles that continue to guide the movement today.

Meanwhile, federal investment in climate science stagnated. Although global warming was acknowledged as a potential threat, U.S. funding for climate research remained minimal, with just $50 million allocated annually during the 1980s through the National Climate Program Office, a trivial amount compared to other government programs.[56] International efforts to fill this gap were largely driven by a small, dedicated group of scientists and officials committed to collaboration.

Amid growing scientific consensus, key developments shaped the trajectory of climate research. The 1985 Villach conference marked a turning point when scientists agreed that global warming posed an imminent threat within their lifetimes, urging governments to take swift action.[57] These workshops laid the groundwork for the 1988 Toronto Conference, where scientists called for ambitious targets to reduce greenhouse gas emissions. That same year, the Montreal Protocol in Canada, and the establishment of the Intergovernmental Panel on Climate Change (IPCC) internationally signalled the beginning of coordinated global efforts to address climate change. The IPCC, a hybrid scientific-political body, exemplified international cooperation, operating through consensus and shaping perceptions through its assertion of factual evidence on climate change and about the increasingly precarious state of the planet.

Public awareness of climate change surged in the late 1980s, fuelled by extensive media coverage. By 1989, 79% of Americans had heard of the greenhouse effect, a sharp increase from 38% in 1981.[58] Global warming became a central concern for the environmental movement, though the focus on carbon dioxide gases often overlooked other greenhouse effect emissions like methane and black carbon. Leaders like Margaret Thatcher, who brought a scientific perspective to the issue, began to advocate for action, dedicating funds to climate research and emphasizing the need for global cooperation.

Nevertheless, the influence of free market ideology and capitalist cultural narratives of human dominance over nature hindered meaningful progress. Figures like Tom Pestorius and Fred Singer promoted the belief that technological innovation alone could address environmental challenges without the need for government intervention.[59] This persistent optimism that market forces or technological breakthroughs would save the day reflected a broader unwillingness to confront the systemic causes of climate change. As the decades unfolded, these ideas would resurface repeatedly, slowing efforts to address the escalating climate crisis.

Chapter 4

The 1990s, Climate Certainty, and the Millennium

We see the internet and its associated technologies as a massive leap forward in human evolution, as it has enabled our species to mimic resilient, interconnected forest networks - while simultaneously working and thinking across space and time.

–Willa Köerner
Meg Miller

4.1 Environmentalism and New Media Art in the 1990s

While the 1980s and early 1990s witnessed the rise of personal computing, enabling individual connections via the Internet and personalized virtual reality experiences, the late 1990s and 2000s marked a transition toward mobile telephone use, crowdsourcing, and collective endeavours. This period witnessed a cyclical pattern, with renewed interest in addressing ecological concerns and an intensified focus on environmental data. This was driven in part, by developments in reporting on climate change. The IPCC's 1990 landmark inaugural assessment report, FAR (First Assessment Report) presented a comprehensive evaluation of the available scientific evidence, confirming that human activities were indeed contributing to global warming and subsequent climate change, setting the stage for subsequent international actions and policy responses.

Subsequent assessment reports - Supplemental Reports to FAR in 1992, SAR (Second Assessment Report) in 1995, and TAR (Third Assessment Report) in 2001 - played a foundational role in furthering our understanding of climate change and its impacts, marking significant milestones in the recognition of the global climate challenge.[2] These reports revealed significant anthropogenic disturbances in pre-human cycles of elements such as carbon, nitrogen, phosphorus, in erosion and sediment transport from activities including colonization, agriculture, and urbanization, as well as changes in biosphere cycles of ocean acidity, temperature, species migration, and loss.

All of these were measured statistically in data, which could now be used as raw material to produce art. Artists begin engaging directly with environmental issues, producing works that blend art, activism, and scientific awareness. Once again artists pushed the limits of the tools of the times to explore planetary concerns, deploying environmental data-driven visualizations and sonification to engage audiences while challenging established notions of ecologies and prompting re-evaluations of our preconceptions about the planet.

Digital media art is perhaps uniquely well-suited to communicating about the environment. For example, the mediuminherent systems, such as operating systems, bear a resemblance to environmental ecosystems, comprising planetary systems and subsystems. Additionally, digital media offers a sense of agency, allowing participants to engage with a world that responds coherently to their actions, mirroring the interaction with reality itself but on a more condensed scale, both in terms of time and space. This encapsulation quality facilitates the rapid transmission of narratives and the creation of meaning, transforming the conventional, static, object-oriented nature of previous artforms and eroding the perceived separation between observer and observed. Lastly, computational media artworks'operating systems enable author-user symbiosis through interactive engagement, offering a means of communication between participants, even across species, and it does so over potentially great physical distances and in near real-time. Taken together, digital media's breakthroughs have ushered in an array of new tools for engagement that have continued to evolve in subsequent decades.

4.2 Art and Activism in the Neoliberal 1990s

In the 1990s, North American media and political discourse routinely pathologized climate scientists and activists, dismissing them as alarmists. Their marginalization was reinforced by corporate capture— the undue influence of a private economic elite, particularly large corporations, over state policy, laws, and resources, yielding private gain at the expense of the public interest.[3] This dynamic helps explain the United States' sharply contradictory stance in 1990: while Congress enacted major amendments to the Clean Air Act, the Executive Branch simultaneously worked to discredit climate science. In a political landscape shaped by powerful business interests, climate change was framed as a distant problem, and one predominantly pertaining to countries that now hosted the manufacturing and mining off-shored by neoliberal globalization, rather than a significant threat confronting the so-called "first-world" countries.

Amid this context, artists continued their countercultural attempts to offer compelling alternatives. Through emerging computational art forms like net art and telematics, they challenged capitalist values and sought to foster global connections over the newly proliferating Internet and personal home computing. Although decades of willful political domination and economic extraction would continue to be exported by the United States worldwide, art nonetheless grew as a powerful tool for emphasizing shared humanity and collective responsibility towards the environment.

4.3 Fostering Empathy through Non-locative Interconnectivity

The years leading up to the millennium saw the proliferation of personal home computers connected to the Internet, which brought real-time and non-locative technology out of university laboratories and into residential living rooms. Concurrently, real-time remote environmental monitoring expanded through government-funded efforts, helping to contribute to global discussions on an increasingly changing climate and suspicions of biodiversity loss through real-time environmental monitoring.[4][5] These developments paved the way for artworks centred around communication and remote environmental monitoring and communication. Hubs such as the Banff New Media Institute (1995) were established to foster artistic experimentation at intersections of technology, media, and art.[6]

Some artists became captivated by the sense of greater access to the "real" world through the immediacy and accuracy of "real-time" information:

> The ability to interact with or control remotely located data in real time, to control various technologies (sensors, motors, other computers) in real time constitute the very foundation of our information society. . . (and) many forms of new media art and culture . . . real-time networking and control seem to constitute qualitatively new phenomena.[7]

A compelling example of this is Eduardo Kac's 1994 installation, *Essay Concerning Human Understanding*, which he co-created with Ikuo Nakamura. This installation unfolded simultaneously in Kentucky and New York, via web-based remote communication.

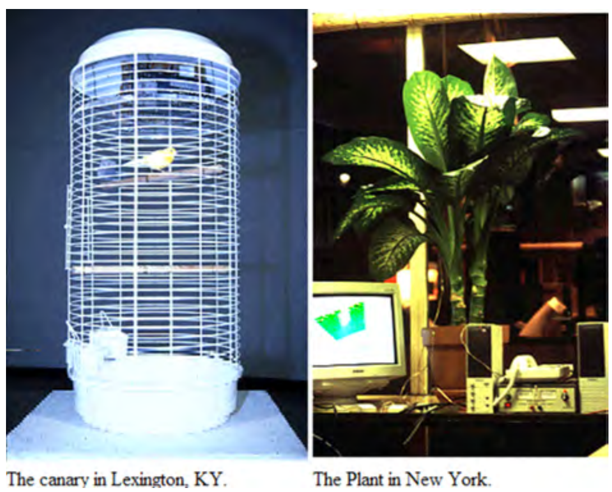


Figure 4.1: *Essay Concerning Human Understanding* by Eduardo Kac collaborating with Ikuo Nakamura, 1994. (Image from https://artelectronicmedia.com/en/artwork/essay-concerning-human-understanding/).

It involved a canary in Kentucky and a philodendron plant in New York, connected online through an electrode attached to the plant's leaf which conveyed the philodendron's response to the singing of the bird. Voltage fluctuation was monitored via their custom software "Interactive Brain-Wave analyzer," which communicated online with another computer controlling a MIDI sequencer. In response to the canary's singing in Kentucky, sounds were played in real-time in New York. Kac observed that viewer interactions with the bird and plant influenced the system, turning all participants into integral components of a cybernetic system characterized by interconnected feedback loops, each influencing the behaviour of the others and the overall system.[8] *Essay Concerning Human Understanding* utilized data sonification to delve into the more-than-human realm and explore the potential of interspecies communication. While it may not definitively foster greater understanding, empathy, or Einfühlung, as conceptualized by Jacob von Uexküll, it invites a critical examination of our assumptions and stimulates the imagination of augmented futures where such dialogues are possible.[9]

4.4 Making Art With Purpose

Art theory in the 1990s shifted to embrace a broader and more interconnected view of cultural practices. It placed the environmental crisis within the context of human-made systems like art, design, science, and philosophy, treating them all as equal contributors. This approach moves away from focusing solely on symbolic or abstract strategies in art and instead brings those symbols into dialogue with practical, real-world applications.

The result is art that has a clear objective, as described by Janeil Engelstad's idea of "making art with purpose."[10] Rather than rejecting the independence of traditional, individualistic art practices, this perspective enhances them by giving artists a space where creativity and meaningful impact coexist. It also encourages creative professionals to think about ethics and meaning in their work.

For artists interested in how art relates to the built (human-made) and natural world, this new way of thinking opens up exciting opportunities. It envisions a collaborative, cross-disciplinary way of working, where different fields come together to create a shared, "transdisciplinary" approach that inspires innovation and addresses complex issues like the environmental crisis.

4.5 A Global Garden

The 1990s saw the emergence of both Telematics and the Net Art movement.[11] The rapid growth of the internet fostered a this creative movement in which artists across North America, Europe, and parts of Asia and Australia began to explore telematic and virtual collaborations. Telematic art redefines the traditional dynamic between active viewers and passive art objects by creating interactive, behavioural contexts for remote aesthetic experiences.

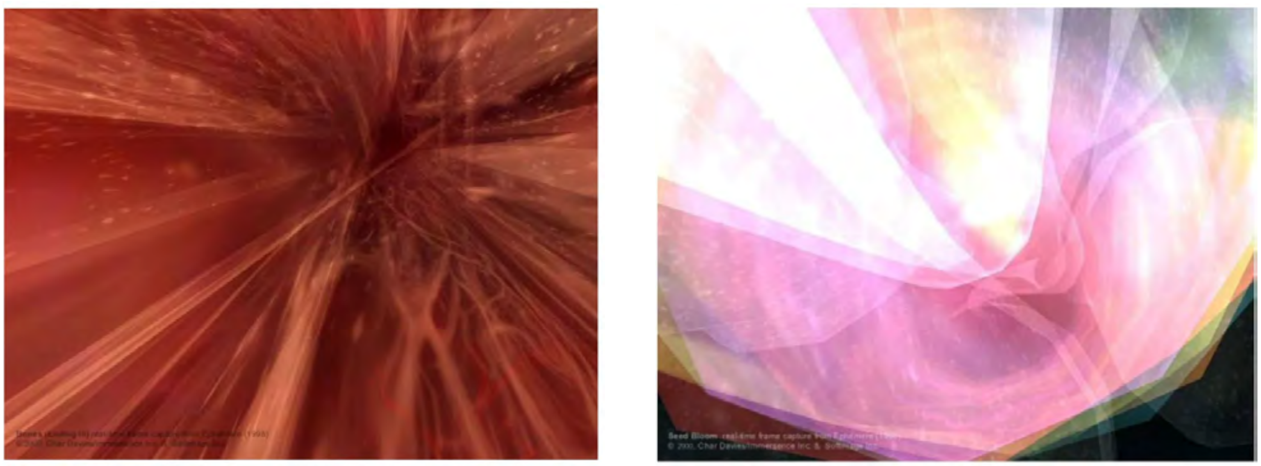
Figure 4.2: *Telematic Garden* by Ken Goldberg and Joseph Santarromana, 1995-2004, in the Ars Electronica Museum, Linz Austria. (Photo from https://goldberg.berkeley.edu/garden/Ars/).

In this context, Kenneth Goldberg's project, *Telematic Garden*, stands out as an important artwork. Collaborating with a team at the University of California Berkeley's robotics lab, Goldberg developed a web-based interface that enabled participants worldwide to tend to a garden via a robotic arm.[12] From planting seeds to maintaining proper water and light levels, "telegardeners" could experience mediated interspecies interactions, and in fact, exercise total control of the garden via a robotic arm.[13] The plants within were at the mercy of anonymous online caretakers, and, as described on Ars Electronica's website, some plants suffered: "there are insects in the garden, certain plants die from lack of water."[14]

However, for the most part, the results of this social experiment were acts of care and community, reflecting positively on society. The artwork allowed participants to chat with one other, and so dialogue, camaraderie, and even friendships emerged as the telegardeners interacted, with some going out of their way to ensure the plants'well-being, arranging surrogate caregivers in the absence of web contact.[15] What was at once a very mechanical system, unexpectedly generated feelings of nurturance and care, establishing an important precedent for subsequent projects involving interactions between humans, other species, and machines.

4.6 Inviting Contemplation in Virtual Environments

Char Davies, is a Canadian contemporary artist considered to be a pioneer in the field of virtual reality (VR) and of the use of bio-feedback in VR.[16] Her ground-breaking artworks *Osmose* (1995) and *Éphémère* (1998) recreated environments in virtual space, accessed through headsets. In both *Osmose* and *Éphémère* she built worlds meant to fully connect the participant's body with her abstractions of a natural environment. For example in *Éphémère*, fractal iconography from nature, including elements like roots, rocks, and streams also reference body organs, blood vessels, and bones, with the aim of symbolically connecting the interior body and the subterranean earth.[17]



(a) *Bones (Ending III)* (b) *Seed Bloom*

Figure 4.3: Two real-time frame captures taken from the *Éphémère* virtual experience created by Char Davies. Left: *Bones (Ending III)* and right: *Seed Bloom*. (Images by Char Davies from https://www.fondation-langlois.org/html/e/page.php?NumPage=102).

Éphémère is structured vertically into three levels: landscape, earth, and interior body. Navigation within *Éphémère* is achieved through the participant's breath and balance, analyzed by a computer program she wrote to link the body via an interface vest and stereoscopic head-mounted display. This biofeedback method of navigation was developed to encourage a contemplative or meditative experience, reaffirming the priority of "being in the world" compared to "doing" things in it or to it.

During public installations of *Éphémère* immersion takes place in a private chamber facing a large darkened space where museum visitors can witness the immersive performances in real-time. The shadow-silhouette of the immersant is projected live onto another screen, emphasizing the relationship between bodily presence and the immersive experience. *Éphémère* premiered at the National Gallery of Canada in 1998 in a solo exhibition.

4.7 Protesting in Physical Environments

At a similar time to the development of the artworks by Eduardo Kac, Kenneth Goldberg, and Char Davies described above, eco art was gaining ground and raising its voice. An important example of this is Rebecca Belmore's performance series *Ayum-ee-aawach Oomama-mowan: Speaking to Their Mother*, begun in 1991.[18] These were powerful performance pieces addressing Indigenous land rights and environmental concerns across Canada. Initially created as a response to the Oka Crisis of 1990, a protest against a proposed golf course on Mohawk territory in Quebec, it was later iterated in a number of contexts in subsequent years.

Figure 4.4: Documentation of Rebecca Belmore's performance series *Ayum-ee-aawach Oomama-mowan: Speaking to Their Mother*. (Photo from https://www.rebeccabelmore.com/exhibit/Speaking-to-Their-Mother.html#null).

Belmore's original 1991 performance consists of a two-meter-wide wooden megaphone that was carried by a procession of about sixty people to a mountain meadow in Banff National Park.[19] The megaphone was used to address the land directly, reflecting her interest in locating the Aboriginal voice on the land and hearing political protest as poetic action. These performances were taking place at at time of heightened public outcry against clearcut logging in British Columbia, such as the *Clayoquot Sound Protests* (1993) in which thousands protested, bringing international attention to the urgent need for forest conservation.

4.8 Climate Change: Moving Beyond Doubt

The 1990s represented a critical decade in the growing realization of climate change as a scientific fact and global crisis. Several key milestones during this period underscored the urgency of the issue, even as political and public consensus lagged behind.

One major event was the Earth Summit held in Rio de Janeiro in 1992, where both Canada and the United States participated in a global conference on environmental protection. The summit emphasized the need for international cooperation, setting the stage for subsequent agreements like the Kyoto Protocol, drafted in 1995. However, progress remained uneven. In 1997, Canada initially signed onto the Kyoto Protocol's goal of reducing greenhouse gas emissions, but the United States unanimously voted against ratification, signalling political resistance despite mounting scientific evidence.

Scientific advancements in climate science at this time were still largely driven by rapid improvements in computer modelling, increased processing power, and access to decades of consistent weather data. These advancements allowed bioclimatology researchers to couple ocean and atmosphere models, offering a detailed and comprehensive representation of the climate system. Satellite instruments further refined the understanding of climate processes, monitoring key parameters like radiation, cloud cover, and temperature patterns, which revealed how clouds influenced warming and cooling in different regions.

A major turning point came in 1995, with the IPCC's publishing of their SAR (Second Assessment Report), a ground-breaking report that solidified the scientific consensus on climate change. The report's key conclusion stated, "The balance of evidence suggests that there is a discernible human influence on global climate."[20] This was echoed by *Science* magazine's proclamation: "It's official. Greenhouse warming has been seen."[21]

While the scientific community rallied around the evidence presented in the IPCC's report, political will, particularly in the United States, remained stagnant. In July 1997, three months before the Kyoto Protocol's finalization, U.S. senators Robert Byrd and Charles Hagel introduced a resolution opposing binding greenhouse gas reductions, which passed the Senate with unanimous support.[22] This stark political refusal contrasted with the growing certainty in the scientific community, as climate change became both an established fact and an even more politically contentious issue.

At the same time, public engagement with it remained limited. Despite the advancements in climate science, the broader public failed to grasp the full scale of global warming. It would take external events, such as the fear surrounding the Y2K systems crisis and the 1999 Erika oil spill off the coast of France, to reignite widespread discussion and concern about global vulnerabilities, including those related to the climate crisis.

Amid this political and social inertia, incremental progress was still made. Canada passed the Canadian Environmental Protection Act (CEPA) in 1999, modernizing and strengthening its environmental policies, particularly in pollution prevention and chemical management. These efforts, while commendable, highlighted the stark contrast between scientific urgency and the sluggish pace of political action during the decade. The 1990s ultimately marked a turning point in the recognition of climate change, with science firmly establishing its reality. However, the lack of political alignment, particularly in the United States, delayed meaningful action, creating a legacy of missed opportunities that would shape the global response to the climate crisis for decades.

4.9 The Y2K Millennial Crisis

The Y2K systems crisis, with its looming threat of global technological collapse, marked an unexpected resurgence of climate discourse. This renewed concern, however, also reflected the deeply entrenched two-party politics of the United States, leading to divergent responses across the global political spectrum. Meanwhile, Western Europeans began to surpass North Americans in environmental leadership during the 1990s and 2000s.

Y2K highlights an important realization - that immediate and local existential threats like system collapse resonate more strongly with political leaders than isolated disasters such as extreme weather events or oil spills. Y2K, much like the iconic Earthrise photograph, evoked a profound sense of planetarity, a shared awareness of the Earth as an interconnected and fragile system.

This phenomenon raises an important question: Can art, if supported by society, play a similar role in fostering a shared sense of planetarity? Art at the least holds the potential to evoke this understanding. It does so by presenting alternative ways of thinking and being. By challenging dominant cultural narratives and exploring new perspectives, art can inspire shifts in collective values and priorities, paving the way for transformative societal change.

Part of the challenge lies in the nature of climate change itself. Its invisibility, global scale, and long timeline make it difficult for individuals to perceive and prioritize this profound problem. Timothy Morton's concept of hyperobjects aptly describes this, as climate change exists beyond direct human experience, further complicating the public's engagement with it.[23] While advances in technology, such as sensors and satellites, have made the invisible measurable - for example, tracking temperature, greenhouse gases, and particulate matter - still they cannot fully address the human disconnect from the problem's scale and scope. Perhaps only art can.

The 2001 IPCC report, the Third Assessment Report (TAR), which targeted climate sceptics, solidified the scientific consensus. It marks the end of debate about whether or not climate change exists, except for a very small group of scientists. However, another major obstacle to action is the monumental paradigm shift required to combat climate change. Addressing the crisis demands unprecedented global cooperation, a challenge compounded by political inertia and a few powerful individuals who continue to undermine collective efforts. The United States, as the leading global power in the late 20th and early 21st centuries, consistently failed to take the necessary steps, unwilling to embrace the systemic changes required. The potential for transformative action existed, but without widespread cultural shifts and systemic cooperation, meaningful progress remained elusive.

Chapter 5

The Twenty-First Century and The Great Transition

> The planetary helps us consider how, in the age of the Anthropocene, the human being is involved in a process of mutual becoming: we are becoming the more-than-human as the more-than-human world is becoming us. This process of intensifying transparency between the human social imaginary and the commingling agencies of the non-human world is the new, uncanny reality of the planetary. We are being invited— some might say initiated— to not only recognise but also creatively realize this way of knowing and being in our time.
>
> *–Jeremy D. Johnston*

5.1 Tipping Points

Around 2005, the phrase "tipping point" began to show up frequently in scientific papers and in media reporting on climate.[1] A climate change tipping point is defined as a critical threshold in the Earth's system or related processes. If such a planetary threshold is crossed, it can cause sudden or even irreversible changes to some of the Earth's largest systems, such as ice sheets or rainforests like the Amazon in South America. The IPCC AR4 (Fourth Assessment Report) was published in 2007, and it describes conclusively that potentially irreversible tipping points do exist in climate, ecosystems, and global processes. The AR4 report highlights the risks that abrupt changes in the climate pose, such as the collapse of major ice sheets, disruptions in ocean circulation patterns, and widespread desertification. Further, the IPCC warns of the interconnectedness of such issues, and crucially, how they will escalate risks of biodiversity collapse. These complex and interrelated systemic developments demand urgent attention and concerted efforts to mitigate their potentially devastating consequences.

Public discussion around these tipping points increases, particularly their potential near-term impacts on rainforests like the Amazon and glaciers at the poles. Below is a history of searches on the popular google search engine for the term "rainforest."[1] They cyclical peaks and valleys seen in this chronology are largely attributed to the return to classrooms each fall, compared with a decline during periods of summer break. "Rainforest" searches would not peak again until August of 2019 during the surge in wildfires reported that summer. In subsequent years, however, searches for "rainforest" as well as "global warming" and other similar terms trend downward overall.

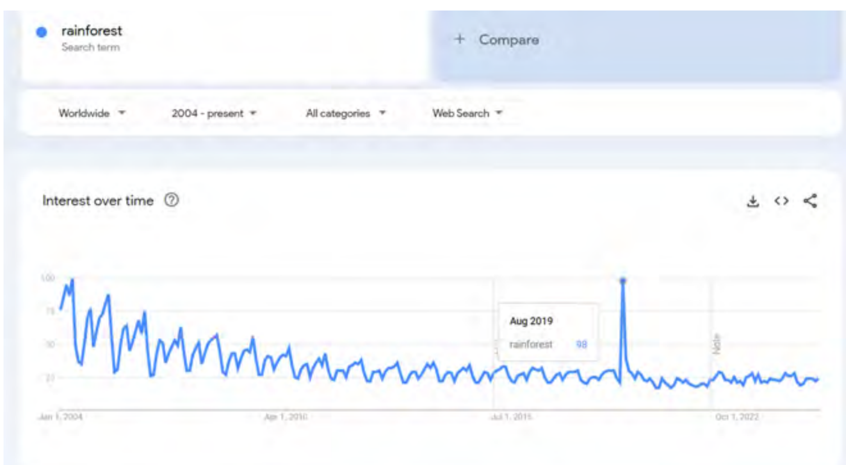


Figure 5.1: Trendline of searches over time on popular search engine Google for term rainforest. (Image from https://trends.google.com/trends/explore?date=all&q=rainforest&hl=en)).

At the organizational level, the 2007 IPCC report created its own tipping points. Attention finally turns sharply from proving climate change to finding solutions. The United Nations Security Council holding its first-ever debate about the international projected impacts of climate change on societies, on April 17th, 2007.[2] Solution-oriented, rather than fact-finding research grew in earnest at universities, non-governmental organizations (NGOs), and some businesses. Banks began estimating the economic costs of climate change up to the end of the century vs mitigation measures. Militaries, notably the United States Department of Defense (DOD), began reporting about the threats of not addressing climate change, from "natural" disasters at military bases to climate refugee migration predictions.[3] Scientists at this time began to adopt a more urgent tone in communicating the risks of climate change. The 2007 IPCC report underscored the dramatic differences between 1.5 and 2 degrees of warming, projecting tens of millions more people exposed to heat waves, water shortages, and flooding if the higher threshold was reached. While the findings themselves were not new, the tone was. For the first time, the message was explicitly alarmist. As noted in David Wallace-Well's *The Uninhabitable Earth*, this marked a moment when it became acceptable for scientists to express the fear and urgency they had long felt, sparking a shift in how climate risks were publicly framed and discussed.[4]

General public concern about climate change was growing too at this time. Below is a history of searches on google for "global warming," with a peak in April of 2007 concurrent with the UN security council debate on climate change.[5]

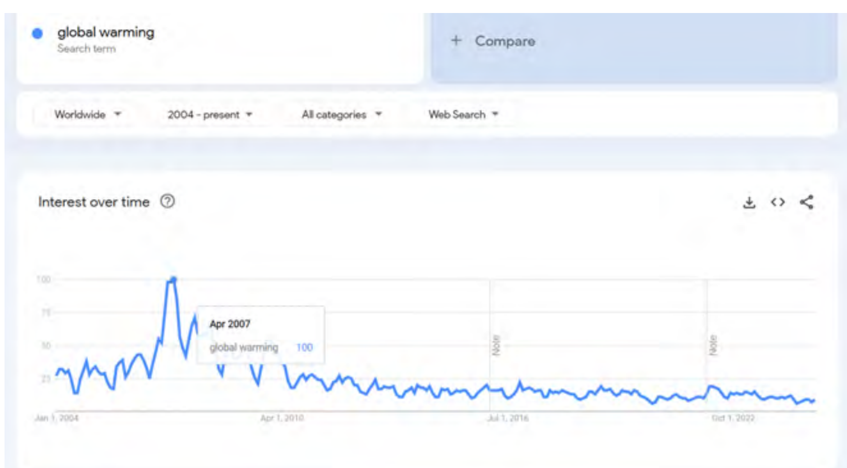


Figure 5.2: Trendline of searches over time on popular search engine Google for term global warming. (Image from https://trends.google.com/trends/explore?date=all&q=globalwarming&hl=en)).

Artworks that responded to these developments at the time include The Harrison Studio's *Greenhouse Britain*

(2007-09). Created by Helen Mayer Harrison, Newton Harrison, and the Harrison Studio, *Greenhouse Britain*, was a multi-part installation that examined the potential impacts of global warming on Britain. Presented across several venues between 2007 and 2009, the project investigated how rising waters and environmental changes might reshape societies in Great Britain, using the slogan, "losing ground, gaining wisdom."[6]

Figure 5.3: Helen Mayer Harrison and Newton Harrison with their work, *Greenhouse Britain*. (Photo from https://www.theharrisonstudio.net/greenhouse-britain-2007-2009)).

The installation included a featured elevation model of Britain with floor projections showing rising waters, accompanied by an audio narration reflecting on societal responses to environmental change. The work involved collaborations with architects, planners, and scientists, proposing new ways to adapt to and mitigate the effects of climate change. *Greenhouse Britain* was exhibited at venues including the Center for Contemporary Art and the Natural World in 2007 and Ronald Feldman Fine Arts in 2009.

5.2 Solastalgia, Eco-Anxiety, and The Sixth Great Extinction

The concept of the sixth great extinction, also known as the sixth mass extinction, refers to our present period of significant biodiversity loss driven by human activities. Unlike previous extinction events caused by natural phenomena, this one is taking place at a rapid timescale like never before. Books such as Elizabeth

Kolbert's 2014 text, *The Sixth Extinction: An Unnatural History* attempt to popularize understanding about this threat.[7]

Meanwhile, artwork of the twenty-first century increasingly addresses ideas of the planet as one of post-natural systems interactions, mourning what is perceived to already have been lost, expressing desires for rewilding, and exploring current and speculative future human-mediated roles in (re)balancing planetary systems. The concept "solastalgia" is proposed by Philosopher Glenn Albrecht and quickly adopted by artists, as a means of describing a form of emotional or existential distress caused by negatively perceived environmental change in the present.[8] Psychologists begin reporting also that "eco-anxiety," or fear of future negative environmental impacts, is on the rise worldwide. There is a growing sense that humanity is at fault: "at this historical junction, the real beasts are man-created; we face ourselves as the enemy."[9]

Figure 5.4: Interactive sculptural, sound and video installation *Skull Stories* by Jordan Bennett, 2012. (Photo from https://www.jordanbennett.ca/2012-skull-stories-1)).

Canadian artist Jordan Bennett's *Skull Stories* (2012) features amongst those addressing the current threats to biodiversity. His interactive sculptural, sound, and video installation, delves into the concept of accessing the memories and histories of once-animate creatures.[10] In *Skull Stories*, a series of cast animal skulls, encompassing rabbit, bear, beaver, and coyote specimens, feature concealed USB drives.[11] Viewers are invited to connect to each via a USB adapter, initiating a video and audio projection throughout the space. These projections depict "key moments" in the animals'past, offering glimpses of video sequences and soundscapes that are Bennett's interpretation of the animals'perspectives and his "imagining of whether the minds of these animals mirror what we perceive they would hold within their memories."[12] The artwork serves as a tribute to these animals.

Through the act of plugging into the skulls, viewers become participants in the narrative. *Skull Stories* raises important questions about how our own actions and perceptions align with those of the animal world. What agency and consciousness do each of the animals possess? Furthermore, how should society interact with these so-called "wild" animals and what are our responsibilities to them and to one another? We are asked to reflect on our contemporary relationship with the natural world and examine our preconceptions in this important installation by Bennett.

Pinar Yoldas's *Orchestra of Endangered Species* (2013), also addresses issues around biodiversity loss as well as species extinction. This artwork was developed in collaboration with researcher Clinton Francis, composer Jamie Keesecker, and engineer Leevina Gray.[13] *The Very Loud Chamber Orchestra of Endangered Species* uses data visualization and sonification to highlight the impact of human activities, such as pollution and habitat loss, on non-human animals. The installation consists of animal skulls, referred to as "Cranial Units," equipped with servo motors, actuators, and speakers that produce sound and movement in response to environmental data.[14] By combining animal sounds with mechanical noise, the project creates a visceral, emotionally charged experience that aims to make environmental data more accessible to the public.

Figure 5.5: *The Very Loud Chamber Orchestra of Endangered Species* by Pinar Yoldas, 2013. (Photo from https://pinaryoldas.info/WORK/The-Very-Loud-Chamber-Orchestra-of-Endangered-Species-2013).

The installation seeks to reconnect humans with the "interspecies culture" of the planet, restoring dignity to non-human life and serving as both a memorial for threatened species and a wake-up call to humanity. The work relies on datasets like CO2 emissions and habitat loss to generate sounds representing the impact of industrialization and environmental degradation. Interactivity is central to the project: a Kinect sensor tracks the presence and location of viewers, influencing the intensity of the sounds and movements, effectively creating a dynamic relationship between the audience and the data.[15]

5.3 Holobionts and The Myth of Individuality

Increasingly in the twenty-first century humanity is perceived more commonly as inextricable from the more-than-human world of other species and the non-living geographies we live upon. "All of our flourishing is mutual," famously explains indigenous scientist Robin Wall Kimmerer, whose writings on the subject in her immensely popular landmark book *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants* from 2013.[16] A similar perspective is echoed in the writing of theorist Achille Mbembe when he states:

> When I look at cosmologies of existence among the Dogon in Mali, or among the Yoruba in Nigeria or other communities in the Congo Basin, what strikes me is the central place these cultures give to the principle of animation— with the sharing of vital breath. Breath is a right that is universal, in the sense that we all breathe, but we do not simply breathe individually. We also share the vital breath. In that sense, we have here cosmogonies that are not at all convinced that there is a fundamental difference between the human subject and the world around it, between the human universe and the universe of nature, of objects and so forth. Everything is an effect of power, an agency that is shaped by all. It is a different ontology.[17]

On this, biologist Scott F. Gilbert appears to be in agreement as well, in his polemic essay *A Symbiotic View of Life: we have never been individuals*, published in 2012, the same year as Bennett's *Skull Stories. A Symbiotic View of Life* was written in collaboration with a historian of symbiosis theory, Jan Sapp, and philosopher of science, Alfred Tauber, to argue that the concept of the individual itself has little scientific merit.[18]

For Gilbert et al., recent advancements in nucleic acid analysis, such as genomics and high-throughput RNA techniques, have challenged conventional definitions of biological individuality by highlighting the essential role of symbiotic microorganisms; essentially blurring the boundaries between animals and plants.

This paper highlights the essential role of symbionts as integral components, introducing a shifted understanding of living entities known as “holobionts.” It updates information first covered by Lynn Margulis in the 1970s. As she articulated, a holobiont is an organism recognized as both a biological individual and a biome composed of integrated ecosystems.[19] Everything in the biosphere is both a whole and a part. This concept was also introduced in *The Ghost in the Machine* by Arther Koestler, although to a lesser degree than by Margulis. Although Koestler’s writings interestingly described computational tools as well, emphasizing that humans and their apparatuses, computers, are not isolated entities either.[20]

Contemporary new media art in the early 2000’s through to today have been significantly shaped by these concepts. As described by theorists Maja and Reuben Fowkes, once believed boundaries between science and indigenous knowledges are eroding:

> Such artistic approaches draw equally on the insights of contemporary science and theory, as well as on traditional wisdoms and indigenous knowledges to overcome the societal disconnect from nature. . . . In light of these insights, climate change is approached here as a planetary process that affects not only populations across the globe, but also natural entities, interferes in vegetal worlds, conditions animal existences and demands a radical rethinking of the human in the terrestrial order.[21]

It is as though we are not only living through a crisis of environmental change, but also once again undergoing massive societal changes in understanding ourselves and our relations here on planet Earth.

A moving example of this can be found in the works of Gilberto Esparza. Gilberto Esparza’s *Plantas Nómadas* (2008-2014) are sculptural holobionts created from custom electronics and featuring living plants and microbial life.[22]

Plantas Nómadas is a symbiotic organism designed with robotic systems, combining organic plant life, microbial fuel cells, and photovoltaic energy. Described by the artist as "an autonomous species whose metabolic cycle has the potential to restore ecological damage," it improves the environment by processing

Figure 5.6: *Plantas Nómadas* (2008-2014) by Gilberto Esparza. (Photo from https://gilbertoesparza.net/proyectos/).

contaminated water.[23] When it encounters polluted water, it absorbs and stores it in microbial cells, where native bacteria biodegrade organic waste and transform toxins. This process not only generates electricity for its energy system, but also enhances water quality, supporting the plants it carries. *Plantas Nómadas* is intended to thrive in polluted environments, such as areas impacted by industrial waste and urban pollution, both present and future.[24]

5.4 Decentring the Human, Pluriversality, and Tentacular Thinking

Contemporary artists of recent years are increasingly seeking to address the challenge of perceiving the planetary biosphere as an interconnected entity, embracing the concept of 'natureculture'over the traditional divisions of nature and culture, highlighting inherent entanglements and dissolution of perceived boundaries, and "shattering the myth of individuality through understanding organisms as sites of microbial kinship and cooperation."[25][26] Furthermore, many artists are frequently attempting remediation, acts of care and kinship across species, and imagining speculative futures in which mutual flourishing is once again commonplace, and they are doing so without monocultures.

Artists are asking questions about whose perspective is being addressed, they are complicating utopic forecasting and notions of singular truths. Artists and theorists in numerous countries are recognizing that plurality in perspectives and acts of care are essential, as there is no single answer. Conceptions of radical interdependence between species and decentring of the human are coming to the foreground, as is an elevation of relation and web-like thinking between, or tentacular thinking, over belief in autonomy.[27] Bioregionalism is slowly replacing globalization, expansive multi-perspectival conceptions of a pluriverse are eroding singular utopias, and eco-feminist approaches are overturning capitalist logic.[28][29][30] Deep listening and careful looking are encouraged, "premised on the capacity to know together, to generate knowledge together."[31][32] In the beautiful critical anthology *Along Ecological Lines* Barnaby Drabble describes these developments as a leaning into an "expansive ethos of human-decentered cosmologies towards a pluriversal, ecocentric position."[33] Through this lens, artists are calling on humanity to address issues such as climate change and environmental pollution, while linking them to gender justice, social equity, and global solidarity.

Donna Haraway's writings on the subject feature prominently in a number of artists'practices. She eschews anthropic perspectives, and even the word Anthropocene itself, in favour of "Chtulucene" and tentacular thinking with regards to the interconnectedness of all life, "a rich wallow in multispecies muddles."[34] Haraway's Chthulucene name comes from Pimoa cthulhu, a spider in the redwood forests of California near her home, and she describes her thinking about relationality: "Tentacularity is about life lived along lines - and such a wealth of lines - not at points, not in spheres."[35] Haraway ascribes the importance of thinking along lines as a gentle coming towards understanding Planetarity, defining Gaia as "complex nonlinear couplings between processes that compose and sustain entwined but non-addictive subsystems as a partially cohering systemic whole," and utterly transcendent of the sum of its parts.[36]

Artists today are reimagining the environment as a shared "bio-technosphere" where humans and non-humans coexist and co-create through "cosmotechnics", rather than viewing nature as external to humanity.[37][38] As curators Mariana Pestana and Pedro Gadhano describe in their recent ground-breaking exhibition *Ecovisionaries: Art, Architecture, and New Media After the Anthropocene* state, "The environment, the surrounding world, is no longer what is external to the human animal, no longer 'nature;' it is instead 'our' bio-technosphere, which we share, inhabit together, and therefore also engender."[39] This perspective critiques economic systems that exploit and devalue the world outside their interests, turning it into waste. Through interdisciplinary collaboration and the use of media technologies, artists seek to draw attention to these dynamics and invite reflection on how humans interact with and impact the world around them.

5.5 More-Than-Human Worlds and Multispecies Exchanges

A prime early example of more-than-human interspecies exchange can be found in artist Terike Häppöjä's work. In her 2008 installation, *Dialogue*, museum visitors are invited to sustain live trees growing through a platform by engaging in a unique interaction. A bench near the trees invites visitors to sit and initiate the process of providing a gift to the trees through whistling. When they do, a carbon dioxide sensor activates and turns on spotlights focused on the trees'branches, initiating the photosynthesis process. The trees respond to the visitors'contributions with an audible whistling, creating a call-and-response interaction. Haapoja explains her intentions by stating,

> The interaction between species is thus physical, as we are practically parts of the same metabolism. I wanted to address the relations of human and nonhuman world in a playful tone, by suggesting that the interaction with human breathing, technology, and photosynthesis could be understood as a dialogue, not as a mere reaction, but as communication.[41]

Terike Häppöjä aimed to convey that the relationship between humans and the natural world is a form of exchange, emphasizing interconnectedness and even interdependency between species. Häppöjä's work reflects the idea that there is no *other*. As humans exhale carbon dioxide into the atmosphere, photosynthetic organisms fix the carbon dioxide and release oxygen, creating a symbiotic cycle that sustains life. Her writings regarding her shift to digital media and electronics are reminiscent of not only Donna Haraway's tentacular thinking but also harken back to Jack Burnham in *System Esthetics*. As Spela Petric describes it, "I was frustrated dealing with dead subjects in dead museum spaces that were so detached from what is really happening in the world. I needed to return to real time and substance."[42] Here, electronics offer a means of sensing the "more-than-human" and provide a closer approximation of understanding the ontologies of other species.

Another exciting artwork to use electronics to attempt communication across species is Spela Petric's artwork, *PL'AI,* as it undertakes the use of machine learning as a translational tool, learning from the plants over time through the framework of a game, and rendering that communication visible to us as an artwork. Furthermore, it does so from a perspective of optimism, scarce in the field at this time.

Spela Petric's artwork, *PL'AI*, represents the third installment within her broader opus, *PLANT-MACHINE*, and stands as a compelling example of agential exchange with a plant, emphasizing the central role of play in this creative process. *PL'AI*, delves into the idea that play constitutes "an ontological condition for all

Figure 5.7: Installation view of *Dialogue* by Terike Haapoja in the Venice Biennale, The Nordic Pavilion, 2013. (Photo from https://www.terikehaapoja.net/dialogue-2/).

Figure 5.8: *PL'AI* by Spela Petric, 2020. (Photo from https://www.spelapetric.org/plai).

living entities, including plants."[43] Play, distinct from games with clear rules and goals, is an embodiment of curiosity, essential for self-awareness.

The artwork unfolds as a multi-month process involving the interaction between plants grown from seed and an AI robot, whose perceptual world is confined to these plants. This prolonged play transcends human timescales, offering insight into how artificial intelligence can be shaped by plants, and conversely, how plant morphology can be influenced by the robot's interventions, echoing in many ways Kenneth Goldberg's

Telegarden. Petric's work aligns these seemingly disparate entities, a plant and an AI, within the context of play. Historically, plants and machines were not held as distinctly separated. Philosophers, tracing back to Aristotle, often viewed plants as devoid of agency or soul due to their apparent immobility, treating them merely as mechanical entities.[44]

Rather than deconstructing or denying this hierarchical perspective on life forms, Petric embraces the companionship and shared history of imaginings between plants and machines. Through play, we witness the transformation of their constraints, unlocking the possibility of their existence in a different context. This artwork unveils a new temporality, one that is neither solely that of a plant nor exclusively of a machine but is already mutated by their respective needs and desires, along with our own implications. *PL'AI* blurs the boundaries between plant, machine, human, and non-human, fostering a collective experience where bodies engage in laughter, celebrating the joy of play and evolving into something more profound. As Petric puts it, "Through *PL'AI*, what is a plant, what is a machine, what is a human, what is a non-human blurs and overlaps [and] we become bodies laughing, embracing the joy of play while becoming otherwise."[45]

Today, a number of artists recognize that we are all interconnected entities engaged in symbiotic entanglement, where our lives depend on each other for sustenance, thriving, and ultimately for our collective survival. Contemporary digital media artists such as Petric and Häppöjä have embraced this reality, aligning their work with the interconnectedness found in the ecosystems we share with our more-than-human companions.

5.6 The Great Transition and Envirographic Art

The breach of the 1.5-degree warming threshold in 2024, followed by the U.S. withdrawal from the Paris Agreement in January 2025, together mark another critical loss in the effort to slow climate change. With the world's systems increasingly destabilized, there is a need for "what some innovative economic thinkers have taken to calling 'The Great Transition.'"[45]

The Great Transition, a comprehensive reorganization of human and planetary systems, has never been more urgent. This can be defined as a period of rapid change that results in planetary systems characterized by cooperative social organization and the creation of less ecocidal relationships with more-than-human worlds on a post-carbon planet. The goal is to balance anthropic demands on the Earth with its capability to regenerate.[46]

The attempt to transition will challenge long-standing economic, cultural, and political paradigms. As Achille Mbembe asks, “Can we rely on infrastructures that have, to some extent, contributed to turning the world into a burning house?”[47] We cannot, therefore we are faced with the necessity of what Naomi Klein describes as the “overturning the divisive logic of rationalist modernity.”[48] Similarly, Klein highlights the need to replace the failed stories of hyper-individualism, growth, and exploitation with narratives rooted in reciprocity, interdependence, and cooperation.[49] We are faced with a generational transition period, in which climate solutions equal climate justice through working to rebuild a world that we want to live in ecologically and socially. This is not simply a call for policy reform but a demand for an entirely new worldview— one that liberates the political imagination and enables humanity to see itself as part of a collective planetary system.

I believe that envirographic art has a vital role to play in this. As Gyorgy Kepes argues, creative imagination and artistic sensibility act as self-regulating forces, helping us “register and reject what is toxic and find what is useful and meaningful.”[50] Art can shift cultural narratives by making visible the values of collectivity and solidarity and by confronting the myths of modernity that have perpetuated the divide between humanity and nature. Through its speculative and imaginative power, art allows us to explore alternative futures and rethink our relationship with the planet.

Managed degrowth, as described by numerous economists and critical theorists, aligns with this transition, emphasizing the need to address overconsumption, reduce inequality, and create a more equitable and sustainable society. As Raimar Stange writes, “art must communicate the urgency of fast and uncomfortable action, while fostering the cultural shift required to meet the demands of the climate crisis.”[51] This vision is not about returning to pre-industrial systems but about building a world that prioritizes collective well-being over exploitation.

Drawing lessons from transformative movements of the past, we see that cultural change, though intangible and difficult to measure, is central to systemic transformation. These movements expanded the realm of possibility by imagining alternative futures and embedding morality and compassion in their work. In the context of the climate crisis, envirographic art can inspire humanity to embrace the challenges that face us, choosing bravely to see them as a generational opportunity to redefine humanity's relationship with the Earth. "The future cannot be predicted," as Gyorgy Kepes reminds us in *Arts and the Environment*, "but can be invented."[52]

Part III

Theoretical and Methodological Framework

Chapter 6

Introducing the Theoretical and Methodological Frameworks of Envirographics

6.1 An Overview of the Theoretical and Methodological Frameworks of Envirographics

In the following four chapters, I lay out the conceptual and practical foundations that underpin my envirographic art practice, an approach I position within a broader movement in digital art that merges environmental engagement with creative data practices. In research-creation, theory and method are not separate domains; instead, they co-evolve, each informing and transforming the other. Throughout this section, I draw on participatory, interdisciplinary, and data-focused lenses to show how envirographic art can produce new modes of knowing about our environment, ourselves, and the computational systems that mediate them.

In chapter two, I examine collaborative and participatory approaches that bring artists, scientists, and local communities together in producing knowledge. Here, I highlight how these methodologies challenge hierarchies of expertise, shift authority dynamics, and help democratize inquiry— fostering both social impact and artistic innovation.

Chapter three traces the historical separation of art and science, then explores how contemporary thinkers and practitioners have sought to bridge these divides. Drawing on examples of art-science collaborations, I illustrate how cross-pollination among disciplines germinates hybrid methods and new frameworks for understanding and communicating environmental issues— a key element of the envirographic art landscape I proposed in the introduction.

Focusing on data as both raw material and medium, chapter four discusses varied artistic approaches to the interpretive act of translating ecological and atmospheric data into tangible, affective experiences. This chapter discusses how art practitioners employ visualization, physicalization, sonification techniques to render the imperceptible vivid and urgent. I show how these strategies extend public consciousness of planetary change and redefine the scope of computational art.

Lastly, in chapter five I offer a personal account of how I integrate these theoretical and methodological insights into my envirographic art practice. This section delves into my fieldwork processes, computational experiments, and visual strategies, setting the stage for the data-driven artworks I discuss in subsequent chapters. By reflecting on my own methods, I demonstrate how envirographic art merges environmental inquiry with computational techniques, aligning with the larger movement outlined in my introduction.

Collectively, these chapters articulate a cohesive framework for research-creation in envirographic art, illustrating how social participation, interdisciplinary collaboration, data mediation, and field-based experimentation generate profound insights into environmental phenomena. They also establish the conceptual bedrock on which my own research-creation projects stand, shaping both the questions I ask and the modes of engagement I pursue.

Chapter 7

Social Practice: Citizen Science, Participatory Action Research, and Co-creation

7.1 Introduction

The act of knowledge production has traditionally been framed as the domain of institutions— universities, research labs, and government bodies— where experts dictate the terms of inquiry. However, participatory epistemologies challenge this hierarchical model, arguing instead that knowledge is situated, collective, and co-constructed through interaction.[1] Feminist epistemologists such as Donna Haraway have emphasized situated knowledge, the idea that objectivity is not an all-seeing, neutral position, but rather an embodied, partial perspective shaped by lived experience. Similarly, participatory action research (PAR), citizen science, and co-creation methodologies assert that research should not be something done to a community but rather something co-produced with and by those it seeks to engage.

When researchers invite public participation into the process of knowledge production, they do not simply expand access to research— they transform its very structure and impact. The integration of diverse lived experiences introduces new modes of inquiry, alternative forms of expertise, and a more reflexive, relational approach to knowledge-making. Rather than reinforcing top-down, institutional models of authority, participatory research can foster reciprocal knowledge exchange, where insights emerge through dialogue, practice, and collective sense-making.

In envirographic art, participatory methodologies take on additional significance. Environmental issues— particularly those related to pollution, climate change, and ecosystem degradation— are often imperceptible, large-scale, or slow-moving, making them difficult to experience directly. Additionally they are not merely abstract scientific concerns but deeply lived realities that affect people (and species) unequally. Art-science collaborations that employ use participatory methods create alternate infrastructures for sensing, interpreting, knowing, and responding to these crises, offering embodied, affective, and localized modes of engagement. By positioning the public as active participants in environmental research— whether in data collection, environmental monitoring, or knowledge dissemination— such projects dismantle conventional boundaries between expert and amateur, artist and scientist, observer and observed.

This chapter explores how these participatory methodologies operate in contemporary research-creation practices, examining key projects by Brandon Ballengèe, Beatriz da Costa, Natalie Jeremijenko, and others. Through my selection of practitioners and projects, I highlight notable artworks that have had a significant public impact, demonstrating how participatory approaches can expand the boundaries of environmental awareness, foster new modes of engagement, and redefine what it means to "know" in an era of ecological uncertainty. At the same time, I call attention to works that have significantly influenced my own envirographic practice, shaping the approaches I outline in the final chapter of this section.

7.2 Using Citizen Science Methods in Art

Citizen science is a means of involving non-professional scientists in the scientific process: in collection, analysis, and/or interpretation of data for scientific research. Its aims include democratization of knowledge production, broadening the scale of data collection, and fostering public engagement with science and often, environmental, issues.

One notable example can be seen in the artwork of Brandon Ballengèe, a researcher who is both an artist and a biologist by training. Ballengèe's research-creation practice often begins with exploratory walks through various ecosystems, and these experiences position him to directly observe environmental changes caused by human activities. Through curiosity-led project development he has progressed from solo walks inspiring the creation of artworks to leading public walks and creating space for their participation to inform the work.

Through his early solo walks in the mid 1990s, Ballengèe was among the first to raise the alarm when nitrogen and phosphorus pollution from agriculture, ranching and residential runoff led to a significant rise in amphibian deformities and fatalities in North America.[1] As an environmental activist and artist, Ballengèe responded to what he saw with a plan to document this concerning phenomenon and share it with others. This led him to develop a novel photography process which became both an artistic and scientific method. He developed a special chemical process that renders skin and other tissues transparent while staining bones and cartilage in vibrant colours.

Figure 7.1: *DFB 45: Arès* by Brandon Ballengèe, 2008. Photo of a cleared and stained Pacific tree frog collected in Aptos, California in scientific collaboration with Stanley K. Sessions. (Image from Art + Science Now by Stephen Wilson).

This technique enabled Ballengèe to create his aesthetically arresting images, which act as photographic records of the affected frogs and catalysts to spur on environmental remediation efforts. His series of light-box reliquaries featuring these images, are both visually captivating and emotionally evocative. In addition, this process became adopted more broadly by the scientific community as a new and useful scientific imaging method for other research applications.[2]

Ballengèe views the dissemination of scientifically accurate, visually provocative information as a critical component of engaging the public in environmental research and activism. In an interview with the Smithsonian, he elaborated on this philosophy:

> I'm really interested in the term activist meaning "to activate." Imagine if you can activate people to look at an environment as all those little individuals— all those little insects, all the little frogs, all the organisms that are out there— as part of their community. Getting people to look at ecosystems that way, I think, really changes their perspective and their actions and behavior. I just love the idea of sculpting society through ideas. That way you can activate and inspire one another toward better and more sustainable behaviors.[3]

Ballengèe's approach is an artistic one, but not only. Through citizen science, he is also actively engaging in giving a broader audience access to scientific research. He refers to these public field research outings as "ecoactions," and sees them as a means of reciprocal learning: "I'm learning from them too... I'm often a tourist as a researcher ... going in for a year or two and don't have the background of growing up in the area."[4] This approach embodies the spirit of citizen science, democratizing knowledge production.

Ballengèe's approach exemplifies how artistic and scientific processes can work jointly to shed light on complex topics, highlighting their common aims. I believe that this type of collaborative culture is increasingly necessary in the face of rapid climate change because it can enable more rapid discovery of and response to environmental problems.

Two more citizen-science projects that arose in the period following Ballengee's pioneering research are *Pigeon Blog* by Beatriz da Costa (2006-08), and *Feral Robotic Dogs* by Natalie Jeremijenko (2005-ongoing). Both feature a type of citizen science activity sometimes also referred to as grassroots data collection.

Figure 7.2: *Pigeon Blog* by Beatriz da Costa, 2006-08. (Image from https://nideffer.net/shaniweb/pigeonblog.php).

Pigeon Blog by Beatriz da Costa is a project that brought together homing pigeons, artists, engineers, and pigeon enthusiasts in the greater Los Angeles area through a common goal of engaging in "citizen science", a grassroots initiative for collecting scientific data. The particular focus of this work was the gathering and dissemination of information regarding air quality in Southern California.[5] In contrast to many other artists'environmental data visualization projects of the time, which commenced with an existing scientific dataset, *Pigeon Blog* distinguished itself by uniting artists, scientists, and the public; thereby democratizing the process of data collection. The project endeavoured to redefine the concept of citizen science, bridging the divide between scientific research agendas and the concerns championed by activist-minded citizens. Furthermore, it aimed to reignite a sense of urgency surrounding air quality issues that have substantial health repercussions but frequently lack a commensurate level of public action and commitment.

The project outfitted pigeons with custom-designed miniature air pollution sensors, facilitating the real-time transmission of localized data to an online server accessible via Google's mapping environment.[6] This unique endeavour sought to amalgamate do-it-yourself (DIY) electronics development with a citizen science framework while exploring the potential for interspecies collaboration in advocating for societal change and environmental justice. It reimagined the coexistence of pigeons in urban environments, acknowledging the remarkable adaptability of these often-maligned creatures, representative of vulnerable populations.

On the opposite coast, Natalie Jeremijenko was undertaking *Feral Robotic Dogs* (2005-ongoing), a grassroots data collection campaign similar in many ways to da Costa's work.

Figure 7.3: *Feral Robotic Dogs* by Natalie Jeremijenko, 2005-onward, (Photo from https://inhabitat.com/robotic-pollution-sniffing-eco-dogs/).

Feral Robotic Dogs involves the creative repurposing of toy robotic dogs for environmental sensing. The toys are retrofitted with sensors by Jeremijenko in collaboration with engineering students at Yale and deployed by volunteer citizen scientists to monitor and detect environmental contamination in industrial and brownfield areas in the united states. The project aims to raise awareness about potential environmental hazards in areas "officially declared decontaminated" and "safe for redevelopment."[7] Jeremijenko underscores the importance of this type of citizen science engagement and the use of the toy dogs to do so:

> It's necessary to have such devices to ground the information in something comprehensible, because the EPA, satellite images, GIS, they're not publicly legible. Even though they're publicly accessible, they're not an active part of public discourse.[8]

These new and improved robo-dogs acted as "undercover agents" sniffing out lead, arsenic, ozone, and other hazardous substances, which were officially declared non-existent.[9] Projects like this work to give power back to people, enabling them to do their own environmental monitoring and potentially push back against established narratives about pollution data.

These two projects emerged at a pivotal moment, aligning with other environmentally interrogative new media artworks from the early 2000s. Artists at this time were measuring pollution levels in air, water, and soil, relying on electronic sensors and systems as strategic tools for creating awareness and promoting solution-oriented action or critical inquiry into the complexity of pressing socioenvironmental issues. These media developments aligned with crucial moments in climate change awareness outlined in the context section of this paper, specifically key early IPCC reports and the watershed international attempt at intergovernmental collaboration the Kyoto Protocol represents. These artworks and others like them underscore the essential role art and artists can play in civic engagement and mobilizing audiences toward proactive responses to environmental challenges.

7.3 Co-creation and Participatory Action Research (PAR)

Community engagement in art takes place through many methods and given the collaborative nature of the work, often the lines dividing them aren't clear. For this reason, I'm introducing co-creation and Participatory Action Research, or PAR, methods together.

Co-design, as described in *Collective Wisdom* (Cicek and Uricchio), refers to collaborative processes where diverse individuals or groups work together to generate new knowledge, solutions, or creative outputs. It emphasizes shared agency, mutual learning, and the integration of different perspectives, fostering innovation and inclusivity.[10]

Participatory Action Research (PAR) is a collaborative research methodology that involves researchers and community members working together to identify issues, collect data, and implement solutions. It aims to empower participants, generate actionable insights, and produce knowledge that directly benefits the community.

There is significant overlap between the two, however the difference between co-design and PAR can be explained in how co-design involves bringing different forms of knowledge together, whereas PAR aims to diminish or eliminate the distinction between researcher and public or publics involved. This is done for the purpose of challenging and/or disrupting power relationships found in more traditional methodologies. In addition, there is overlap between citizen science and PAR or co-design, but generally the distinction is that the latter methodologies invite participants into the development of the project itself, employing decentralized structures rather than merely carrying out a task.[1]

Take for example Camila Marambio's co-design project *Turba Tol Hol-Hol Tol* (2022). Since 2010, Marambio has spearheaded Ensayos, a collective research initiative that "brings together artists, scientists, and activists to conceptualize long-term, process-based projects focused on ecocultural conservation."[12] Her work, centred in Chile, specifically in Tierra del Fuego, demonstrates the power of multi-perspectival activities in influencing both local and global perspectives.

After a decade of community work carried out by volunteers on a shoestring budget, their collective efforts gained momentum. In 2022, Ensayos'efforts were showcased on the international stage at the Venice Biennale through the presentation of their multifaceted project, *Turba Tol Hol-Hol Tol*.[13] This project, which in the Selk'nam language means "Heart of Peatlands," pays homage to the Selk'nam people, who coexisted for thousands of years with the peat bogs of Karokynka/Tierra del Fuego before decimation via colonial genocide.[14] Furthermore, they were written about as extinct people in western histories of the world, despite their tenacious survival. Today the Selk'nam people are fighting to be recognized as a living culture and protect both their peatland home and their society of mutual care. Marambio, in her curatorial role, fostered *Turba Tol Hol-Hol Tol* to acknowledge the indissoluble connection between the peatlands and the Selk'nam, championing their voices and ways of coexisting with the environment through artistic actions and scientific research.[15]

Turba Tol Hol-Hol Tol was presented in the Chilean Pavilion of the Biennale through an immersive video installation, inviting visitors to traverse a peatmoss garden into a circular projection room constructed from bioplastic film grown from the peatland microbiome of Karokynka. The installation featured a 360-degree screen, tensioned by a steel frame, displaying video footage of the peat bogs and Selk'nam stories conveyed through song. This immersive experience was just one facet of the overarching *Turba Tol Hol-Hol Tol* project, which also included the *SphagnumLAB*. *SphagnumLAB*, a functional scientific experiment within the project, was built upon research from the Greifsald Mire Centre (GMC), a leading institution in peatland research.[16] The lab involved harvesting living Sphagnum moss from Karokynka and creating a conducive environment for its growth within the pavilion, with data on its growth being recorded throughout the exhibition's duration. Peatland is a biome more efficient at trapping carbon than any other, and yet one of the least studied.

Figure 7.4: *Turba Tol Hol-Hol Tol*, Chilean Pavilion, 2022 Venice Biennale, Venice, Italy. (Photo from https://turbatol.org/).

Turba Tol Hol-Hol Tol stands as a rare and exemplary model of collective wisdom in action. It was co-created by a diverse team of hundreds, combining the expertise of curators, art historians, architects, filmmakers, poets, scientists, and indigenous knowledge bearers. The project's success was further bolstered by the support and recognition from the Chilean Ministry of Cultures, Arts and Heritage, and the Ministry of Foreign Affairs.[17] This collaborative effort, both hyperlocal in its focus and global in its impact, has garnered support for preserving local ways of life and attracted international attention.

Mel Chin's *The Fundred Project* (2015) is another excellent example of deep commitment to public engagement throughout the work. This was a PAR artwork made to raise awareness of the seriousness of lead poisoning across the United States. Community members created "fundred" drawings, colourful annotations on imaginary paper bills, to raise real world funds to combat environmental toxicity. As per the artists' website:

> I was compelled to do something that relied on science, which led me to a research scientist at the Tulane/Xavier Center for Bioenvironmental Research, who had been studying the lead in the soil of New Orleans for twenty-five years. He showed me a map of New Orleans: it showed that

Figure 7.5: Mel Chin's public artwork in New Orleans in the aftermath of hurricane Katrina as part of his broader initiative *The Fundred Project*. (Photo from https://art21.org/read/mel-chins-fundred-project/).

> thirty to fifty percent of inner-city children were poisoned with lead before Hurricane Katrina, and there was little being done about it or even being mentioned. That's when I got the idea of showing the value of individuals— especially those who are most threatened— through a work of art. The project began in New Orleans, but it's about lead in the blood, brains, and bodies of young people nationwide. A drawing from an individual is like a vote, petition, or voice. Originally, we thought about the project in terms of an even exchange, to solve the problem in New Orleans, but we realized it was much more valuable than that: these voices could possibly transform [political] policy in the end. And that's where we are now.[18]

Ultimately, Chin's project's reach went all the way to the white house in Washington DC and had a substantial impact on lead remediation practices in residences nationwide.

7.4 Examining Pluralism in Practice

The practice of involving pluralistic perspectives through public participation, core to both co-design and PAR research-creation practices, offer substantial benefits to society. The principle of pluralism in science posits that multiple theoretical perspectives within the same domain can each yield valuable insights:

> …alternative theoretical perspectives within the same domain or scope of inquiry may each yield useful insights, depending on the questions of interest and the goals and values in play…

> assuming that scientist diversity is correlated with diversity in methods and theoretical orientations, we have a compelling reason to believe that scientist diversity makes for better science.[19]

In the opinions of researchers Bethany Ojalehto and Douglas Medin, cultural models in observers'minds influenced their perception of interspecies interactions. For example, when shown the same images of hunting interactions between wolves and badgers, a majority of Indigenous Panamanian Ngöbe participants in a study interpreted the interactions as cooperative, while most non-indigenous U.S. participants in the study viewed the same images as depictions of competitive interactions.[20] This study echoes also the sentiments of the early natural philosophers such as Alexander von Humboldt and twentieth century interdisciplinary research Gyorgy Kepes, who both firmly believed in the inevitability of subjectivity and, thus, argued for the necessity of including personal opinions and emotional reactions in scientific research.[21]

If absolute objectivity is not possible, it stands to reason that holistic perspectives in science can only be achieved through increased diversity in its practitioners.[22] Furthermore, collective action in research and citizen science initiatives can help facilitate a multiplicity of perspectives, thereby reducing biases and cultural hegemony in research.[23] Divergent disciplines and methods provide a means to grasp complexity, as do the varied perspectives arising from different life experiences. The collective approach offers a pathway to inclusivity:

> Collectivity is multiperspectival by nature and, when designed intentionally, offers a way to be inclusive. Divergent disciplines and methods provide a way to grasp complexity, but so too do the perspectives that emerge from different life experiences.[24]

All research exists within a social context. Although rigorous peer review aims to correct for biases and ensure objectivity, it can only prevent research from diverging in directions that contradict the consensus of the group. The more homogeneous the group of researchers, the greater the risk, as the peer review process is limited by the diversity of perspectives within that group.

Public participation, particularly in the form of PAR or co-design, offers effective methods for achieving a greater diversity of perspectives. Consider the following statement from *Who's Asking? Native Science, Western Science, and Science Education* published by MIT Press:

> If a field of scientific endeavor sees only one true way of doing things and one true set of values, it may succeed in supressing alternative views and approaches. And in a field dominated by white, middle-class (male) scientists, the words "one true" may be infused with cultural assumptions and values that its practitioners perceive as acultural and objective. Under these conditions scientist diversity will not help, and minority scholars are likely to be turned off by the fact that they do not see their cultural orientations reflected in the science.[25]

A similar perspective is given by Alan Lashner, chief executive officer of the American Association for the Advancement of science and executive publisher of the Journal science in a 2011 statement in the Chronicle of Higher Education:

> We need to reward those who nurture a diversity of ideas in science… innovation requires the ability to think in new and transformative ways. Many of the best new ideas come from new participants in science and engineering enterprises, from those who have been less influenced by traditional scientific paradigms, thinking, and theories than those who have always been a part of the established scientific community… the diversity dialogue too often focuses solely on a concern for equity, or just increasing numbers, and overlooks the central role that novel and creative ideas play in the scientific enterprise. Creativity is found everywhere and needs to be nurtured. Now people and collaborations bring new ideas and approaches that are critical to scientific progress, even if at times they challenge long-established paradigms.[26]

As described by both writers, diversity is needed in multiple dimensions - in disciplinary expertise, in lived experience, identity, and more beyond. Diversity improves health in all systems. And artists in particular often lead the way in diversifying research practice, even in the face of limited resources, as we saw in the co-creation efforts of Camila Marambio and Ensayos.

The adoption of citizen science, co-creation, and participatory action research (PAR) in the arts thus not only amplifies these pluralistic ideals but also fundamentally reconfigures how knowledge is produced and who gets to participate in its making. By foregrounding situated and collective expertise, these approaches resist the notion that research is the exclusive domain of institutional experts. Instead, they propose that knowledge is always partial, relational, and shaped by the lived experience of those involved. This paradigm shift enables communities to act not merely as subjects but as active collaborators— contributing local insight, alternative forms of expertise, and practices of reflexive engagement. Public participation, when meaningfully enacted, transforms the very structure and impact of research, fostering reciprocal exchange and generating dialogue that transcends institutional boundaries. In areas like envirographic art, where environmental phenomena are often abstract, large-scale, or imperceptible, participatory art-science projects build alternate infrastructures for sensing, interpreting, and responding to environmental crises— making them accessible and affectively meaningful.

Yet these promising benefits are inseparable from a host of ongoing challenges and ethical debates. At the core of all three methodological categories lies a persistent tension between democratization and exploitation, and between research-creation innovation and the risks of extractivism. These debates have only grown more urgent in recent decades as these methods have moved from the margins into mainstream art, science, and activism.

7.5 Contested Terrain: Challenges and debates

The use of citizen science, co-creation, and participatory action research (PAR) practices in the arts has invigorated research and creative practice, but are not without challenges and ethical debates. At the core of all three methodological categories lies a tension between democratization and exploitation, and between research-creation innovation and the risks of extractivism. These debates have only grown more urgent in recent decades as these methods have moved from the margins into mainstream art, science, and activism.

One of the primary points of contention centres on data quality, validity, and rigour as perceived by scientific fields. Critics question whether data collected by non-experts can meet the standards required for robust academic or policy outcomes. Some artistic projects may further complicate this by blurring boundaries between subjective, situated knowledge and scientific protocols, sometimes privileging affect and narrative over replicability. This tension is acknowledged by scholars such as Bruno Latour, who note that all science is in some ways social and relational. In this regard, artworks can challenge what counts as evidence, sometimes to productive, sometimes to problematic, effect. Debates around methodological innovation versus standardization are especially pronounced in the arts. Artistic and PAR methods frequently prioritize creativity, narrative, and contextual understanding, which may conflict with the demand for replicability and comparability in scientific citizen science. There is ongoing tension between the freedom to experiment and the need for accepted standards that will allow broader uptake or influence. Issues of inclusivity, access, and equity are also central. Despite their stated aim of democratizing knowledge production, participatory and citizen science projects often remain inaccessible to those lacking technical, linguistic, or social capital, thus reinforcing existing divides. PAR aspires to deep inclusivity, but the reality is artistic projects may unintentionally reproduce hierarchies if they do not attend to the complexities of access and participation.

Closely tied to the question of rigor are debates over research legitimacy and authority. Participatory methods can disrupt the conventional flow of knowledge from credentialed experts to the public, instead elevating local, lay, and marginalized expertise in positive ways. Yet this challenge to top-down authority is not always welcomed by academic or policy gatekeepers, who may dismiss grassroots data as anecdotal or unreliable. In the arts, projects like Natalie Jeremijenko's Environmental Health Clinic and the work of the collective Forensic Architecture have succeeded in pushing the boundaries of what counts as credible knowledge, though not without facing scepticism from scientific and governmental institutions. Although even with these drawbacks one might look to the educational and consciousness raising benefits as points of success in the artworks. Finally, the challenges of translation, mediation, and communication—making data and insights legible and actionable across communities, disciplines, and publics— are especially acute for artists working at the intersection of art and science. The risk of misrepresentation or oversimplification is real, yet so too is the opportunity to bridge divides and provoke new understanding.

Ownership, attribution, and credit are recurrent flashpoints in participatory work. In principle, PAR aspires to equitable co-authorship and shared credit, but the reality is often far more complicated. Artists and researchers may take undue ownership of data or narratives contributed by communities, sometimes even presenting these in prestigious exhibitions or publications without meaningful acknowledgment or benefit for those who contributed. This dynamic has been criticized as a form of cultural or intellectual extractivism— akin to the colonial extraction of natural resources— where the primary benefits accrue to outsiders rather than to the people whose knowledge or creativity made the project possible. The problem is not limited to communities: artists themselves, particularly those from marginalized backgrounds, have increasingly reported instances of institutional appropriation. For example, their conceptual frameworks, participatory methods, or visual languages may be taken up by collaborating curators, NGOs, or scientists, who then receive primary credit or compensation, a critique echoed by artist and scholar Tania Bruguera. Such issues inevitably foreground the power dynamics and representation that shape these collaborations. While participatory and citizen science methods are often celebrated for empowering participants, there is always the risk that community involvement is merely superficial. Questions arise about who sets the research agenda, who frames the story, and who ultimately benefits from the outcomes. Genuine empowerment requires sustained commitment, ongoing dialogue, and structures that ensure communities retain agency and benefit from their own knowledge and labour. Underpinning these concerns are critical questions of ethics, consent, and exploitation. In the rush to launch participatory projects, there can be lapses in fully informing participants of how their data, stories, or creative contributions will be used. Even well-intentioned projects may fail in one or more aspects of implementation.

Scale, sustainability, and institutionalization pose further challenges. While grassroots and PAR projects can yield profound local impacts, questions remain about their scalability and sustainability. When such methods are institutionalized— absorbed into university, governmental, or large NGO structures— they may lose their critical edge, becoming bureaucratized or diluted. Temporalities such as project duration and follow-through are another critical concern. Sustaining momentum and often short-term funding windows remains a perennial problem for all practitioners, sometimes leading to what is pejoratively called "parachute" projects— projects in which communities feel they are left with little lasting benefit. In addition, resulting policy and societal impact of participatory methods is uneven. Despite some celebrated successes, such as Mel Chin's Fundred Project, many projects struggle to gain traction with policymakers or regulators, their outputs dismissed as unofficial or "unscientific."

Given these complexities, extractivism and authorship emerge as the dominant potentially fraught terrains. Extractivism, in this context, does not only threaten communities: it also haunts the artists themselves, who may see their labor, intellectual property, or creative strategies appropriated by larger institutions, curators, or collaborating scientists. High-profile cases abound— artists whose data visualization techniques are used by advocacy groups without acknowledgment; innovative participatory methods adopted by municipalities with little credit to their originators; or even language and frameworks lifted wholesale by curators or other scholars.

These debates are ongoing and often overlapping. The boundaries between citizen science, grassroots data collection, PAR, and socially engaged art are fluid and contested, and while all share commitments to participation and democratization, each faces significant challenges around rigor, ethics, equity, and impact—often intensified, rather than resolved, when these methods are hybridized in the arts. The way forward requires more than rhetorical commitment: it demands robust, transparent dialogue around structures of co-authorship, reciprocal benefit, and reflexive practice, ensuring that the democratizing promise of these methods is realized, and not simply rebranded extractivism under the guise of participation.

7.6 Conclusion

The cases explored in this chapter illuminate both the necessity and the complexity of fostering pluralism and public participation in contemporary research-creation. As demonstrated, integrating methodologies such as citizen science, PAR, and co-creation enables a richer, more inclusive, and more responsive approach to knowledge production— one that is attuned to multiple ways of knowing and being. As exemplified by the works of Brandon Ballengèe, Beatriz da Costa, Natalie Jeremijenko, Mel Chin, and Camila Marambio, these pluralistic approaches and inclusive methodologies created spaces for the democratization of knowledge production and also inspire others and amplify the societal impact of research.

Yet, as the preceding analysis underscores, these ethical dilemmas and tensions that accompany democratized, pluralistic inquiry: questions of research rigor, legitimacy, equity, and extractivism remain. Ultimately, it is in the ongoing negotiation of these tensions— through transparent structures, ongoing dialogue, and a commitment to genuine engagement— that the transformative potential of pluralism in art-science collaboration may be most fully realized.

Chapter 8

Interdisciplinarity as a Methodology

8.1 Introduction

Art and science have long been positioned as separate domains, a division reinforced by the specialization of knowledge within modern institutions. Francis Bacon's rationalist scientific method, which emphasized empirical experimentation over holistic inquiry, helped set the foundation for this separation. Over time, the fragmentation of knowledge into discrete disciplines became entrenched within the university system, sidelining earlier traditions of natural philosophy, where artistic and scientific inquiry were deeply interconnected. However, this divide was neither inevitable nor absolute. Critics such as C.P. Snow have long argued that the "two cultures" of the sciences and humanities should be reconciled, while contemporary thinkers like Achille Mbembe call for a fundamental reframing of disciplines in response to planetary crises, arguing that knowledge must be reconsidered through the lens of global interdependence.

Despite these calls for integration, the split between art and science has given rise to persistent controversies and challenges for both domains. Within science, the emphasis on objectivity and empirical reductionism has sometimes come at the expense of context, interpretation, and ethical nuance. Increasing specialization has led at times to knowledge being siloed within narrow fields, making it difficult to address multifaceted or systemic problems that cross disciplinary boundaries. There is also skepticism towards alternative or affective forms of knowledge, such as those rooted in Indigenous ways of knowing or lay expertise.

For the arts and humanities, the subjective, experiential, and affective dimensions of knowledge— often central to artistic inquiry— are often side lined or treated as less rigorous, despite their capacity to open up new forms of understanding. Non-empirical, interpretive, or sensory methodologies are often undervalued in broader academic and societal discourses, leading to ongoing frictions, particularly in an academic research context. Lastly, the arts frequently struggle to secure equivalent resources and institutional legitimacy compared to STEM disciplines (science, technology, engineering, and mathematics).

Across both domains, these differences manifest in persistent difficulties surrounding interdisciplinary communication and collaboration. Disparate vocabularies, standards of evidence, and institutional incentives can impede joint work. Scientists may fear that interdisciplinary projects will dilute scientific rigor or undermine established standards, while artists may worry about being relegated to the role of communicators or graphic illustrators, rather than recognized as independent producers of knowledge. Such concerns can result in mutual misunderstandings and an uneven valuation of each discipline's contributions.

This hybridization itself can provoke controversy: while collaboration holds the promise of new forms of knowledge, it also raises anxieties about the loss of disciplinary identity or status. Scientists sometimes resist what they perceive as the "softening" or aestheticization of science, whereas artists may resist what they perceive as datafication or reject collaborations that treat them merely as translators of scientific ideas.

At the heart of these tensions lies an ongoing debate about the value of subjective, sensory, or emotional forms of knowing, which are often marginalized within STEM-dominated environments. Feminist theorists such as Donna Haraway have critiqued the myth of scientific objectivity, instead advancing an understanding of situated knowledge— that all knowledge is partial, embodied, and shaped by context and perspective. The longstanding separation of logic (given attribution as the domain of science) and emotion (considered the domain of art) can function as a form of disciplinary boundary policing, limiting the kinds of questions both fields are permitted to ask or answer, and constraining possibilities for truly novel or holistic inquiry.

Meaningful interdisciplinary collaboration, as a methodology, is not simply about borrowing tools or methods across disciplines; rather, it entails the creation of new forms of knowledge production that do not fit neatly within pre-existing academic categories. Scientific inquiry and artistic expression, while often framed as distinct, actually share a fundamental commitment to observation, experimentation, and interpretation.

Artists, like scientists, develop methods for perceiving and understanding the world, translating complex ideas into forms that can be shared, debated, and built upon. When these disciplines collaborate, they generate hybrid approaches that merge empirical analysis with aesthetic, intuitive, and affective modes of engagement.

This type of work at the intersection of art, science, and technology is often called “SciArt” or described as “transdisciplinary research,” and I would argue further that it deserves recognition as a methodology in its own right. In such a framework, the artist is not merely an illustrator of scientific concepts but an investigator who can shape research agendas and provoke new lines of inquiry. Media theorist Stephen Wilson articulates a vision of this type of artistic research:

> The arts can function as an independent zone of research. The concept of artist could incorporate other roles, such as that of researcher, inventor, hacker, and entrepreneur. Even within research labs, artist participation in research teams might add a perspective that could drive the research process and continue to contribute at all stages.[1]

Wilson’s framing aligns with Gyorgy Kepes’ call for “interseeing” and “interthinking,” which sought to collapse the artificial barriers between aesthetic and scientific inquiry. Kepes argued that knowledge must be both sensory and systematic to be truly comprehensible. Similarly, media ecologists contend that each mode of representation— whether linguistic, visual, sonic, or computational— fundamentally shapes the knowledge it conveys.

In this chapter, I examine interdisciplinary collaboration as a methodology by tracing its historical emergence and contemporary applications in environmental art-science. Through examples ranging from Kepes’ unrealized public “data fountains” to contemporary collaborations at MIT’s Center for the Arts, Science, and Technology (CAST), I explore how artists and scientists working together do not simply illustrate scientific concepts but instead co-create new ways of perceiving, interpreting, and engaging with environmental systems.

8.2 Origins in Natural Philosophy

The delineation between artistic inquiry and scientific experimentation has not always been clear. In pre-Renaissance Europe, the precursor to modern science was "natural philosophy." This was the pursuit of knowledge about the physical universe. This practice was not just a precursor to the scientific method but a holistic approach to knowledge, as championed by Aristotle (384-322 BCE). His methods of knowledge acquisition centred around cycles of induction and deduction. Aristotle inducted "general principles" about the world from observation, deduced theories from these principles which were checked against further observation, and so forth. These practices included drawing from observation and literary forms of writing in conjunction with mathematical measurement and calculations.

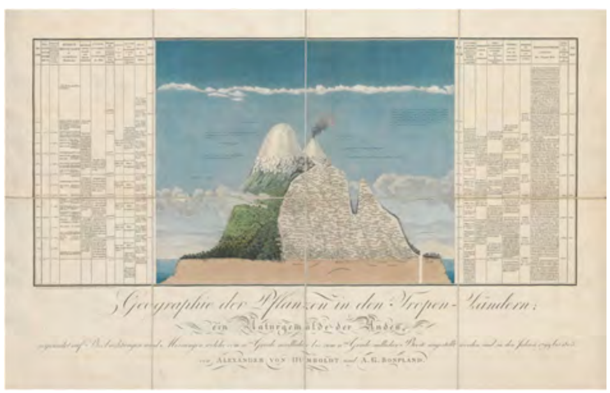


Figure 8.1: *Naturgemälde der Anden* by Alexander von Humboldt and Bonpland, 2' x 3'. Considered by some to be ecology's first infographic, this poster charts the distribution of plant species by elevation in addition to data on altitude, climate, and the heights to which previous mountaineers had ascended. (Image from https://blog.biodiversitylibrary.org/2020/10/alexander-von-humboldt.html).

Researchers who engaged in natural philosophy, predominantly members of the aristocracy such as Alexander von Humboldt, maintained this broad and varied approach until the paradigm shift initiated by Sir Francis Bacon (1561-1626).[2] Bacon critiqued the Aristotelian method for its potential to yield erroneous conclusions. In response, he advocated for a more stringent approach, laying the foundation for what would become the modern scientific method. This new method emphasized rigorous experimentation to test and disprove theories, marking a departure from the more integrative approach of natural philosophy.

8.3 Twentieth Century Disciplinary Polarization

From the time of Sir Francis Bacon onward, a distinct division between the methodologies of art and science grew. Humboldt, while practicing both disciplines, acknowledged the onset of this separation, and it became more pronounced in subsequent years. The twentieth century, in particular, marked an era where the divergence between artistic and scientific methodologies was profoundly evident. As described in section two, the interjection of post-WWII governmental research funding into some specific STEM disciplines but not into the arts hastened the divide.

This shift created a fertile ground for new forms of controversy and tension. The influx of government and military funding into STEM fields not only elevated their institutional status but also entrenched a hierarchy in which the arts and humanities were increasingly marginalized. Disproportionate funding led to neglect of these fields, fuelling a sense of resentment and reinforcing the perception of an institutional hierarchy that privileged science and technology. Within science, the rapid growth of specialization sometimes resulted in scholars becoming disconnected from the broader ethical, social, or cultural implications of their work. This was particularly apparent in fields like nuclear science, where some scientists became whistleblowers or activists, raising concerns about the potential societal harms of their own research.

For the arts and humanities, this marginalization and chronic underfunding fostered a sense of bitterness and, in some quarters, open opposition to the ascendancy of science and technology. There were well-justified concerns that the increasing valorization of scientific "objectivity" would be weaponized to dismiss or devalue the subjective, narrative, and affective forms of knowledge central to artistic practice. The long-standing emotion-versus-logic divide became more pronounced, with art embracing ambiguity, affect, and personal truth, while science increasingly privileging at times logical abstractions over real-world observation. The era was also marked by ongoing debates over what constitutes valid knowledge, who sets research agendas, and who is recognized as a legitimate knower within academic institutions.

The work of Donna Haraway, Bruno Latour, and other science and technology studies philosophers is particularly significant here, as they critiqued the dominant narrative of neutral scientific objectivity. Haraway advocated for an understanding of knowledge as always partial, embodied, and accountable— arguing that the pursuit of complete neutrality obscures the perspectival nature of all inquiry and reality itself.

As many artists have pointed out, including Helen Mayer Harrison and Newton Harrison— proponents of environmental art as acts of care and remediation— this disciplinary divide "contributed greatly to our mental remove from planetary concerns," deepening a contemporary sense of "alienation from the natural world."[3] C.P. Snow, uniquely a scholar of humanities at Cambridge with early scientific training, vividly described this schism in his influential 1959 essay, *Two Cultures and the Scientific Revolution*. Snow articulated his first-hand observations of an academic world split into two divergent camps— the humanities (art, literature, history, and philosophy) and STEM (science, technology, engineering, and mathematics)— each operating in isolation and with a growing mutual incomprehension. He observed that despite similarities in intelligence, social origin, and income, these two groups were diverging to the point of almost complete non-communication.[4]

Snow's essay highlighted a critical issue in the world of academia: the entrenched elitism in research practices and the necessity for democratizing knowledge. This divide, prevalent not only in England but across North America and other occidental nations, emphasized a rigid compartmentalization of disciplines, an approach that Snow argued was detrimental to intellectual progress and societal advancement. His poignant critique served as a precursor to an essential and, fortunately, growing discourse on the need for more inclusive and collaborative research practices.

8.4 Interseeing Countercultures

Despite increasing divisions between the arts and sciences, the twentieth century also witnessed the emergence of visionary thinkers who sought to bridge this growing divide. Among the most influential was Gyorgy Kepes (1906-2001), an artist, educator, and theorist who persistently challenged the dualistic perception of human knowledge and experience prevalent of his times. Writing in a period contemporaneous with C.P. Snow's, "two cultures" critique, Kepes articulated a different vision— one that saw art and science not as antagonists but as fundamentally interdependent:

> science and art, intellect, and emotion, have come to be regarded as separate aspects of life

> whose mutual contact would only endanger the strength and clarity of each. Yet history shows us that art and science, two basic human activities springing from a common love of nature, are interdependent. Each achieves stronger growth when cross-pollinated by the ether.[5]

He posited that these two fundamental human activities achieve greater advancement through mutual enrichment, not isolation; arguing that information provided by emotions and explored through the arts was a necessary addition to the logic of science. This stance was radical for its time, as many in the scientific establishment viewed emotion, intuition, and aesthetic judgment as impediments to clarity and rigor, rather than as sources of insight. This friction was not merely philosophical— it often influenced funding, institutional support, and public perceptions of legitimacy.

As a practitioner, Kepes embodied his philosophy through action. Initially trained as a painter, he later pioneered kinetic and light-based artworks, and in 1945 he founded the Center for Advanced Visual Studies (CAVS) at MIT. This was a ground breaking initiative that integrated artists into the research laboratory, challenging the entrenched disciplinary boundaries of the university and establishing a new paradigm for creative and scientific inquiry. At CAVS, Kepes promoted "interthinking" and "interseeing."— collaborative processes that drew on the unique strengths of artists, engineers, and scientists working side by side.[6]

Kepes' vision, while celebrated by many, was not without significant institutional resistance. Within the very framework of MIT, which at the time epitomized disciplinary specialization and technological rationality, his push for collaboration and pluralism was sometimes met with skepticism, and even obstruction. Some of his most ambitious proposals remained unrealized, not due to a lack of imagination, but because their successful implementation demanded a level of cross-disciplinary partnership, infrastructural support, and shared vision that the academy was not yet ready to provide. A notable example is his plan for public "data fountains"— towering kinetic monuments that would both visualize real-time environmental data and provide water purification as a civic good.[7]

> an immense, transparent, kinetic structure that would make the hydraulic processes visible: a contained, but legible ballet of water forcing through obstacles of filters, tinted and purified by chemicals, or moving sluggishly in intricate but legible patterns of transparent containers.[8]

The project was never built, yet it foreshadowed the integration of data-driven public art and eco-technology

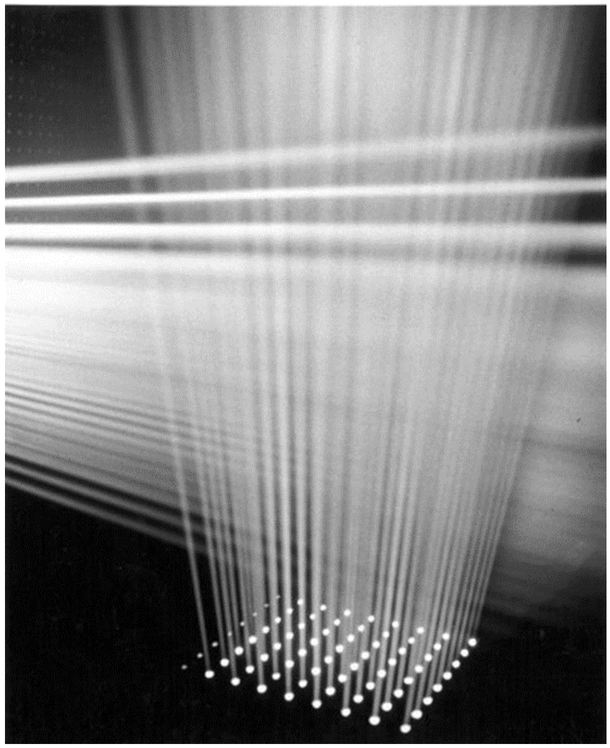


Figure 8.2: Simulated light architecture for Boston Harbor by Gyorgy Kepes, 1966. (Photo by Nishan Bichajian, 1966 from the Center for Advanced Visual Studies Special Collection, MIT Program in Art, Culture and Technology, Massachusetts Institute of Technology, https://act.mit.edu/special-collections/cavs-special-collection/).

in later decades, such as Andrea Polli's *Particle Falls*.

Through his collaborations and advocacy, Kepes became a central figure in art and science debates, demonstrating how interdisciplinary work could not only produce aesthetic innovation but also foster new ethical frameworks and ways of seeing the world. His legacy, though not without controversy and unfulfilled ambitions, was foundational in establishing interdisciplinary research as a credible and vital domain within the university. Kepes' efforts helped pave the way for subsequent generations of artists, scientists, and engineers to pursue hybrid methodologies— ones that could address both the possibilities and the perils of scientific and technological advancement and recognized the necessity of combining empirical rigor with ethical, aesthetic, and affective insight.

8.5 Center for the Arts, Science, and Technology (CAST)

The legacy of Gyorgy Kepes and his interdisciplinary Center for Advanced Visual Studies at MIT has been perpetuated and evolved through initiatives like the Center for the Arts, Science and Technology (CAST). Under the leadership of Laila Kinney and others, CAST has significantly expanded the collaborative landscape of the field in recent years.[9] The objective here transcends mere collaboration; it aims to create partnerships where the resulting work is as innovative and insightful for the scientists and engineers as it is for the artists involved. This modern approach, more widely accepted now than in Kepes'time, has paved the way for projects where artists function simultaneously as scientists, working alongside them to produce outputs that are both artistic and scientific advancements.

> ...when art engages with science the outcome should transcend a straight illustration of a scientific concept (the task of science communication), but instead offer a creative repositioning of the ideas presented. Rather than reiterating an accepted paradigm, the artist offers the possibility of a new thinking tool. ... to facilitate an intuitive, more fully embodied engagement with the Earth that we increasingly deconstruct and reconfigure.[10]

A notable collaboration at CAST involves the joint efforts of Tomás Saraceno and Markus Buehler. Saraceno, drawing creative inspiration from spider web-building techniques, has crafted intricate gallery installations using cable and wire to mimic these natural structures. Buehler, a materials scientist with a keen interest in music, saw the potential for a unique collaboration. Together, they explored the possibility of deriving music from spider webs, pondering over the idea that these structures could offer a new source of musical inspiration, vastly different from conventional human experiences.[11]

Their joint endeavour, launched in 2018, involved recording spider webs during construction. The project not only produced novel musical compositions but also advanced our understanding of spider communication. This collaboration led to the development of a virtual model, enabling for the first time the accurate sonification and analysis of web architecture. To create it, Saraceno developed an original tomographic method for scanning using a laser sheet. This invention "made access to the complete and accurate three-dimensional data of a spider web possible for the first time," information useful across numerous fields including architecture, art, evolutionary biology, ethnology, and engineering.[12]

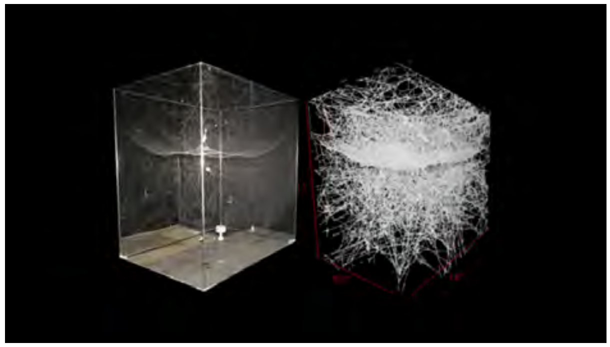


Figure 8.3: Real spiderweb alonside a 3D modeled spider web created by Tomàs Saraceno and Markus Buehler with assistance from postdoc Zhao Qin and graduate student Bogda Demian, 2014. (Photo from https://royalsocietypublishing.org/doi/10.1098/rsif.2018.0193).

The results of their explorations have been manifested in new artworks, performances, and peer-reviewed publications. The project's success is such that it continues to yield ongoing discoveries, including potential applications in 3D printing technology based on spider web scaffolding techniques.

Another ground-breaking collaboration is *Heirloom* from 2016, created by British artist Gina Czarnecki in collaboration with clinical scientist John Hunt at the University of Liverpool's Institute of Aging and Chronic Disease. Together, they developed innovative methods for growing tissue in sculptural forms from cultured cells. The cells, sourced from Czarnecki's daughters, were grown in the shape of their faces, creating living portraits. This process led to the invention of new techniques for culturing stem cells in compound curves, addressing a significant challenge in clinical applications where cells had previously been grown flat and then stretched over curved surfaces.[13] This breakthrough has revolutionized the tools available for treating burn patients. The artwork *Heirloom* has since been exhibited globally in major galleries and museums, such as FACT (Foundation for Art and Creative Technology), showcasing the intersection of art, science, and clinical innovation.

Figure 8.4: *Heirloom* by Gina Czarnecki and John Hunt, 2016. Cultured cells cast into moulds taken of the donor's faces. (Photo from https://www.ginaczarnecki.com/).

8.6 Open by Design, Driven by Curiosity

The interdisciplinary methodologies exemplified by the artworks of Tomás Saraceno and Gina Czarnecki are distinguished not only by their technical and conceptual innovations, but also by the spirit in which they are conceived: curiosity-driven and open-ended, rather than strictly goal-oriented. Many projects at the MIT Center for the Arts, Science and Technology (CAST), including those by Saraceno, have been intentionally "organized more around the free pursuit of ideas than any predefined product, and, as a result, particularly in the case of Saraceno, they often lead to wild and unexpected outcomes."[14] This ethos of open-ended exploration, which embraces serendipity and improvisation, has long underpinned both scientific and artistic breakthroughs. For example, the fundamental Maxwell Hertz theory of electromagnetism— later so central to radio, radar, and all wireless communication— arose from explorations that were "without thought of use."[15] Abraham Flexner famously observed that "most of the really great discoveries which had ultimately proved to be beneficial to mankind had been made by men and women who were driven not by the desire to be useful but merely the desire to satisfy their curiosity."[16] For many in both the arts and sciences, this perspective validates the conviction that the most meaningful research is often propelled by intrinsic fascination and the freedom to explore what is not yet known.

Yet this philosophy is not without its detractors or institutional challenges. In some academic and research settings, curiosity-driven inquiry— whether pursued by artists, scientists, or collaborative teams— remains undervalued compared to research promising concrete, fundable outcomes. Grant agencies, university administrators, and policymakers frequently prioritize work with clear applications or short-term deliverables, casting open-ended, speculative, or playful projects as indulgent or even wasteful. This tension is particularly acute in environments where the metrics of success are narrowly defined by productivity, technological utility, or immediate societal impact.

Ongoing debates also persist over the place of "play," intuition, and non-instrumental approaches in settings increasingly shaped by accountability and efficiency. Advocates for interdisciplinary and curiosity-driven research point to the rich history of advances generated by such methods, arguing that rigid adherence to pre-established goals can stifle innovation and close off unforeseen possibilities. Critics, meanwhile, may worry about the allocation of limited resources, or about maintaining rigorous standards of evidence and relevance.

Despite these controversies, projects that are "open by design" provide a compelling counter-narrative to instrumentalist tendencies in academia. They show how creative exploration— unconstrained by narrow definitions of utility— can foster environments where the unexpected is possible, and where meaningful new knowledge, forms, and relationships can emerge. In this light, curiosity is not only a legitimate motive, but a vital engine for both scientific and artistic fields.

8.7 Climate Pressures Uniting the Disciplines

I believe recent disciplinary convergence to be propelled by three primary forces. First, technological advancements, second, the growing urgency of climate change, and thirdly, a contributor propelled by the first two, that of a reconsideration of what knowledge production is.

In the words of theorist Archille Mbembe, "The biggest challenge facing critical theory now is arguably the reframing of the disciplines... in light of contemporary conditions and the long-term sustainability of life on Earth."[17] He sees reconsideration of the divisions between art, science and technology to be part of a larger re-evaluation:

> The extent to which new modes of being human are prefigured in the contemporary arts, technology and natural and environmental sciences is increasingly at the core of ongoing projects to

rethink knowledge itself.[18]

His perspective highlights broad efforts to reconsider Western knowledge systems in light of Indigenous ways of knowing, in an attempt to reconcile what it means to be human today living as we are embedded in our complex built systems.

The evolution of technology has led to the widespread availability of sophisticated and affordable tools, facilitating the democratization of tool access. Today, artists and members of the public alike can utilize equipment comparable to that found in university laboratories. This technological shift has sparked global conversations about open science and fostered a proliferation of citizen science initiatives and art-as-science experimentation.

Our planet is changing at an unprecedented pace and facing uncertain futures. The pressing issue of climate change acts as a catalyst, driving artists to employ scientific methods and tools to accurately reflect these planetary changes in their practices. This trend reflects an increasing inclination towards artworks that are not merely representational but are substantiated by real-world, and often real-time, data.

8.8 Conclusion

Interdisciplinary collaboration between art and science, as explored in this chapter, thus functions not as a simple merger of fields, but as an ongoing attempt to develop new methodologies that recognize the value— and the necessity— of hybrid knowledge production. Projects like those of Kepes, or Saraceno and Buehler, demonstrate how such collaborations can transcend disciplinary boundaries to yield outcomes that are simultaneously artistic, scientific, and technically innovative. These endeavours, rooted in curiosity and experimentation, have led to unexpected advancements, from living portraits that revolutionize tissue engineering to novel sonic models of spider webs that expand both aesthetic and scientific understanding.

However, these achievements must be understood alongside the persistent tensions that continue to shape the field. The historical split between the arts and sciences left a legacy of institutional inertia, where new interdisciplinary, "post-disciplinary," and STEAM (science, technology, engineering, arts, and mathematics) approaches are sometimes marginalized, underfunded, or treated as additive supplements rather than as fully integrative paradigms. Even as more institutions gesture toward collaboration, entrenched structures and incentive systems may relegate hybrid projects to the periphery, impeding genuine integration.

Within the arts and humanities, there is a continued struggle to secure recognition and resources for modes of knowing that are subjective, emotional, ethical, and embodied. Advocates insist that these ways of knowing are not ancillary but vital, particularly as we confront complex, urgent planetary crises that cannot be fully understood through measurement or modelling alone. Meanwhile, science as a discipline grapples with how to meaningfully include interpretive, affective, and context-dependent approaches— such as those offered by Indigenous knowledge systems and lay expertise— while maintaining commitments to rigor, transparency, and reproducibility. These questions are not easily resolved, and often generate anxiety about the dilution of disciplinary standards. Both domains must also navigate the increasingly visible demands of ethical responsibility and social impact in research.

Despite these persistent controversies, the promise and potential of interdisciplinarity remain clear. By bringing together empirical rigor with empathetic, sensory, and interpretive insights, interdisciplinary practice creates new avenues for discovery, innovation, and democratization of knowledge production. When artists and scientists work in genuine partnership, they not only expand the ways we can see and understand our world, but also help to build creative, inclusive, and adaptive infrastructures— capacities that are urgently needed as we face accelerating planetary change.

Nevertheless, the promise of interdisciplinarity is clear. By bringing together empirical rigor with empathetic, sensory, and interpretive insights, interdisciplinary practice opens up new avenues for discovery and innovation, as well as for democratizing knowledge production itself. When artists and scientists work in genuine partnership, they not only create new ways of seeing and understanding the world, but also build the kinds of creative, inclusive, and adaptive infrastructures that are increasingly vital in the face of planetary crises. The movement toward interdisciplinarity does not signal a return to the pre-disciplinary knowledge production modes of early researchers, but rather an evolution toward a more comprehensive, holistic-minded, and perhaps in some ways, post-disciplinary understanding. These inter-developments across art, science and engineering encourage us to view our planet and its challenges in a multifaceted way, combining empirical rigor with empathetic and interpretive insights. In the process hopefully we move towards a greater recognition of the value of difference, nurturing curiosity, and fostering collaborative inquiry as foundational to both research and cultural life.

Chapter 9

Rendering Data Experienceable

> From embodied cognition to embodied Earth by making complex datasets senseable, what if we could extend our nerve endings and neural processes to include the whole Earth? What if our experience of the Earth could span geological time? If we experienced our planet as an extension of our body, might we treat it differently?
>
> *–David Green*

9.1 Introducing Data Translation Practices

Much of what determines the conditions of life on Earth— climate patterns, atmospheric composition, pollution levels, and ecosystem dynamics— is beyond the threshold of direct human perception. These phenomena can be too vast, too slow, too small, or too abstract for our unaided senses to detect. Scientific instruments— satellites, spectrometers, air quality sensors, remote sensing arrays— extend our perception, but they also introduce layers of mediation: data must be translated, visualized, sonified, or physically materialized for it to become experienceable by broader publics.

According to theorists such as Jennifer Gabrys, environmental sensing technologies do not merely capture data but actively produce new ways of sensing and knowing the world. Drawing from Alfred North

Whitehead's concept of relational ontology, Gabrys suggests that data is not an objective mirror of reality but a co-constructed experience emerging through material and computational processes. Artists working in envirographic art engage directly with this process of "data mediation," transforming otherwise imperceptible phenomena— whether CO2 levels, sound frequencies outside human hearing, or cosmic signals— into aesthetic, affective, and embodied encounters that render planetary-scale changes perceptible.

Our sensory experiences are remarkably limited in scope compared to the breadth of environmental phenomena. Take, for example, sunlight reaching Earth— the energy on which most life depends— which represents only a tiny portion of the broader electromagnetic spectrum:

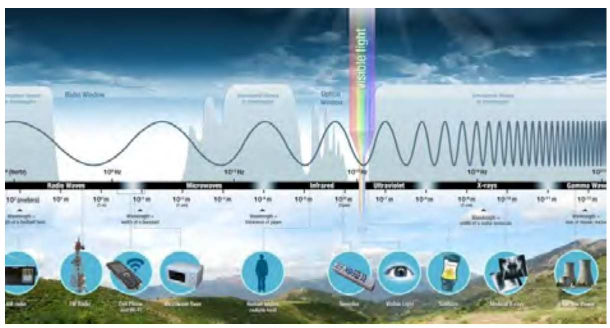


Figure 9.1: Infographic depicting the electromagnetic spectrum and its common uses. (Image http://science.nasa.gov /ems/01_intro.

Only visible light is directly experienceable to humans; the rest of the spectrum requires instrumentation and translation to be understood. As one scholar notes:

> Since the initial publication of the chart of the electromagnetic spectrum, humans have learned that what they can touch, smell, see, and hear is less than one-millionth of reality. Ninety-nine percent of all that is going to affect our tomorrows is being developed by humans using instruments and working in ranges of reality that are nonhumanly sensible.[2]

Climate change similarly defies direct sensory perception. It is too expansive in scale and too intricate in scope to be grasped by immediate experience alone, demanding instrumentation, modeling, and increasingly, artistic mediation.[3] In envirographic art, this mediation process involves converting raw, invisible, or imperceptible data— whether atmospheric carbon dioxide measurements or remote sensing data— into formats humans can see, hear, or even touch.

This chapter examines how artists translate environmental data into embodied experiences, focusing on data visualization, physicalization, sonification, and immersive installation. Through the works of Tiffany Holmes, Andrea Polli, Suzanne Anker, and Nathalie Miebach, I highlight artworks that I find notable and whose use of data translation to expand the boundaries of environmental awareness, foster new modes of engagement, and redefine what it means to “know” in an era of ecological uncertainty, resonate with and inform my own methods of creating data-driven artworks, which I discuss more in-depth in the next chapter.

9.2 Data Visualization

In 2005, digital media artist Tiffany Holmes introduced the term “eco-visualization” to describe her own focus on “the practice of reinterpreting environmental data” in order “to promote stewardship” of the living systems on our planet and to garner public interest in ecological issues.[5] Her net art site *Floating Point* from 2004 is a prime example.

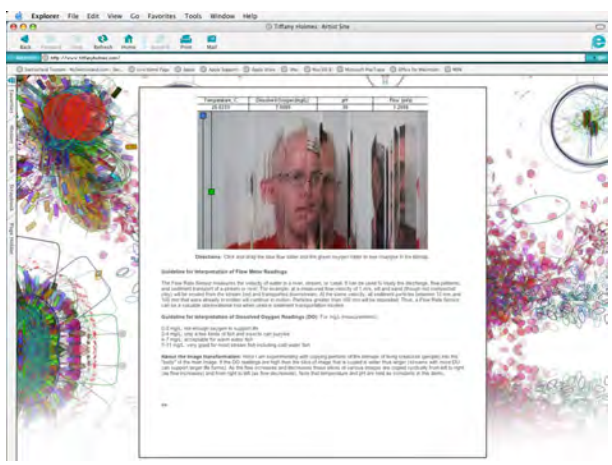


Figure 9.2: *Floating Point* by Tiffany Holmes, 2004. (Screenshot from https://tholme.myportfolio.com/floating-point-2004).

In *Floating Point*, a project generated by Tiffany Holmes during a residency at the Swiss Federal Institute of Technology’s Computational/Collaborational Laboratory (CoLab), data on water quality is visualized. Holmes utilized data collected by scientists affiliated with the CoLab to create shockwave animations that effectively depict visual characteristics of water and elucidate ramifications of water pollution in the location she studied. The mechanics of the animation are a series of interactive sliders corresponding to real world temperature, dissolved oxygen, pH, and flow data. The visual results are shifting, watery images: human faces, photographs of water, and abstractions meant to represent essential commonalities:

> When developing "Floating Point," I started with a small, pixel sized square. Water is the basic unit of life, the pixel is the basic unit of the screen environment. Data gathered over time can create complexity out of very simple things.[6]

Her animations are complemented by accompanying textual explanations, seamlessly amalgamating scientific insights with the artistic impetus that underpins the project.[8] The utilization of shockwave animations as a medium allows for the dynamic representation of changes in essential parameters, offering viewers an opportunity to directly engage with and comprehend the far-reaching impacts of water pollution.

> Data-driven environmental art is not illustrating ideas or a didactic data visualization but rather a form of knowledge production. it takes complex data-sets and thinks through them, rendering them tangible and sense-able. . . . art enables me to sense, and make sense, of the world in ways beyond language.[7]

Holmes' *Floating Point* represents an emerging trend characterized interdisciplinary collaborations with environmental scientists of all kinds: hydrogeologists, atmospheric physicists, and pedologists, or soil scientists among others and an increased focus on environmental data collection for the purpose of visualization. Another means of obtaining data for this purpose is through collaboration with the engineers who develop scientific tools of measurement.

This means of collaboration is employed by artist Andrea Polli in the development of her public installation, *Particle Falls* (2015). *Particle Falls* establishes multiple points of connection with preceding environmental data artworks such as Holmes'*Floating Point*. *Particle Falls* seeks to depict, in real-time, air pollution in situ, thus rendering the intangible into a visible experience for viewers. Depicting a backdrop of descending blue light, her installation introduces vivid and dynamic colours that signify the presence of fine particulate matter, as detected by a nearby stationary air monitor, a nephelometer.[9] *Particle Falls* mirrors many of the principles of its precursors, including use of real-time environmental monitoring to call public attention to unnoticed but harmful imperceptible environmental threats. In this way, *Particle Falls* assumes a significant role as a tool for augmenting our comprehension of air quality. The public dissemination of real-time air pollution data through visually compelling means underscores the artists'ability to engage in public discourse on environmental concerns.

Figure 9.3: *Particle Falls* by Andrea Polli, 2015. A public light artwork that responds to air pollution in near real time. (Photo by Jared Rendon-Trompak from https://www.andreapolli.com/projects).

Another example of environmental data turned image is *The Data Imaginaries of Climate Art: The Manifest Data Project* (2009-ongoing) by collaborators Tom Corby, Gavin Baily, Jonathan Mackenzie, Giles Lane, Erin Dickson, Louise Sime, and George Roussos. Together they have produced a series of artworks including *The Southern Ocean Studies* (2012), *The Northern Polar Studies* (2014) and *Carbon Topographies* (2020) that explore how computational models of climate change can be employed to develop data-driven visualizations of climate change, both impacts and origins.[10]

The Manifest Data Project team argue for the experiential potential of this information for producing differently situated ways of knowing climate and term this methodology as "data manifestation."[11]

9.3 Data Physicalization

Suzanne Anker, a pioneer in the field of bioart and director of a laboratory in New York City that she conceives of as a place where "scientific tools and techniques become methodologies in art practice."[12] Anker's *Remote Sensing* Series (2015-2017), is a fantastic example of this practice in action. Using datasets from remote sensing satellites, she creates sculptures that enable us to see places "that are either too toxic or inaccessible to visit,"[13]. Anker describes her process:

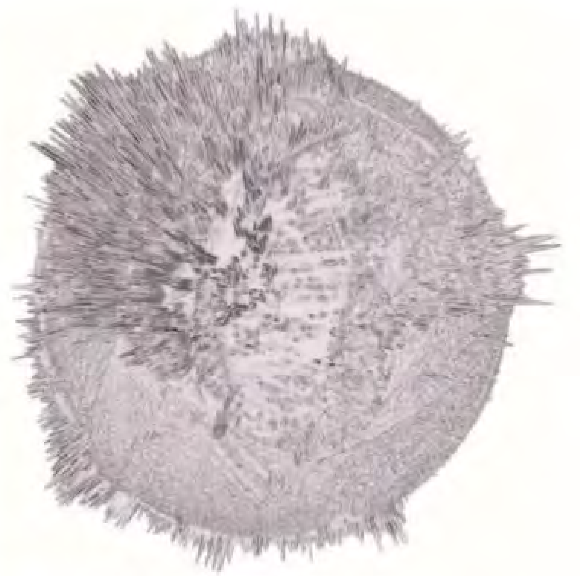


Figure 9.4: *Carbon Topographies* by The Manifest Data Project, 2020. A 3D global projection of CO2 from cruise ships and flights from 1970 onwards using the EDGAR dataset. (Image from https://doi.org/10.1162/leon_a_02136.

> The fabrication of my *Remote Sensing* (2015-2017) series begins with two-dimensional digital photographs, which are converted into three-dimensional virtual models using a technique called displacement mapping. The resulting files are employed to fabricate physical objects using a 3D printer. The software program determines the deposition of variegated color applied to the structure as it is being printed, one layer at a time. Dark areas are extruded less than bright colors, keeping in tune with the ways in which pictorial spaces are perceived.[14]

Below is a photograph showing one of the resulting prints. She displays them in petrie dishes, a reference to other bio art in her oeuvre.

Another artist who makes sculpture out of data is Nathalie Miebach. Like Suzanne Anker, Miebach's research is situated at the intersection of art and science. She uses scientific data sets of complex systems, such as weather, as a point of departure. Literally weaving the data, she translates the records into layers of basket-like wood and fibre sculptures.

For Miebach, the baskets, weavings, and gridded sculptures form "functions as a simple, tactile grid through

Figure 9.5: *Remote Sensing* by Suzanne Anker, 2016. 4 x 4 x 2 inches. Plaster, pigment, resin, and glass. (Photo from https://brooklynrail.org/2017/12/criticspage/Remote-Sensing/).

which to interpret data into 3D space."[15] Central to her work is a desire to explore the roles visual and musical aesthetics can occupy in the translation and understanding of complex systems.

In her work *The Last Ride* (2012), she translates weather and ocean data from Hurricane Sandy, when it destroyed, or in her words "took the last ride" on the Star Jet Rollercoaster from Seaside Heights, New Jersey.[16] Miebach writes:

> Inspired by Hurricane Sandy, numerical data in these pieces build actual amusement park rides. At the same time, they suggest another narrative of what coastal life might be like in the future living with a changing climate.[17]

Complex and humorous, her work is also a serious reflection on climate concerns.

9.4 Data Sonification

Data does not lend only to visual forms of expression, but also quite easily to audible forms. At times, this process can even be more direct due to the development of numerous sonification software programs. However, as with Miebach, the art lies in the creative act of translation itself, and crafting a compelling aural experience can be quite complex. Take for example artist Tomàs Saraceno's work with spiders. In an ambitious time-based collaboration which took place over a period of six months, Saraceno worked with

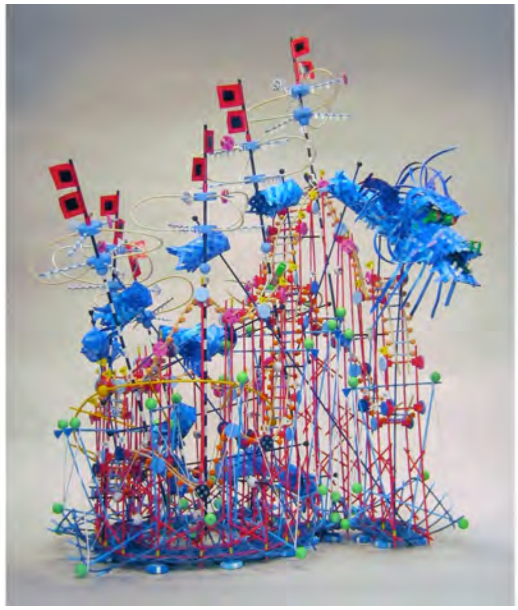
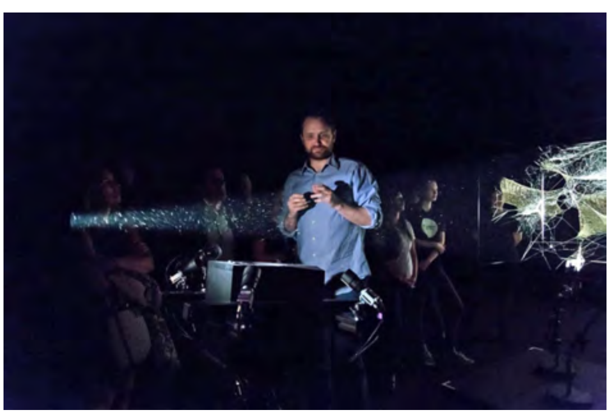


Figure 9.6: *The Last Ride* by Nathalie Miebach, 2012. (Image from https://www.nathaliemiebach.com/).

7,000 spiders of the species *Parawixia bistriage* to grow a sonified installation titled *Quasi-social musical instrument IC 342* (2017).[18] Their movement triggered changes in a slowly evolving soundscape. It was one of two installations in the exhibition How to Entangle the Universe in a Spider Web shown at The Museo de Arte Moderno de Buenos Aires. Images of visitors attuning to the rhythms of the cosmos and the slow cadence of arachnids are below. Through the work, Saraceno aimed to challenge visitors'"perceptions of the very nature of 'being' and 'becoming' in the cosmos."[19]



(a) *Tomàs Saraceno interaction with installation.*

(b) *Installation view of Quasi-social musical instrument IC 342*

Figure 9.7: Two images of *Quasi-social musical instrument IC 342* by Tomàs Saraceno, 2017. (Photos from https://universes.art/en/magazine/articles/2017/tomas-saraceno).

Another recent environmental data sonification work inspiring to me is *Re:Peat* (2021) by artist Anne Yoncha, created in collaboration with composer Daniel Townsend.[20] The installation explores peatland extraction and restoration in Finland. It features a six-foot by eight-foot quilt made of handmade and hand-dyed paper, embroidered with imagery from aerial maps of former peatland in Finland. Integrated into the quilt is a two-channel sonification of hyperspectral data from restored and unrestored soil samples, allowing viewers to experience these environmental transformations through sound and tactile engagement.[21] The quilt itself is a resonant surface with speakers attached to it which amplify the sounds of altered landscapes through the materials extracted from those very environments.

Figure 9.8: *Re:Peat* by Anne Yoncha created in collaboration with composer Daniel Townsend, 2021. (Photo https://anneyoncha.com/peat-quilt/).

9.5 Immersive Multisensory Translation

> Artists have always worked with information structures and as designers of enhanced sensory experience. - Patrick Clancy [22]

Some watershed environmental data artworks eschew the use of one or two senses to instead engage them all via complex, immersive experiences, such as *Breathing With the Forest* (2023) by artist collective Marshmallow Laser Feast and *The City as an Artwork* by collective Pulsa.

Marshmallow Laser Feast's *Breathing with the Forest* is an immersive video installation that highlights the intricate reciprocity within a tropical rainforest ecosystem, centering on a capinuri tree *Maquira coriacea* in the Colombian Amazon.[23] Through beautifully detailed LiDAR scans (laser imaging, detection, and ranging), the installation shows a rainforest ecosystem around the tree and aims to highlight the delicate symbiotic relationships among various species and systems around it, from carbon sequestration to water cycles and mycorrhizal networks.

Visitors navigate a cavernous space filled with rippling light and soundscapes, and are invited to meditatively synchronize their breath with the pulsing rhythms of the forest, thereby transforming the rainforest into an extension of the human body and nurturing an awareness of ecological interdependence.[24]

Figure 9.9: *Breathing with the Forest* by Marshmallow Laser Feast, 2023. (Image from https://marshmallowlaserfeast.com/project/breathing-with-the-forest/).

Another important environmental data artwork to mention, and similar to *Breathing with the Forest* in it's immersivity, large-scale scope, and its situating of the human within the landscape, is an installation created by collective Pulsa in MoMA's sculpture garden (1970).[25] Pulsa formed as a collective of students who, inspired by a workshop held at Yale by Buckminster Fuller, dedicated years to developing experimental artworks that translated invisible "wave energies" into immersive experiences. In their essay *The City as an Artwork* they describe their two-month long installation at MoMA.[26] Using microphones, infrared sensors, and photocells to capture environmental inputs like sound, light, movement, and heat, they translated received signals into responsive outputs via strobe lights, infrared heaters, and loudspeakers, creating a continuously interactive space where natural elements and even visitors'body heat triggered sensory responses.[27] This innovative integration of environmental data and real-time interaction exemplified Pulsa's interest in systems and their belief in the inseparability of city, human, and environment.

Figure 9.10: Pulsa's 1970 installation in the sculpture garden at MoMA. (Image from https://yatesmckee.wordpress.com/wp-content/uploads/2011/02/mckee_pulsa1.pdf).

9.6 A Note on Mediation

It is important to recognize that when data mediation is necessary to experience phenomena, we are not perceiving reality directly, but rather a mediated, and therefore potentially biased, representation of it. This perspective aligns with Alfred North Whitehead's concept of relational ontology, especially his idea of "prehension," which suggests that entities do not simply observe external phenomena; rather, they actively engage in a relational process of experiencing and interpreting the world.[28] In Whitehead's view, experience is not just the passive reception of information but an active, interpretive, and constructive process that shapes reality itself. This approach, along with the ideas of media scholar Jennifer Gabrys— who draws from Whitehead— proves especially useful when considering how scientific instrumentation generates environmental data. Gabrys argues that “sensors might also be understood not as detecting substantialist external phenomena but as contributing to inventive processes for making interpretive acts of sensation possible and for articulating environmental change and matters of concern.”[29] She contends that environmental sensors are not passive detectors of pre-existing phenomena but active participants in an interpretive process. This perspective is significant in understanding how envirographic art is created and experienced, as it frames art not as a mere reflection of environmental data but as an active participant in shaping how environmental realities are sensed, understood, and emotionally felt by the audience.

9.7 Conclusion

In an age of rapid change and overlapping systems crisis, the need to make sense of the imperceptible has never been greater. Data-driven environmental art, or envirographic art, emerges as a powerful tool for navigating this complexity, drawing on the conceptual lineage of systems art such as those described by Jack Burnham:

> By rendering the invisible visible through systems consciousness, we are beginning to accept responsibility for the well-being and continued existence of life upon the Earth.[30]

Building on its capacities for making the invisible visible, whether through physical, visual, or auditory methods, envirographic art offers new ways to understand the interconnected systems of our planet. As Jennifer Gabrys’work on mediation and Whitehead’s concept of relational ontology emphasize, this process is not neutral; the act of translating data into perceptible forms is inherently interpretive and relational, shaping not only what is sensed but how it is felt and understood. However this capacity to communicate personal perspectives and to foster embodied and affective connections is also its strength.

Chapter 10

In the Field, In the Code, In the Image: Reflections on my own Research-Creation Methodologies

10.1 Introduction

The methodologies explored in the preceding chapters of this section— participatory approaches, interdisciplinary collaboration, and data mediation— serve as foundational strategies for engaging with environmental knowledge through artistic practice. These methods reflect broader shifts in epistemology, particularly in how we understand knowledge production as a relational, embodied, and situated practice. Whether through citizen science and co-creation, transdisciplinary collaboration, or the sensory translation of environmental data, these approaches challenge conventional disciplinary boundaries, expanding who gets to know and how knowledge is experienced.

Yet, methodologies are not just abstract frameworks; they are lived, iterative, and deeply embedded in the artistic process itself. As an envirographics practitioner working at the intersection of art, computation, and environmental sensing, my approach to research-creation is shaped by the methodological concerns outlined in this section but also by the contingencies of artistic practice— material constraints, technological affordances, site-specific conditions, and the evolving relationship between artist, audience, and environment.

This final chapter of the methods section reflects on my own research-creation, tracing how it emerges through direct engagement with planetary sensing, computational systems, and participatory knowledge-making. I explore how my practice enacts the methodological principles and practices discussed earlier, while also developing idiosyncratic strategies for making planetary transformations visceral, perceptible, and culturally resonant. This discussion serves as a bridge to the results section, where I analyze six of my own artworks as sites of knowledge production, each articulating a different mode of sensing, interpreting, and responding to planetary change.

10.2 Situating My Theoretical Framework

I perceive my current work to be informed by the intersection of posthumanism, environmental humanities, and speculative design.[1][2] Drawing from theories such as Donna Haraway's exploration of the more-than-human, Timothy Morton's concept of "hyperobjects," and Robin Wall Kimmerer's multispecies perspectives on agential being, my work explores the interconnectedness of humanity, other species and non-human systems, challenging anthropocentric perspectives.[3][4][5] These perspectives guide my artistic inquiry into how technological and cultural production interacts with ecology, encouraging audiences to consider how human agency affects planetary futures.

My work also aligns with the hybrid practices articulated by Benjamin Bratton (*The Stack*) and Jennifer Gabrys (*Program Earth*), which situate computational systems within planetary-scale processes, envisioning new ecological relationships between technology, culture, and ecosystems.[6][7] Through speculative design and environmental data visualization, my projects explore how technologies can make visible the invisible, encouraging critical engagement with climate-related issues. Linda Weintraub (*To Life!: Eco Art in Pursuit of a Sustainable Planet*) and Natalie Loveless (*How to Make Art at the End of the World: A Manifesto for Research-Creation*) further inform my approach to ecocritical aesthetics and participatory art, emphasizing how creative practices can catalyse environmental awareness and social action.[8][9] This theoretical foundation is reflected in my practice's interdisciplinary methodologies, which draw from art-science-technology hybridity explored by scholars like Stephen Wilson (Information Arts) and Chris Salter (Sensing Machines).[10][11]

I approach the climate crisis as a complex, systemic challenge requiring both speculative imagination and grounded, interdisciplinary methodologies. Using computational media, physical computing, IoT, and digital fabrication, I aim to create works that bridge abstraction and lived experience, enabling audiences to engage with complex systems on sensory, intellectual, and emotional levels.[12][13]

10.3 Defining Interdisciplinarity as a Methodology in My Practice

As discussed in Chapter 8, the persistent division between the arts and sciences has historically been reinforced by institutional structures, disciplinary hierarchies, and cultural assumptions about what constitutes legitimate knowledge. Yet, as Gyorgy Kepes and other visionary figures have demonstrated, art and science need not remain isolated; their mutual enrichment offers vital pathways for addressing the complexity of contemporary planetary crises. My own practice is fundamentally grounded in this ethos of interdisciplinarity. I see scientific inquiry and artistic expression not as antithetical, but as co-constitutive— each expanding the possibilities of the other.

Climate change, by its very scope and intricacy, demands a methodological pluralism that bridges sensory experience, quantitative measurement, and interpretive engagement. While weather can be apprehended through lived, embodied experience, the dynamics of climate itself— its temporality, vastness, and abstraction— require scientific investigation to be comprehended in full. For me, any serious artistic engagement with the climate crisis must therefore be rooted in scientific research and data, not simply for the sake of accuracy, but to anchor the work in independently verifiable realities. To create artwork about the living world without attention to the underlying science would, within the context of my practice, feel unmoored and incomplete.

This conviction is also rooted in my commitment to open-endedness. As articulated in Chapter 8, interdisciplinarity thrives when it resists instrumentalization— when it is not constrained by the prescriptive demands of graphic illustration or science communication, but instead allows for interpretive openness, ambiguity, and the co-existence of multiple meanings. My approach is to balance planetary thinking and scientific rigor with a space for subjectivity, affect, and the viewer's own sense-making. Rather than closing down interpretation through didacticism, I seek to create works that invite ongoing dialogue— works that, as with many envirographic artworks, foreground translation, complexity, and poetic nuance over simple messaging.

This methodology is evident in both the research processes and the outcomes of my recent practice. Reading widely in climate science and adjacent art and humanities scholarship is woven into my everyday research process. This reading is not a passive backdrop, but a generative site of artistic inquiry. Each project— *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eaters* (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024)— is in some sense an outgrowth of this iterative dialogue between scientific literature, data, and creative experimentation. The continual encounter with divergent theories, evidence, and cultural perspectives directly shapes both the conceptual underpinnings and the material manifestations of my work.

The most recent projects in particular, *Celestial Objects and Aeriform Masses* and *AtmoSpheres 01*, push this methodology into explicit SciArt territory through direct collaborations with scientific laboratories at York University. The process of working alongside Dr. Regina Lee's Nanosatellite Laboratory team, Dr. Mark Gordon's Air Pollution lab, and Dr. Gerd Grau's Electronics Additive Manufacturing Lab students has offered deep, first-hand engagement with the tools, techniques, and epistemic cultures of scientific research. Far from treating these collaborations as opportunities for simple illustration or data visualization, I embrace the complexities and indeterminacies inherent in translating scientific data into artistic form. For instance, the cubesat launch data from Dr. Lee's lab was not rendered as a straightforward graphic; instead, it served as one of many layered inputs into a poetic, interpretive animation. Here, I find a resonance with the work of artists like Nathalie Miebach, whose data-driven sculptures refuse clear boundaries and complexly weave weather data into colourful notation.

This blending of quantitative and qualitative modes is a throughline in my approach. In *Sun Eaters* (2022-2023), for example, I devised new methods for visualizing plant bioelectrical activity— an endeavour that is at once an experiment and an artwork. My engagement with plant electrophysiology does not aspire to meet the strict protocols of the scientific method; instead, it operates as a form of "science-like play," an exploration that values discovery, iteration, and the pleasures of encountering the unexpected. I have observed patterns that suggest intriguing biological phenomena: changes in electrical activity correlated with species, diurnal cycles, seasonal variations, and physiological health. Yet my aim is not to produce publishable scientific results, but rather to learn from and share the imaginative and speculative dimensions that emerge from this close observation of plant-beings who experience the world so differently from humans.

Drawing on the arguments articulated in Chapter 8, I see such interdisciplinary work as a site for hybrid knowledge production— one that is urgently needed to confront the epistemic, cultural, and existential challenges posed by climate change. The complex problems we face are not amenable to singular disciplinary perspectives. By weaving together empirical data, subjective interpretation, and open-ended dialogue, I strive to foster new ways of seeing, feeling, and responding to the planetary crises of our time.

10.4 Fieldwork

Fieldwork occupies a central position within my practice, constituting a direct mode of engagement with environments, communities, and ecological contexts beyond the conventional boundaries of studio or gallery spaces. I approach fieldwork as an immersive, embodied methodology— one that privileges first-hand interaction, observation, and participation in real-world settings. This commitment aligns closely with the interdisciplinary ethos articulated in my broader research, where knowledge is understood to be both situated and relational. Through fieldwork, my artistic process becomes deeply informed by direct, experiential encounters, resulting in outcomes that are attuned to site-specific relevance and lived context.
In practice, my approach to fieldwork encompasses several interconnected modalities:

- **Observation and documentation:** I employ a range of tools— photography, audio recording, sketching, and electronic sensing— to gather material that captures the complexity of environmental phenomena. For example, in *Dawning* (2023), fieldwork involved an extended investigation of dawn in a forest ecosystem, drawing on exploratory video techniques, ambient sound recording, and reflective note-taking. These layered acts of observation serve as both research and creative process, generating an archive of experiential knowledge that shapes subsequent artistic decisions.

- **Data Collection:** Many of my projects foreground the active collection and interpretation of environmental data. In *AtmoSpheres 01* (2024), the focus is on capturing fine and ultra-fine black carbon particulate pollution— an endeavour that leverages custom-built IoT sensors, digital mapping, and cloud-based data management. This project remains in progress, with the expectation of expanded data collection in the coming year. In earlier works such as *Holonic Chorus* (2021-22), *Daily Chorus* (2022), and *Dawning* (2023), I combined real-time data I collected with feeds collected by others— sometimes even drawing on open platforms such as Twitter— to enrich the analytical and affective depth of each piece. This fusion of empirical and interpretive methods is a hallmark of my interdisciplinary practice.

- **Site-specific research:** Investigating particular landscapes, urban ecologies, or natural systems is essential to my creative inquiry. In *Sun Eaters* (2022-2023), for instance, I explored bioelectrical flux patterns in trees in-situ across diverse environments, examining how these readings shift according to ecological context, species, and even states of health. While recent projects have increasingly sought to reveal broader planetary patterns, I continue to recognize the value of specificity and intend for future projects— such as new envirographic video studies developed from the groundwork laid by *Dawning*— to return to more focused, place-based investigations. This approach echoes earlier projects like *Openseed* (2018-2021), where fieldwork was the foundation of both conceptual and material development.

Field experiences are never ancillary in my practice; rather, they are constitutive, shaping not only the conceptual frameworks of each project, but also informing the materials, aesthetics, and modes of presentation I employ. In this way, fieldwork operates as both a research and a creative methodology— one that is deeply informed by interdisciplinary thinking and pluralistic, collaborative values. Through these direct, situated engagements, my practice actively participates in the broader project of bridging art and science, foregrounding the value of embodied, context-rich knowledge as a catalyst for artistic innovation and societal reflection.

10.5 Use of Data

Across my recent body of work— including *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eaters* (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024)— environmental data emerges not simply as a resource but as a principal artistic material, subject to ongoing processes of interpretation, translation, and reimagination. Each of these projects actively engages with diverse forms of environmental information, from bioelectrical signals and atmospheric measurements to particulate matter and satellite telemetry, often interweaving multiple datasets within a single work.

This approach is deeply informed by the arguments outlined in Chapter 9, which addresses the fundamental challenge of making the imperceptible perceptible— of translating the vast, slow, or otherwise inaccessible dimensions of environmental phenomena into embodied, affective experience. My practice responds directly to this reality: by grounding my art in the affordances of scientific instruments— sensors, microcontrollers, remote sensing— I am able to reach beyond the limits of individual, subjective perception to access what I otherwise could not. In so doing, data becomes the bridge, allowing me to grapple with scales of deep time or fleeting moments, planetary magnitudes of geography as well as hyperlocal conditions; and to translate the granular patterns of weather into the slow drift of climate.

The act of data translation— at the heart of envirographic art— offers new pathways for perception, knowledge, and imaginative engagement. As theorists such as Jennifer Gabrys and Alfred North Whitehead contend, data is never a simple, neutral representation of reality but rather an active mediation, one that is co-constructed through technological, material, and social processes. For me, it is in this act that the art resides. The injection of my subjective aesthetic philosophy into the dataset results in beautiful, affective and powerful environmental art. I have found in the writings of Tiffany Holmes, particularly in her pioneering net artwork *Floating Point*, resonance in how the visualization of environmental data can reveal hidden patterns, foster new modes of public engagement, and expand our capacity to "sense" planetary change. Holmes' work, alongside that of Andrea Polli and Nathalie Miebach, among others has deeply influenced my own evolving methods of translating data into multisensory, participatory artworks.

James Bridle's insights further articulate the urgency of this task: "If our inability to tell meaningful, actionable stories about our changing planet is part of the problem, then we need to rethink the tools we use to make culture itself."[14] For me, the deployment of technology— sensors, code, data visualization, sonification— acts as a kind of macroscope, making it possible to see, feel, and interpret ecological systems at scales otherwise impossible. These tools are not merely means of documentation; they are engines of imagination, vehicles for re-encountering the world as interconnected, dynamic, and alive.

Grounding my practice in environmental data not only allows me to extend perception, but also supports my conviction that greater understanding of ecological systems is essential for more just and effective climate action. Artistic engagement with data is not didactic or illustrative in the sense of science communication.

Rather, as the following chapters will show, each of my works employs data as both raw material and generative constraint, leading to new forms of aesthetic inquiry and experiential knowledge. The integration of empirical, quantitative sources with qualitative, affective dimensions is, I believe, critical to fostering a more holistic and pluralistic relationship with our changing planet.

10.6 Co-Creation and Citizen Science

My work consistently draws upon the principles and methodologies of social practice— foregrounding collaboration, reciprocity, and the democratization of knowledge production. This approach is informed by a lineage of art-science projects that engage publics as active participants rather than passive observers, thereby enacting pluralism as both process and outcome.

AtmoSpheres 01 (2024) is directly inspired by the citizen science models advanced by Beatriz da Costa in her project *Pigeon Blog*, as well as by the imaginative engagement and public intervention strategies of Natalie Jeremijenko. Both artists use accessible sensing technologies and inventive participatory frameworks to transform everyday citizens into knowledge producers, thereby challenging the exclusivity of scientific expertise and opening up the processes of environmental monitoring to wider publics. In my work, I similarly employ wearable air quality sensors and collaborative data gathering, positioning the public not just as subjects but as co-investigators. My project's orientation toward participatory sensing draws from da Costa's critical engagement with cross-species grassroots data collection and Jeremijenko's playful, activist methods for empowering communities to address their own environmental conditions.

Equally formative for my approach are the ambitious social engagement and policy— focused objectives of Mel Chin's Fundred Project, which mobilized thousands of individuals in a collective artwork aimed at influencing environmental policy around lead contamination. Chin's insistence that creative practices can catalyze structural change underpins my own belief that art can operate as a form of intervention— raising consciousness, fostering collective agency, and addressing environmental justice issues through inclusive, participatory frameworks.

The development of *Holonic Chorus* (2021-22), *Daily Chorus* (2022) exemplifies the practice of co-creation.

Both projects emerged through collaborative, dialogic processes with diverse contributors— ranging from environmental scientists and engineers to local community members and fellow artists. These works were not designed in isolation but rather shaped and refined through iterative exchange and mutual decision-making. This co-creative methodology ensured that each participant's perspective informed the conceptual, technical, and aesthetic direction of the final work, embodying the ideals of distributed authorship and shared ownership that are central to co-design and participatory art.

Celestial Objects and Aeriform Masses (2023), in particular, is best understood through the lens of Participatory Action Research (PAR). This project developed in close partnership with researchers from York University's Earth and Space Sciences and Engineering departments. The process was marked by cycles of collective inquiry, reflection, and action— core to the ethos of PAR. Community participants contributed not only to the gathering and interpretation of environmental data (from nanosatellites and air quality sensors), but also to the framing of research questions and the envisioning of artistic outputs. In this way, the boundaries between artist, scientist, and participant were intentionally blurred, making the process itself as significant as the outcomes.

Across all of these works, I am motivated by the conviction that pluralistic, participatory methodologies are not merely supplementary to art-making but are vital tools for engaging with the complexities of the current polycrisis. As I have argued elsewhere, social practice forms such as citizen science, co-design, and participatory action research democratize knowledge production by disrupting epistemic hierarchies and valuing the insights of those most affected by planetary crises. They foster networks of care and remediation, allowing for more inclusive, adaptive, and resilient responses to climate change and environmental degradation. By embedding pluralism at the heart of both process and product, these methods generate richer, more situated forms of understanding— offering not only new knowledge, but new ways of being in relation to each other and the world.

10.7 In Conclusion

My artistic practice emerges from a profound need to make sense of this planet and of the complex moment of ecological and societal polycrises we inhabit, a time shaped by ecological degradation and rapid change.

In this sense, my work is externally oriented, grounded in the urgency of our planetary condition. However, it is also deeply personal. It is informed by a continuously evolving worldview and a desire to process, reflect, and respond through making.

As I live and try to understand the world, I am compelled to embed my realizations— however tentative— into objects, actions, and experiences. Some of this work is solitary; much of it is collaborative. I learn through making. And I share what I make because the process feels incomplete without that exchange. My goal is to foster shared learning, dialogue, and mutual discovery through open-ended artistic engagement.

Within this process, computation is not merely a tool but a material and conceptual collaborator. Technological systems do not inherently dictate their use; they can be reimagined, repurposed, hacked, or subverted. In my practice, I regularly interrogate both how a technology functions and what kind of world it presupposes— and then ask what kind of world I want to help shape instead. When needed, I adapt existing systems; when possible, I build new ones. When joyful, I invite others in. This iterative process of prototyping, testing, failing, and refining often leaves few visible traces in the final artwork, but it is where the deepest insights are cultivated.

Crucially, my practice aims not to resolve the tensions inherent in interdisciplinarity, data translation, or social practice, but rather to inhabit them productively— to treat them as generative spaces for critical reflection, poetic exploration, and collective meaning-making. Ultimately, I create not to offer answers but to learn for myself and to open experiences for others that might prompt reflection, provoke feeling, and encourage others to sense differently. The forms these works take vary, but the intention remains: to surface ideas, questions, and meanings through encounter. The intention is not to close the conversation, but to continually open it— inviting others into the ongoing project of sensing, knowing, and caring for our living world.

Part IV

Artworks

Chapter 11

Six Envirographic Artworks: (2021–2025)

> Why do human beings choose at this time in our cultural history to communicate with one another by making complex artifacts out of electrical impulses? For the same reason that we couldnt put down the stylus or the whittling knife. We are drawn to a new medium of representation because we are pattern makers who are thinking beyond our old tools. We cannot rewind our collective cognitive effort, since the digital medium is as much a pattern of thinking and perceiving as it is a pattern of making things.. . . The machine like the book like the painting and the symphony and the photograph is made in our own images and reflects it back again. The task is the same now as it ever has been, familiar, thrilling, unavoidable; we work with all our myriad talents to expand our media of expression to the full measure of our humanity.
>
> *–Janet Murray*

11.1 Introduction: Art as a Technology of the Self

The last year in which Earth was not warming month by month was 1985— a watershed moment for the climate, for all living beings, and, coincidentally, the year of my birth.[1] Time, in this sense, can be understood as the present casting its shadow into the future, and since 1985, we have witnessed cascading and accelerating changes: planetary warming, computational ubiquity, and the entanglement of multiple, interwoven crises.[2]

My work as an artist is shaped by this historical context and arises from an ongoing process of sensemaking—an effort to understand planetary systems, our precarious trajectories, and the interconnected futures we share. Computational tools have become essential to this practice, for the sheer scale and complexity of global ecological change are not fully perceptible without them. Their affordances enable me to work across spatial, temporal, and perceptual dimensions that far exceed the limitations of our senses, fostering a mode of artistic inquiry that is fundamentally planetary in scope.

11.2 Overview

My research investigates shifting systems in built and emergent environments within the context of the climate crisis. Using an interdisciplinary approach, I aim to connect human experiences with planetary ecologies, grounding my artistic expression in evidentiary environmental data and scientific consensus. Through this process, I create artworks that foster deeper connections with ourselves, other species, and the planet. My work renders imperceptible phenomena— such as air pollution, climate/weather, and bioelectrical signalling in plants— into sensory, experienceable forms (visible, audible, tangible), revitalizing our understanding of ecological interdependence and interrogating the supposed separation of planetary built and natural systems.

A central practice in my work is to render tangible the otherwise imperceptible dynamics of planetary processes— such as air pollution, weather and climate, and plant bioelectrical signalling— translating them into forms that can be seen, heard, or felt. In doing so, my practice gestures toward planetarity: not merely as a scale or subject, but as an ethos— an effort to foreground our entanglement with global processes, and to reveal the interdependence of all life within Earth's complex systems. By making planetary phenomena accessible to embodied experience, I seek to revitalize our sense of ecological interconnectedness and challenge the supposed separation of natural and built worlds. In this way, my work serves as both a prompt and a practice of planetary thinking.

11.3 Shifting Directions in My Practice

My early artwork, 2003 to 2020, explored my growing awareness of global systems, the climate crisis and increasingly delt with scales of planetarity in later years. Yet, much of this work was marked by solastalgia and a sense of anxiety about possible futures.[3] The six projects developed during my doctoral studies at York University (2021-2025) represent a conscious philosophical shift. Rather than dwell in or amplify fear, an emotion from which it is challenging not to give in to the inertia of inaction, I have chosen to centre themes of interconnection, care, and awe. While this orientation was already surfacing in earlier art endeavours like Openseed (2018-2021), the onset of SARS-CoV-2 crystallized this intention.

These new works emphasize the positive, connective capacities of digital mediation in enhancing our understanding of ecological systems. In each of the works discussed here— *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eaters* (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024)— digital mediation and environmental data visualization serve as tools for reimagining our relationship to Earth's living systems. These projects do not merely reflect planetary conditions; they invite audiences into participatory explorations of ecological phenomena, foregrounding the connective tissue that binds us to planetary processes and one another. This deliberate shift signals my commitment to fostering a more generative and collective sense of agency in the face of planetary crisis.

11.4 Philosophical Foundations

Underlying these six artworks and my envirographic art practice more broadly are a set of fundamental beliefs; they shape my artistic inquiry, informing both the questions I pursue and the ways I respond to a rapidly changing world.

- Everything alive is intelligent.
- Plants are agential beings.
- All life on earth is interconnected.
- All life processes and many geophysical ones are rhythmically periodic; they are dancing.

- Life on Earth at this moment is post-natural: nature and culture are not separate. Tools and technology are humanity's interface with both.
- Mediation can be used to connect, not just attenuate.
- Art can reshape mental models, of vital importance as they form the frameworks we live by.

These principles serve as touchstones, shaping my creative choices and reinforcing my belief in art's capacity to foster connection, agency, and new possibilities for planetary care.

11.5 Reflections on Form and Image in the Work

Creative decisions about form and image in my practice are influenced by the limitations and opportunities presented by current materials and technologies. Equally, they are informed by a recurring, sometimes unconscious, attraction to particular motifs. The limitations of current industrial processes include factors include the narrow range of materials available for three-dimensional printing, for instance, and the fact that others— such as clay or metal— remain prohibitively expensive. In electronics fabrication, I am able to produce some components but not others. As a result, I often find myself expanding the expressive potential of available materials— embedding LEDs, for example, within unconventional structures. In *Sun Eaters*, this takes the form of translucent printed branches; in *AtmoSpheres 01*, layered, custom-fabricated fibre. Looking ahead, I aim to further refine my technical vocabulary for integrating computational outputs into physical media, drawing inspiration in part from the scholarship of Hiroshi Ishii and the Tangible Media Group.[15] Material exploration remains central to my evolving practice, particularly in relation to electrically responsive media such as thermochromic paints and pneumatic systems. At present, I am experimenting with conductive ink and laser-induced graphene to explore their capacity for responsive interaction.

Beyond such constraints, my work is also informed by a clear material affinity— an ongoing gravitation toward certain forms and media. Light and shadow, for example, recur throughout my practice. In *Dawning*, a sculpted canopy of dappled light serves as a projection screen; in *Sun Eaters* and *AtmoSpheres 01*, light is deployed as a strategy for data visualization. Invisible atmospheric phenomena, particularly wind and air pollution, also surface frequently. Wind is visualized in *Holonic Chorus* and *Daily Chorus*, while air pollution is a central theme in *We Are Air Aware: AtmoSpheres*. The presence of light has been consistent in my work since the early 2000s. I continue to find it among the most compelling media available to me: immaterial yet often the dominant visual feature in a space. Conceptually, light resonates as both the origin of life and a metaphor for energy. Practically, it also provides the most immediate output in physical computing, requiring little translation from digital input to sensory experience.

Another persistent thread in my practice is the use of waveforms. Many aspects of reality— both material and immaterial— are wave-based: the short and long bioelectrical action potentials of plants, the electrical patterns of biological systems, and the oscillations of atmospheric or electromagnetic phenomena. Visualizing data through waveforms— waves of light, undulating animations, rhythmic colour shifts— feels both intuitive and symbolically rich. This approach appears in earlier works such as *Rise*, which made sound visible through cymatic vibrations in water, and in more recent projects including the branching structures of *Sun Eaters* and the animated elements of *Celestial Objects and Aeriform Masses*.

11.6 On Affect: The Importance of Awe and Wonder

Artworks such as Sun Eaters and Dawning are motivated by a desire to express my sense of awe and to share it with others, creating spaces for contemplation, wonder, and renewed reconnection with the living world. Through these works, I aim to cultivate awareness of ontological connections across species, while also honouring our differences. These recognitions form the building blocks of empathy— and perhaps even love. Can we care for what we do not love?

Indeed, fostering empathy across species may offer the reframing necessary to move society beyond extractive, divisive mentalities. In their place, we might cultivate systems that respect ecological limits, prioritize regenerative cycles, and embrace collaborative, nurturing behaviours. Nature provides abundant models for collaborative and regenerative relationships: in the resource-sharing of plant and fungal networks, and in the cooperative alliances that cross species boundaries.[16][17]

For me, art has always carried a spiritual resonance, a capacity to engage not only intellect and emotion but something deeper and more expansive. In my practice, I strive to create works that invite a holistic engagement of mind, heart, and spirit— believing that a truly grounded response to planetary change must encompass all three. Immersing myself in research on climate, ecology, and planetary systems continually deepens my appreciation for the intricate mechanisms and relationships that sustain life on Earth. This expanding knowledge, acquired not only through scholarly reading but also through dialogue, field observation, and making, nourishes a persistent sense of awe and gratitude. My artworks, then, become instruments of inquiry— serving both as a means of processing my own understanding and as an offering to others, inviting collective reflection and connection.

I believe that awe and wonder are personally healing, and collectively vital. For me, awe and wonder are not simply private feelings, but social and ecological resources— antidotes to despair and inertia. In cultivating these affects, I hope to offer a necessary balm for those wrestling with the enormity of ecological crises, and a point of entry for new forms of planetary care.

11.7 On Environmental Degradation, Deep Time, and the Present Crisis

To me, environmental degradation means the reduction of suitable conditions for the emergence and continuation of complex life - both materially and across temporal scales. This distinction is important because nature itself is indifferent to which elements and compounds are present, and "life" encompasses a far broader range of forms than we often acknowledge. For instance, some bacteria thrive in conditions that are utterly inhospitable to most other life on Earth. Labeling elements as inherently "toxic" overlooks the adaptive capacities of extremophiles and the ongoing evolutionary processes continually unfolding all around us. Plastic, for example, is already being metabolized by certain bacterial strains, and a new species of microbe was recently identified in the harsh environmental conditions of the International Space Station.[18][19] Evolution is ongoing— and indifferent to human values.

The ecological crises we face today are not urgent because particular materials are intrinsically harmful, but because of the *scale* and *speed* at which these materials have been amassed. The volume of waste now present— much of it inimical to most known life— has accumulated at a pace entirely without precedent in Earth's history. Entirely unprecedented.

Temporal scale throws this crisis into sharper relief. The processes that led from Earth's earliest life to the emergence of humanity unfolded over approximately *3.5 billion years*. The processes by which we have destabilized the climate through greenhouse gas emissions have occurred in just *200 years*.

It's almost unbearable to imagine a future in which runaway climate change and waste accumulation render most current forms of life unviable, and in such a scenario, extremophile bacteria may well persist, and evolutionary processes will continue. But consider how long it might take— how unimaginably vast the time— to return even a fraction of the stunningly beautiful breadth of breathing life that is co-extant right now on our dancing blue marble to re-emerge. Personally, my heart breaks when considering it.

Through my art, I seek to create space for this reflection - for myself and for others. I want to invite reverence for what exists now, for the lives with whom we are privileged to co-exist. I want to help cultivate awe, not despair, and to imagine polyphonic paths toward better tomorrows— for as vast and inclusive a multi-species "we" as only we can envision.

11.8 Conclusion

Across these reflections, a throughline emerges: my practice is animated by a commitment to planetarity— both as a scale of inquiry and as an ethical orientation. By engaging with environmental data, computational tools, and embodied processes, I strive to make visible the entanglement of all life within planetary systems, and to open new possibilities for connection, empathy, and action. The recurring motifs of light and waveform, the turn toward participatory and connective methods, and the cultivation of awe are not merely aesthetic choices, but strategies for inviting others into a shared project of reimagining our relationship to Earth.

In an era defined by rapid planetary change, I believe that art can function as a technology of the self and of society: a means of sensemaking, a tool for deepening understanding, and a catalyst for collective transformation. By foregrounding the interdependence of all life and making planetary processes newly perceptible, my work aspires to help foster the cultural shifts— of mind, of heart, of practice— necessary for meeting the challenges and responsibilities of this moment.

Chapter 12

Holonic Chorus

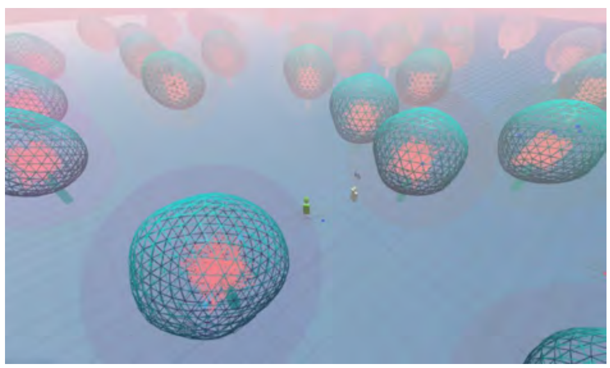


Figure 12.1: Still image of *Holonic Chorus* featuring two virtual participants meeting. (Photo by the author, 2021).

12.1 Introduction

Holonic Chorus invites viewers into a shared WebXR world - a fluctuating forest generated from real biometeorological data.[1][2] It is a collaboratively developed artwork created by Kwame Kyei-Boateng, Eyal Assaf, Douglas Gregory, Ilze Briede (aka "Kavi"), and myself.[3][4][5][6] In this playful virtual environment, groups of participants interact with trees to generate musical tones via keyboard navigation. As participants approach various trees, distinct tones are triggered. Each new set of interactions produces a unique song.

A holon - derived from the Greek *holos* (whole) and *on* (part) - is defined as something that is simultaneously a whole in itself and part of a larger whole (Arthur Koestler, *The Ghost in the Machine*).[7] In this artwork, participants are holons: individually generating tones, yet collectively contributing to a larger chorus.

Due to the mediation inherent in the work, participants are both connected and apart - mirroring the conditions of our real lives at the time, shaped by social distancing during the pandemic. In creating *Holonic Chorus*, we hoped to offer a sense of community and shared space despite physical separation.[8]

12.2 Artist's Statement

My thinking in the collaboratively developed artwork *Holonic Chorus* was shaped by three key influences of the context in which it was created in 2021. First, it began during the lockdowns imposed by the SARS-CoV-2 pandemic. Having recently relocated from San Diego to Toronto to join a longstanding research community within York University's Computational Arts Department, I was eager to engage collaboratively despite my relative physical isolation.

Second, my personal conceptual focus at the time centred on exploring the recognition and tangible expression of interconnectedness and interdependence among all living organisms and planetary systems, for example how climate or meterological conditions impact ecologies and individuals. In this context of a collaborative co-designed artwork, that inquiry took the form of investigating how mutual play might facilitate the a greater appreciation and awareness of these ecological relationships.

The third aspect informing the work was my growing interest in the mediating capacities of WebXR, a digital medium our group was collectively learning. I found it uniquely suited to facilitate connections across geographic and experiential distances, yet simultaneously underscored the paradoxical coexistence of connectivity and separation inherent to digital platforms. This mediating tension was particularly evident when exhibited physically, such as during its inclusion in the Vector Festival in July 2024.

My proposal to incorporate the term "holon" into the work's title emerged from my fascination with digital mediation and relational systems. Arthur Koestler coined the term "holon" in The Ghost in the Machine, describing entities— living organisms or social systems— that are simultaneously wholes and parts. Humans exemplify this holonic nature through their internal experiences and external social interdependence. The symbol of a "chorus" metaphorically expressed the synergistic potential of interconnected holons, collectively forming something greater than their individual parts, directly echoing the concepts of planetarity I was beginning to grapple with in my work.

This interest in holonic structures connects further to broader inquiries within emergent materialist philosophy— which explores how complex material interactions yield emergent cognitive properties— and neuroscience's distributed cognition theories, both of which inform my conceptions of planetarity.[9][10] These interdisciplinary intersections underscore how technologies, or techne, are not merely instrumental but actively co-constitutive elements in shaping human cognition and experience within a continually evolving feedback loop over time and generations. As Bernard Stiegler argues, techne significantly influences human evolution, arguably equal in impact to our physical environment and the biological beings we coexist with, a point made poignantly clear in the contemporary context of the Anthropocene, where human-made materials now outweigh Earth's biomass.

Holonic Chorus thus represented an early experiment into environmental data visualization, explicitly bridging artistic practice and ecological awareness. By leveraging digital mediation to reflect intricate relationships between individual entities and broader ecological and planetary systems, this project laid groundwork for what I now term "envirographics"— a developing artistic methodology dedicated to translating environmental data into perceptible, experiential forms. As a computational artist deeply invested in ecological discourse and the climate crisis, I find a pressing imperative to continuously interrogate how digital mediation shapes our collective understanding of the interconnected, living world.

12.3 Related Work and Methods

Holonic Chorus took shape through a deliberate process of co-creation— a form of collaborative making in which conceptual, technical, and aesthetic choices are negotiated iteratively among equal partners. Over a series of online jam sessions, and a shared code repository, my colleagues Kwame Kyei-Boateng, Eyal Assaf, Douglas Gregory, Ilze Briede ("Kavi"), and I refined every aspect of the piece together. The finished

WebXR environment lets visitors navigate a living forest which reflect real-time weather, and each time an avatar nears a tree, that tree adds a tone to the communal soundscape; because both the data feeds and the paths people choose continually shift, every gathering produces a one-off musical sketch that belongs equally to its makers and the moment.

One influence on this approach is Goldberg's *Telegarden* (1995-2004), which allowed online visitors to collectively interact across species through cultivating a garden. *Telegarden* suggested that dispersed publics could feel genuine care for a living system mediated by technology; *Holonic Chorus* similarly asks distributed users to "cultivate" an acoustic ecosystem sustained by their shared attention. Tiffany Holmes's browser-based eco-visualizations (2004) also inform the work. Holmes translated water-quality metrics into engaging animations, showing that environmental data can remain legible even when cast in aesthetic form. Following her example, *Holonic Chorus* makes use of real-time wind data to animate the forest's movements.

Our interest in networked presence owes much to Kit Galloway and Sherrie Rabinowitz's *Hole in Space: A Public Communication Sculpture* (1980), which showed how live two-way video could create spontaneous publics across great distance— an "outrageous transcontinental pedestrian intersection" that prefigured contemporary video-conferencing.[12] That sense of synchronous, playful connection reappears here, where geographically scattered performers weave a single acoustic fabric.

JODI's *wwwwwwwww.jodi.org* (1995). *wwwwwwwww.jodi.org*, with its intricate abstraction of basic html, challenges conventional web design, is often considered the first artwork on the web, and is one of the most well-known examples of net.art.[13] As a precursor to WebXR, this work was a signficant influence for *Holonic Chorus*.

More recent mixed-reality works provide additional conceptual scaffolding. Haru Ji and Graham Wakefield's *Inhabitat* (2017) is a mixed-reality artwork exploring an imagined ecosystem of life-forms and encourages playful engagement by viewers; *Holonic Chorus* encourages similar forms of interactive engagement.[14] Benjamin Bacon and Joe Saavedra's Electromechanical Solenoid Orchestra & Weather Ensemble (2011) transformed meteorological feeds into pulsing rhythms and light, foregrounding weather as a constant, co-creative partner.[15] Their material translation of climate data echoes in *Holonic Chorus*, where wind data and user interaction modulate both animation and audio in real time.

Taken together, these influences converge in a work that casts each participant as a co-creator in an shared world, and the resulting chorus renders the very interconnectedness it thematizes— one that remains perpetually unfinished and open to the participants.

12.4 Technical Description

Holonic Chorus is available for viewing through WebXR enabled browsers such as Microsoft Edge, Chrome, or Firefox and through other browsers with WebXR extension installed. All you need to experience the artwork is a computer with a WebGL-capable web browser.

To experience *Holonic Chorus*, follow this link: https://environmentalsensing.herokuapp.com/forest.html

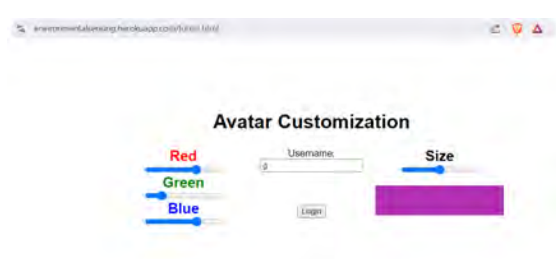


Figure 12.2: Still image of the artwork's landing page. (Photo by the author, 2024).

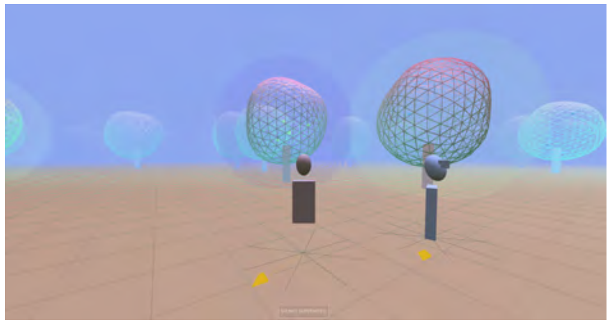


Figure 12.3: Still image of *Holonic Chorus* co-created by Grace Grothaus, Kwame Kyei-Boateng, Eyal Assaf, and Ilze Briede aka Kavi.

(Screenshot by the author, 2021).

This web app consists of 5 main parts:

1. multiplayer.html, is responsible for the log-in form, and calling into the other modules to set up the world/scene/connection, and running the rendering loop.
2. world.mjs, which encapsulates the work of creating an almost-blank-slate THREE.js space with a floor and lighting, and a button to enter VR.
3. connect.mjs, which handles connecting to a Heroku server (running server.mjs) and synchonizing user data over that connection.
4. server.mjs, which handles running the Heroku server, serving the other files and assets to the web browser, and acting as a relay to share data over WebSocket.
5. replication.mjs, which is responsible for tracking and displaying the local user's controllers, saving that information into the data structure connect.js synchronizes, and creating/updating avatars for remote users based on the latest data synched using connect.mjs.

They perform the following:

- Presenting the user with a sign-in interface to set their display name and appearance (colour hex code)
- Transitioning the user to a THREE.js scene with the option to enter VR
- Detecting VR controllers and rendering them with matching 3D models (based on the example at https://github.com/mrdoob/three.js/blob/master/examples/webxr_vr_ballshooter.html)

- Establishing a connection to a WebSocket server (courtesy of Graham Wakefield's connect.js and server.js code for nodes)
- Synchronizing the local user's camera/HMD pose to the server, along with controller poses if available
- Replicating remote users'pose data synchronized from the server, and visualizing them with custom-named and coloured avatars
- Handling removal of an avatar when its user is disconnected
- Remembering user preferences between visits to the app, using local storage [16]

Project code can be accessed in GitHub through this link https://github.com/GGrothaus/holonic_chorus and is also included in the appendices.

12.5 The Team

Each of my collaborators in *Holonic Chorus* brought unique skills and experience to the project. Eyal Assaf, Ph.D. candidate in Digital Media, is a technical artist researching ALife applications and development in-game environments. Kwame Kyei-Boateng, MA Digital Media, is a computational artist exploring Human-Computer Interaction (HCI) and the shifting boundaries between the real and the virtual. Ilze Briede, aka "Kavi", Ph.D. candidate in Digital Media, investigates the phenomenon of perception and the constraints and boundaries between the senses and knowing through bio-physiological sensing, computational creativity, and generative art. Technical assistance was provided by Douglas Gregory, MA Digital Media, game designer and educator.

In developing the artwork, Douglas played a pivotal role in providing technical assistance with the codebase, ensuring the project's functionality and cohesion. Kwame was this artwork's lead contributor - through designing sound interactions within the virtual plane, and the initial tree forms, enriched the immersive experience. Eyal took charge of revising Kwame's visual elements, specifically focusing on modelling spherical meshes for the trees, which became a defining aesthetic feature of the virtual landscape. Kavi selected the colour scheme, weaving a visual narrative through a palette that tied the project's elements together harmoniously. Together with Kavi, I integrated the program with cloud service Shiftr, facilitating real-time data flow and connectivity.[17] Additionally, I built the back-end server to host the project, made possible through tutorials by Associate Professor Graham Wakefield, whose guidance helped bridge the technical framework with the creative vision. This collective effort resulted in an artwork that merged sound, visuals, and interactivity into a cohesive and engaging experience.

12.6 Documentation and Public Presentation

Holonic Chorus was exhibited twice, first in online exhibition *Making a better world*, held by the Digital Media Department of Computational Arts, December 13-31, 2021. Here is a link to the online exhibition. It was installed again more recently in June of 2024 when it was curated by Helen Lee into the *Resonant Futures* exhibition as part of *Vector Festival* in Toronto. Link to press about the exhibition here.[18][19]
Below are still images of the online and in-gallery experience of the artwork and here is a Link to a video of it.

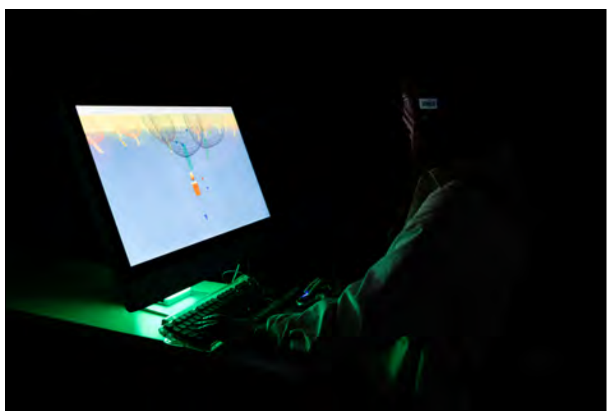


Figure 12.4: Installation view of *Holonic Chorus* at the 2024 Vector Festival's exhibition *Resonant Futures* curated by Helen Lee, photo by Oskar McCarson, 2024.

12.7 Acknowledgements

I want to express my sincere gratitude to my teammates who co-developed the artwork with me. It was their generosity of talent and spirit of collaboration that made *Holonic Chorus* sing. Additionally, the development of *Holonic Chorus* was made possible thanks to the support of Associate Professor Graham Wakefield and the Digital Media Program at York University in Toronto, Ontario.[20]

Chapter 13

Daily Chorus

Figure 13.1: Installation view of *Daily Chorus* with viewer, Transmedia Lab at York University in 2022. (Photo by the author).

13.1 Introduction

Daily Chorus immerses viewers in the interconnectedness of built and natural environments, human and non-human systems— geosphere, biosphere, atmosphere, and noosphere.[1][2] This interactive installation blends physical and virtual elements to represent these interactions. *Daily Chorus* was created by Douglas Gregory, Eyal Assaf, Janica Oplindo, Jorge de Oliveira, Kimberly Davis, Kwame Kyei-Boateng, Raghad El-Shebiny, Xi Lu, and myself.

At rest, the installation space of *Daily Chorus* generates an ambient world of sounds, lights, and digital projections. Streaming data on Toronto's atmospheric conditions shapes these elements based on time of day and environmental states, juxtaposed with sentiment analysis of tweets about Toronto.[3] Light colours correspond to the sentiment spectrum (positive, neutral, and negative), displayed through projections and illuminated gates. In play, viewers interact with the gates by walking through them, triggering light and sound responses, transforming them from observers to participants.[4] Overall, the project aims to evoke a sense of connection to the urban meta-organism we all inhabit, inviting participants to consider their own belonging and agency within city's systems.[5][6]

13.2 Artist's Statement

Daily Chorus, another one of my early envirographic artworks, visualizes the city of Toronto as an interdependent ecosystem, weaving together human activity and environmental conditions. Developed collaboratively according to principles and practices of co-design, it explores the daily rhythms of life within the city's interconnected systems of built and natural environments.[7]

Toronto is framed as a dynamic microcosm of planetary activity, encapsulated by the concept of the *noosphere*, a term popularized by Pierre Teilhard de Chardin to describe a planetary "sphere of reason" shaped by human thought and cultural production within the biosphere.

The project presents a 24-hour time lapse of environmental and human activity in Toronto. Environmental data, including light levels, humidity, wind speed, and air particulates, is dynamically mapped alongside tweets containing the keyword *Toronto*.[8] These tweets represent the evolving discourse within the *noosphere* and are analysed for sentiment on a spectrum from positive to negative. This dual data set raises questions about the interplay between people and the ecology of the city, condensing these patterns into auditory and visual signals in an immersive experience designed to dissolve the supposed separation between built and natural systems.[9]

Daily Chorus synthesizes the team's research interests in environmental data sensing, procedural generation, and interactive sound design, creating a holistic experience that reinforces human inseparability from Earth's interconnected systems. The project asserts that people are not only physically embedded within these systems but are also agential components of the ecosphere. Contemporary urban societies, however, often operate as though detached from natural rhythms— daily, seasonal, and annual.[10] By revealing this disconnect, *Daily Chorus* invites participants to consider the ecology of the city in relation to the broader bioregion around it and to reground and connect to their place within it.

Emerging from a belief that art can engage society with ecological thinking, *Daily Chorus* positions itself as a form of activism, redefining the role of art in fostering environmental awareness and identification.[11][12]

13.3 Related Work and Methods

Daily Chorus was conceived through a co-design process in which our small team and a circle of invited participants iteratively shaped every layer of the piece— what data to collect, how to translate it into image, sound, and physical form, and how an audience might navigate the results. That collaborative method mirrors the definition of co-creation outlined earlier in the dissertation: a distributed decision-making practice where aesthetic, technical, and conceptual choices are negotiated in dialogue rather than handed down by a single author. The outcome is an artwork that braids three complementary strategies— data visualisation, data sonification, and data physicalization— into a single experience, inviting viewers to see, hear, and, in subtle tactile ways, feel Toronto's daily atmospheric and social pulse.

Each strand of the project was informed generally by precedents discussed throughout the methods chapters but most directly influenced by four key artworks. They are Nicholas de Monchaux's *Local Code: 3,659 Proposals about Data, Design, and the Nature of Cities* (2016), *Cabspotting* (2005), by Peter Richards and collaborators, Quasar (2008), by Jean Michel Crettaz with Aaron Bocanegra, Mark-David Hosale, and Duly Lee, as well as *#$%^* (2011) by Tian Li and her collaborators.

Nicholas de Monchaux's *Local Code: 3,659 Proposals about Data, Design, and the Nature of Cities*, for example, uses GIS data to map cities as ecologically interconnected systems, exploring how non-human entities like coyotes or foxes navigate urban spaces. His open-ended visualizations inspired the team to approach urban data poetically, emphasizing the interconnectedness of social and environmental systems.[13]

Cabspotting by Peter Richards and his partners visualized San Francisco's economic and cultural dynamics using GPS data from taxis, revealing urban patterns over time. This project informed the team's thinking about visualizing Toronto's dynamics through tweets and atmospheric data.[14]

Quasar, by Jean Michel Crettaz in collaboration with Aaron Bocanegra, Mark-David Hosale, and Duly Lee, is the first in a series of similar immersive interactive light and sound installations that translated datasets about quasars, bright light formations around black hole events. The significance of quasars to this group of artists is is their symbolic role as markers of the boundary between the known and the unknown, representing the edge of human perception and understanding of the universe.[15] The *Quasar* installation series provided an excellent example to our team of compressing time in a visualized data set.

In *#$%^*, Tian Li and her collaborators used global environmental data to create ambient city noises played through a mechanical silicon sculpture. This project examined the interplay between individuals and their environments, resonating with our themes of human-environment interdependence and collective systems.[16]

Taken together, these works provided a vocabulary rather than a blueprint. By adapting their strategies within a co-designed framework, *Daily Chorus* seeks to frame an understanding of Toronto as a vibrant, interconnected urban meta-organism, encouraging participants to engage deeply with the ecology of the city and their roles within it.

13.4 Technical Description

The interactive installation combines a nine-channel audio system, four projectors, and a physical computing installation. This physical installation has gates participants can walk through, called NeuroID gates, in the middle of the 360-degree projected virtual environment of spatialized sound and animation. The gates, are translucent acrylic columns illuminated by individually addressable LEDs.[17] Their behaviour is controlled via Max MSP developed by Dr. Mark-David Hosale, Kimberly Davis, Kwame Kyei-Boateng, and myself. Abstracted visualizations of the city are projected onto the gates, which respond dynamically to participant interaction.

When participants activate the NeuroID gates by walking through them, they trigger three distinct responses: 1) alterations to the soundscape, 2) illumination changes within the gates, and 3) transformations in the surrounding projected animations. These animations developed by Eyal Assaf and Douglas Gregory include the addition of novel visual elements— multisided geometric forms— that visually represent the participants. As more people engage with the installation, the forms multiply and interact within the virtual environment, creating an evolving A-life system.[18]

The interplay between the physical and virtual components is further shaped by environmental and urban data sources. Elements such as time of day, participant movement, proximity to the gates, and sentiment analysis from Toronto-based Twitter feeds dynamically influence the installation's sound, light, and visual compositions.

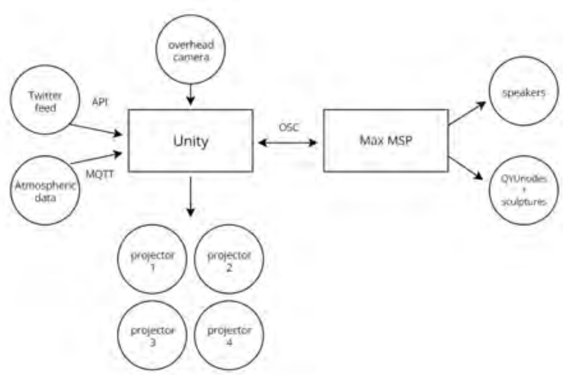


Figure 13.2: System diagram of *Daily Chorus.* (Diagram by the author, 2022).

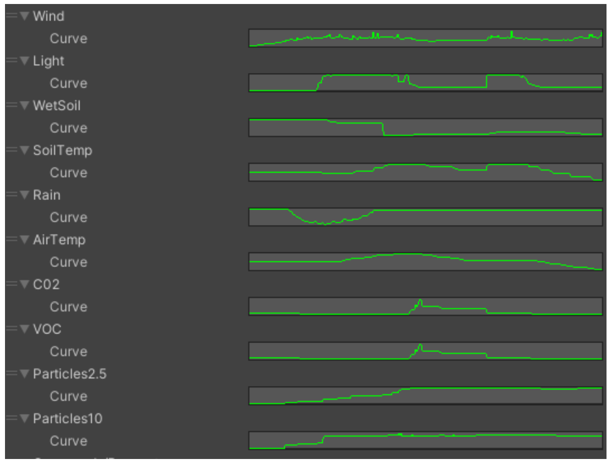


Figure 13.3: Still image of the real-time weather data streamed into *Daily Chorus*. Screenshot by Douglas Gregory, 2022).

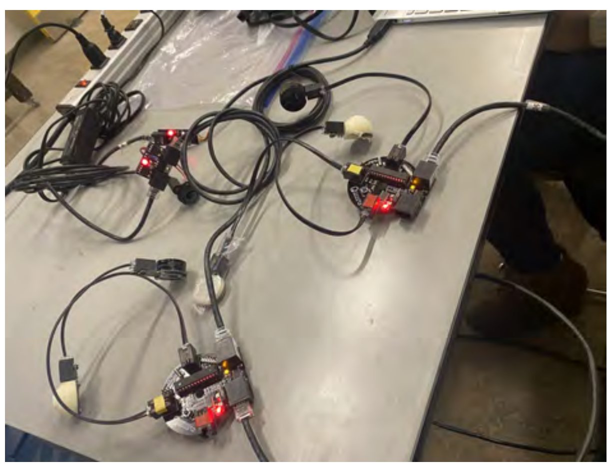


Figure 13.4: QYUnode testing. (Photo by the author, 2022).

13.5 The Team

Figure 13.5: The *Daily Chorus* creators. (Photo by Michael Longford, 2022).

Daily Chorus was created collaboratively by myself and the following team members: Douglas Gregory (MA Digital Media), a game designer researching procedural content generation; Eyal Assaf (PhD Digital Media), a technical artist specializing in ALife applications within game environments; Janica Olpindo (PhD Digital Media), a Queer Filipina artist researching intersections of breakdancing, sound, and human-computer interaction; Jorge de Oliveira (MA Digital Media), researcher focused on artificial life and procedural narrative in game design; Kimberly Davis (MA Digital Media), a computational artist exploring interactive art, data visualization, and mixed reality installations; Kwame Kyei-Boateng (MA Digital Media), exploring human-computer interaction and virtual/real-world intersections. Raghad El-Shebiny (MSc Digital Media), investigating alternative curriculum design in higher education; and Xi Lu (MA Digital Media), an electroacoustic composer researching acousmatic narratives in live performance and interactive media.

My role evolved throughout the project. Initially, I focused on identifying connections between team members'research and proposing ways to weave them into a cohesive whole and integrating elements of my own environmental sensing research. During prototype development, I implemented a workflow for receiving and disseminating environmental data— including particulate matter, VOCs, CO2, O2, light, moisture, and wind— for use as audiovisual outputs. I conducted A/B testing of various particulate sensors and MCUs (ESP8266 and ESP32, for example), managing cloud integration via platforms like adafruit.io and shiftr.io. I also developed a patcher in Max MSP enabling Kimberly's LED visualizations and collaborated with Douglas, who developed a package to integrate the MQTT and API data streams into Unity. Later, I helped Kimberly and Kwame modify the n:D lab's QYUnode interface for spatialized lighting, subsequently shifting to incorporate viewer proximity inputs through ultrasonic sensors (HC-SR04). Recognizing the project's need for greater coherence, I led discussions to unify our diverse contributions into a cohesive installation.

Throughout the project, each team member leveraged unique strengths: Douglas provided dedicated leadership across various elements; Eyal inspired with conceptual frameworks and 3D modelling in Houdini; Janica and Xi crafted immersive audio experiences; Jorge designed a movement detection system; Kimberly excelled in operationalizing the QYUnode network through Max; Raghad kept us organized and excelled in physical prototyping; and Kwame's work on the QYUnode system and the physical installation was foundational to the final artwork. Collectively, our individual and team efforts culminated in a compelling, integrated installation. I am grateful to my teammates and proud of our achievement.

13.6 Documentation and Public Presentation

Daily Chorus debuted in April 2022, when it was exhibited in the Transmedia Lab, ACW, York University. Below is a flyer and photo documentation from the opening.

Figure 13.6: Flyer announcing the public opening of *Daily Chorus.* (Flyer by Eyal Assaf, 2022).

Figure 13.7: Candid documentation of participants interacting with the *Daily Chorus*. (Footage and editing by the author, 2022).

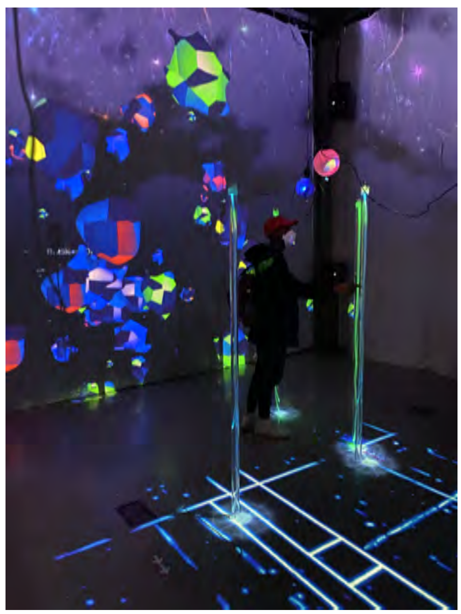


Figure 13.8: Candid documentation of a viewer at the public opening, photo by the author, 2022.

13.7 Acknowledgements

The opportunity to exhibit *Daily Chorus* came with the help and support of Professor Mark-David Hosale and the Digital Media Program at York University in Toronto, Ontario. The work was developed for his course Vertical Studio-Lab I & II and funded through it.[19] The greatest debt of thanks is owed to my teammates who co-developed the artwork with me. Their generosity of talent and openness to collaborate is what made Daily Chorus possible.

Chapter 14

Dawning

> Through our breath, we become the universe, we begin to understand our connections to the universe.
>
> – *Heather Davis*

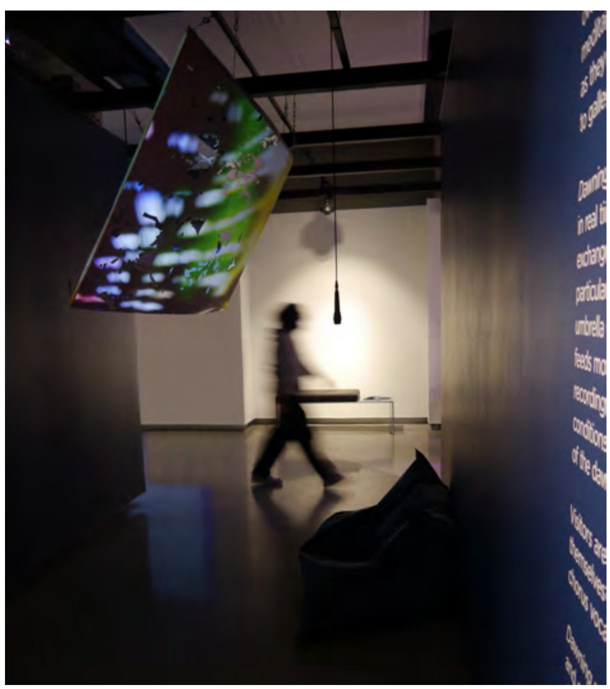


Figure 14.1: Installation view of *Dawning.* (Photo by author, 2023).

14.1 Introduction

Dawning (2023) is an interactive video installation that visualizes forest CO2 levels, temperature, and other environmental data in real time and invites audience participation. As the inaugural work in my exploration of "envirographic" artwork that visualizes environmental data to inspire new understandings of planetary systems. *Dawning* immerses audiences in the dynamic conditions of a forest ecosystem, encouraging reflection on the precarity of biodiverse environments in this moment and the urgency of climate action.

14.2 Artist's Statement

Across the globe living things respond to each new day in a beautiful and endless wave as the sun sweeps over the planet.[2][3] *Dawning* is an audio visual celebratory meditation on this daily circadian rhythm of organisms as they respond vocally to their environment and an invitation to gallery visitors to join in on the chorus.

Dawning is composed of field recordings that are modulated in real time by sensor data of atmospheric exchange: light, CO2, airborne particulate levels, air temperature and humidity.[4] These data feeds are used as inputs or filters generative of live alterations to the playback of the original video and audio. This includes fluctuations in sound levels, screen brightness, red channel intensity, and others. The resulting manipulation of the picture and the sounds of animals, birds, and insects renders the invisible environmental conditions of the forest as audible and observable elements of the arrival of day.

As a work of envirographic art, *Dawning*, represents my first attempt to express the idea of daylight as a slow and certain tide— forever arriving, but always different in how it breaks across each place and moment. Across species, dawn brings a surge of audible life: birds burst into song, monkeys howl, fish emit rhythmic clicks and pulses, and even trees register heightened bioelectrical activity. Humans, for the most part, no longer sing at dawn— but through this work, I wanted to offer an opportunity to listen, to re-join the chorus, and perhaps, to sing back through the microphone provided. The audio composition reintroduces human voices into the planetary chorus— layering recordings of my own singing with that of others as a gesture of participation, resonance, and ecological belonging.

The video is projected onto an overhead screen I created from a sheet of rear-projection film, cut through with a leaf canopy pattern so that the light from the projector would both display the video and approximate sunlight— dappling the gallery walls and floor, as in the forest where the video was filmed. A large cushion is provided so that visitors may rest beneath the screen, immersing themselves in the light of the tree canopy if they choose.

The visual textures I gravitated toward in the video footage are diffuse and atmospheric, and the motion is gently rocking. Through abstraction, I employed visual strategies intended to de-specify the film's location and enhance the emotional resonance of the medium. By bypassing the visually familiar, the work invites viewers to interpret the scene for themselves— responding to the feelings evoked by shifts in colour, light, and shadow.

Dawning aims to provide a means of reconnecting to, and seeing ourselves within, a microcosm of our deeply interconnected collective global biosphere.[5]

14.3 Related Work and Methods

The development of Dawning emerged from methodologies grounded in data visualization and data sonification, aligning with broader practices of envirographic art that seek to render planetary-scale processes perceptible. As previously discussed, much of what shapes life on Earth— such as climate fluctuations, atmospheric conditions, and ecosystem dynamics— remains beyond direct human perception. Environmental sensing technologies, including air quality monitors, spectrometers, and remote sensor arrays, enable us to detect and record these imperceptible phenomena. However, this collected data requires careful mediation through artistic practices to become experienceable. According to theorist Jennifer Gabrys, environmental sensing not only captures but actively shapes how we perceive and understand our surroundings. Informed by Alfred North Whitehead's relational ontology, Gabrys suggests data is not simply an objective reflection of the world, but a co-constructed sensory experience produced through material and computational processes.

Within this context, *Dawning* translates real-time streams of atmospheric data— such as light intensity, carbon dioxide levels, airborne particulates, temperature, and humidity— into synchronized visual and auditory experiences. Sensor data dynamically controls visual elements, such as shifts in brightness, contrast, and colour saturation, alongside corresponding sonic modulations, including variations in tonal richness, rhythm, and harmonic resonance. By linking these data streams directly to sensory outputs, Dawning invites audiences to encounter environmental data as embodied experience, emphasizing the interconnectedness between people and the ecosystems they inhabit.

The methods used in *Dawning* draw inspiration from several artworks discussed in prior chapters that exemplify successful integration of data visualization and sonification to express environmental interdependence. For instance, Camila Marambio's *Turba Tol Hol-Hol Tol* (2022), which I experienced at the Venice Biennale, profoundly impacted me. This installation revealed an extensive collaboration, incorporating work from inhabitants, artists and scientists, which explored the relationship between the Selk'nam people and the peatlands of Karokynka/Tierra del Fuego. It featured a living recreation of a peat bog, complemented by a 360-degree projection room at its center. The projections, displayed on a translucent screen made from living microbes, emphasized interrelations within the peatlands. Marambios blending of artistic action and scientific research inspired *Dawning's* integration of environmental data to convey the profound interconnectedness of ecosystems.[6]

In addition to *Turba Tol Hol-Hol Tol* there are three more direct influences on *Dawning* which I would like to acknowledge. Susanne Schoenberg's *Blind Spots* (2011), Cy Keener's *Remote Winds* (2015), and *Weather Inflections* (2011) by Joel Louie and team. I will expand briefly on each of these below.

First, Susanna Schoenberg's *Blind Spots* influenced *Dawning's* approach to visualizing real-time environmental data. In the installation "Blind Spots," monitored variables (CO2, CO, NO2, LUX, temp C, tVOC, dB noise) were processed in real time by a Factor Analysis. The data was collected in Beijing over the duration of the artwork's exhibition, and visualized in real time as a mask uncovering pixels of recorded videoframes: one channel a real time punctual visualization of all the variables'values, the other representing a days history of the factors identified behind the variables'values development.[7]

Second, *Weather Inflections,* an interactive audio installation by Joel Louie, Jan L Andruszkiewicz, Bryan J

Mather, Kevin Raxworthy, Julian Stadon, and Dr. Paul Thomas. It is an interactive audio installation converting real-time weather data from Perth, Australia— including temperature, humidity, and air quality— into an evocative soundscape. Activated by touch, the project transformed environmental metrics into visceral, tangible forms of interaction. This work resonated with *Dawning's* aim to make invisible environmental processes perceptible, inviting participants to experience and engage with the changing conditions of their environment.[8]

Lastly, In *Remote Winds* by Cy Keener, a series of sculptural weather vanes outside a window register the wind's shifting patterns, transmitting data that activates a grid of rotating lights inside a hallway wall. This quiet, data-driven interplay of motion and light reflects Keener's ongoing efforts to render the invisible forces of climate perceptible through aesthetic experience and technological mediation.[9]

Collectively, these artworks informed how Dawning mediates environmental data into sensory experience, aligning with envirographic methodologies that reveal the planetary phenomena shaping life on planet Earth and the invisible yet omnipresent processes that envelop us.

14.4 Technical Description

Dawning is a live-modulated single channel video on custom projection screen with four channel audio that incorporates audience participation via microphone. Below is a system diagram of the artwork's signal processing and output.

The installation operates through two interconnected systems, blending environmental data with participant interaction:

- **Environmental Data Video Playback**: Live environmental conditions are captured by sensor hubs, which monitor variables such as light, CO_2 levels, airborne particulates, air temperature, and humidity. These data streams are logged via cloud platform shiftr.io and live processed in audio visual software derivative.ca, which transforms the playback of pre-recorded video into a dynamic projection I describe as envirographic.[9][10]

  In the installation this processing is performed on a MacBook and output to a short throw ultra bright

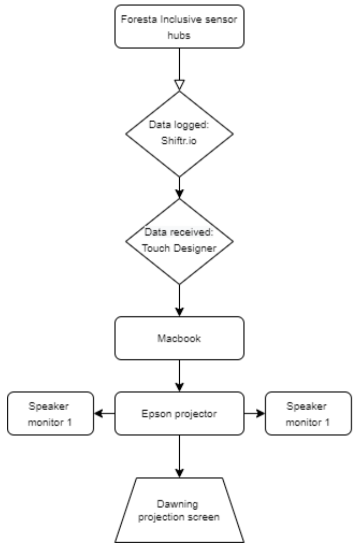


Figure 14.2: System diagram of *Dawning*. (Diagram by the author, 2023).

Figure 14.3: Still image of the rendering of the installation layout for *Dawning*. (Render by the author, 2022).

projector (I used an Epson LS300 ultra short throw laser projector with 3600 lumen output) and onto/through a custom-designed overhead screen I created with cut-outs dappling the projection like sunlight filtering through trees to mimics a forest canopy. This custom screen was a foot foot by eight foot sheet of clear acrylic laminated with rear projection film.[11]

Simultaneously, the modulated audio is broadcast through two-channel monitors (I used Edifier MR4 powered monitors 10 cm), surrounding visitors with an immersive soundscape that gestures towards real-time environmental conditions of the recorded forest ecosystem.

- **Participant Interaction**:

  Participants are invited to contribute their voices to the soundscape of the installation using a hanging microphone. Their vocal inputs are routed through a mixer, which blends them into the existing audio composition, a mix of field recordings and vocal tracks. This live audio is output through monitors 3 and 4, layering onto the output from monitors 1 and 2 to create an evolving auditory experience. In this way, participants become active contributors to the installation's "dawn chorus," mirroring the collective rhythms of life responding to the rising sun.

Through this dual system, I attempted to create a meditative space that merges human voices with the environmental rhythms of a forest, inviting audiences to literally join the dawn chorus and hopefully experience a renewed sense of self as part of a deeply interconnected global biosphere. *Dawning* is the first in a planned series of envirographic art installations that combine video's ability to record fleeting moments of time in precarious ecosystems with real-time weather data visualization, highlighting the ongoing unfolding of the climate crisis that imperils their future.

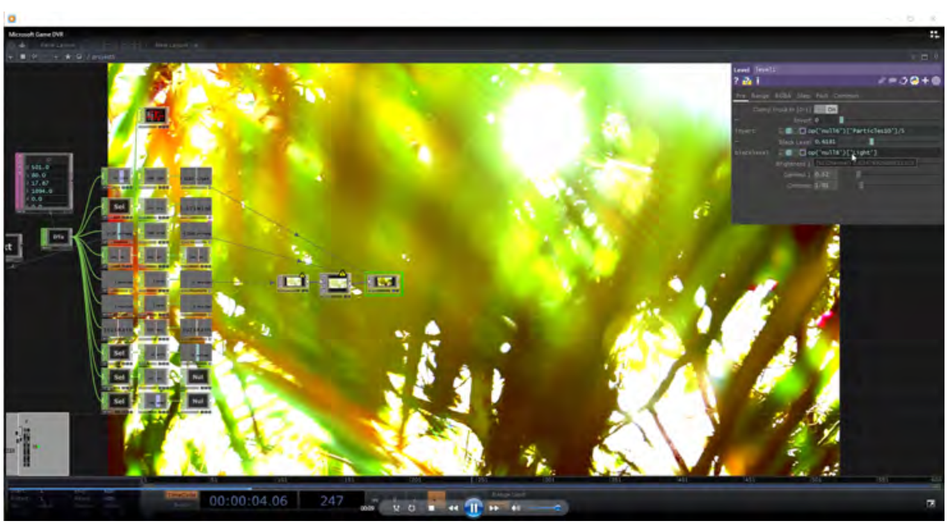


Figure 14.4: Video from the development process of *Dawning,* showing how the above TouchDesigner file was used to modulate video playback according to live environmental data feeds. (Screenshot by the author, 2022).

14.5 Documentation and Public Presentation

Dawning debuted in February 2023, when it was exhibited in the group exhibition *more-than-human* at Onsite Gallery in Toronto. Above is a flyer advertising the opening. Here are links to press about the exhibition in the publication Hyperallergic: (https://hyperallergic.com/796668/onsite-gallery-ocad-university-more-than-human/) and in Centred: (https://centred.ca/um-world-our-static-questions-need-organic-answers/) in which the writer describes *Dawning* as "one of the exhibition's successes."

Video playback of *Dawning*: (https://graceful-mist-a8e.notion.site/IV-Chapter-14-Dawning-18851e007be181a4a7dde4b135d4a464). *Dawning* is eighteen minutes and forty-four seconds in length and was created in 2022-2023; all footage, editing, and audio composition was done by the author.

Photo documentation of *Dawning* in Onsite Gallery:

Figure 14.5: Two installation views of *Dawning*, photos by author, 2023.

Panel discussion and artist interview recordings: The exhibition's public programming included two recorded events available online. The first is a panel discussion featuring myself in conversation with artists

Rasa Smite, Raitis Smits, and Lindsey French, reflecting collectively on our exhibited works (https://www.youtube.com/watch?v=5cWuu3tkRHg). The second is an interview in which I discuss how *Dawning* relates to my broader artistic practice (https://www.youtube.com/watch?v=JRsyPH0a6nk).

14.6 Acknowledgements

The creation and exhibition of *Dawning* was made possible through support from an Environments of Change Partnership Grant through SLO lab and Graduate Fellowship of Academic Distinction funding from York University. In addition, I would like to acknowledge Onsite Gallery and its incredible staff. Special thanks go to the Rossi family: Leilia, Paulo and Felipe, as well as Heloisa Oliveira, who provided accommodation and support for me to record sound and video, assistance that made it possible for *Dawning* to celebrate the dawn chorus.

Chapter 15

Sun Eaters

> As science converges with ancient wisdoms and indigenous knowledges of vegetal life, spurred on by the urgencies of climate change, vital awareness is emerging of our elemental dependence on plants... as well as of their resilient agential power
>
> –*Maja Fowkes*
> *Reuben Fowkes*

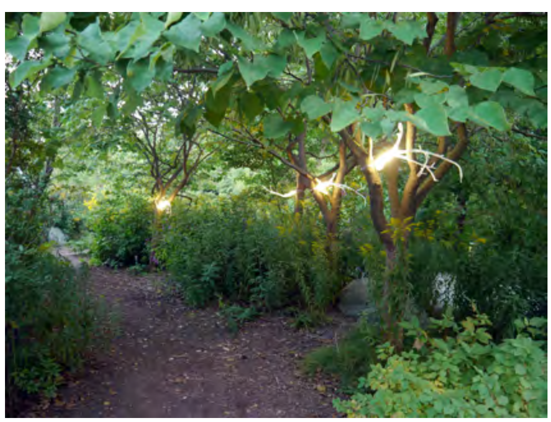


Figure 15.1: Installation view *Sun Eaters*, shown here at the Toronto Botanical Garden for Nuit Blanche Festival. (Photo by the author, 2023).

15.1 Introduction

Sun Eaters, a physical computing installation, translates the bioelectric rhythms of trees into real-time visual changes through custom electronics I developed to measure, process, and visualize plant bioelectric signals. Exploring the conception of art as a tool for sensing, I am exploring how we relate to the non-human plant world(s) around us.

Sun Eaters visualizes plant bioelectricity as light. For example, in a recent installation of the artwork at the Toronto Botanical Garden, a grove of trees are equipped with branches that enable people to both see (through light from LEDs) and feel (via vibration from electric motors) trees' unique "heartbeat". At several touch stations visitors can hold the prosthetic branches that make up the installation, which contain sensors that pick up the bioelectric rhythms of each tree. The branches reveal the electrical patterns unique to each tree, a constantly shifting combination of internal factors and external environmental cues.[2][3] In this way people are able to hold hands with the tree and perceive it in a way they that would otherwise be impossible.

This work was developed out of a desire to create works that facilitate points of connection and increased care between humans and the more-than-human natural world. I am investigating whether artworks can act as an interface for understanding ecological processes. I hope that the installation will prompt a deeper knowledge of trees and a means of seeing them as unique individuals, similar to how people see each other.

15.2 Artist's Statement

I am interested in artworks that function as data visualization tools— becoming prostheses, aesthetic instruments capable of revealing attributes of our environment that are either imperceptible to human senses or challenging to grasp due to their expansive scales. This approach is exemplified by artworks that inspire me, such as Terike Häppöjä's installations *Inhale-Exhale* and *Dialogue*, where electronic artworks illuminate ecological processes otherwise invisible to us, placing them firmly within the field of envirographics.[4][5]

In *Sun Eaters*, trees are outfitted with prosthetic limbs— artificial branches embedded with lights and vibrating motors— that allow people to feel the tree's unique electrical pulse, or "heartbeat," at the exact moment they touch it. In this way, a normally imperceptible characteristic of the tree becomes something one can physically sense, offering a new mode of connecting to a living being. If you can see your heart pulse together with that of a tree, do you perceive the tree differently? If you hold one of the limbs of *Sun Eaters,* do you feel you have held hands with it, like you do when you meet a human being?

Through *Sun Eaters* I am exploring whether artworks can serve as empirical interfaces for comprehending our complex, interwoven, beyond-human ecologies of present-day Earth, fostering new ways of perceiving and thinking about them— a gesture towards the idea of planetarity.

Plant blindness is a form of human cognitive bias, a common tendency to overlook plants and to treat them solely as a beautiful backdrop in front of which human action takes place.[6] As Michael Marder asserts (*Plant-Thinking: A Philosophy of Vegetal Life*), Western epistemology traditionally dismisses plants as "unmoving, inactive, unthinking, unfeeling and inanimate," and in so doing treats them not as agential living beings, but "unconditionally available for unlimited use and exploitation."[7] Yet plants, inhaling atmospheric carbon and exhaling oxygen are vital to the health of our planet's future.[8]

Therefore, through I have illuminated the trees through *Sun Eaters*: to arrest your attention within our oversaturated world and hopefully overcome plant blindness. *Sun Eaters* is a way for met to signpost plant communications, agency and individuality, bringing plants from the background to the fore and negating notions of them as inert. I consider this perspective shift to be both an important and necessary one at this time period in which we need to transition from human-centred to ecological thinking.

As eco-novelist Richard Powers has written: "We have to un-blind ourselves to human exceptionalism. That's the real challenge. Unless forest-health is our health, we're never going to get beyond appetite as a motivator in the world."[9] Thankfully, I see a shift starting to occur, not just in the artworks created by myself and others thinking along similar ecological lines, but in society more broadly.[10] The current threat to biodiversity posed by climate change is prompting a renewed alertness towards all life, but plant life specifically as it is the foundation upon which all animal life relies.

It is my hope that once we begin to see how much we have in common with other species that we'll develop a greater appreciation for the continuity and incredible interconnectivity within global ecosystems, and urgently embrace the responsibility of planetary stewardship.[11]

15.3 Related Work and Methods

The original influence for *Sun Eaters* was Canadian biologist Suzanne Simard's collaboration with German forester Peter Wolleben, *The Hidden Life of Trees* and her solo book *Finding the Mother Tree*.[12][13] In these texts, Simard describes her experimentation which revealed that trees use a network of mycelium to communicate and exchange nutrients with one another, upending competitive models of nature with evidence of intentional, caring systems. The notion that trees send resources to vulnerable kin profoundly shaped the conceptual grounding of *Sun Eaters*— pointing toward a model of ecological community that is as much relational as it is biological. In the context of planetary crisis, this recognition of community among trees is source of profound hope and inspiration.

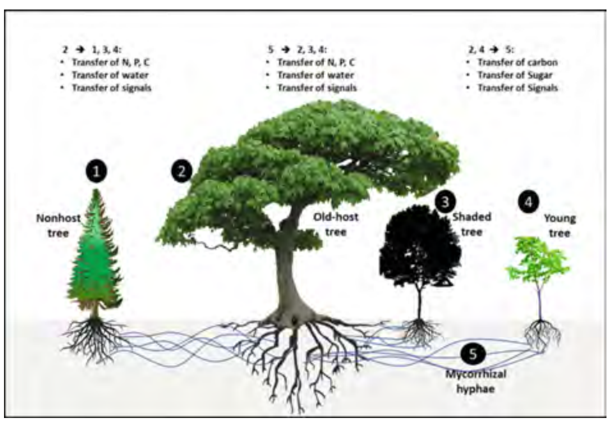


Figure 15.2: Diagram showing the transfer of nutrients from one tree to the next. (Image from https://doi.org/10.1007/978-3-031-28307-9_17.

Further research led me to John Lifton's *Green Music* and the surge of interest in plants and their potential consciousness during the 1970's.[14] Lifton is both an artist and a scientist and *Green Music*, in which music is generated algorithmically in real-time from the natural electricity in plants, was installed in San Francisco's Golden Gate Park, and appeared in the 1976 movie The Secret Life of Plants.[15] This lineage is central to my own practice: *Sun Eaters* extends this tradition by employing data visualization techniques to translate the bioelectrical activity of trees into both visual and tactile forms, making the hidden lives of plants sensible to human participants.

Figure 15.3: Publications about experimental plant electronics from the 1970s. (Image from https://www.researchgate.net/publication/364646477_The_1970s_Plant_Craze.

The development of *Sun Eaters* was also informed by several significant artworks that explore plant communication and the interplay between humans and ecosystems. They include Terike Häppöjä's installations *Inhale-Exhale* (2008), Christine Odlund's *Stress Call of the Stinging Nettle* (2010), and Agnes Meyer Brandis' *One Tree ID- How to Become a Tree for Another Tree,* which I am honoured to have presented *Sun Eaters* alongside in the exhibition *Sensoria: The Art and Science of Our Senses* (2022).

Stress Call of the Stinging Nettle by Odlund translates the biochemical distress signals of stinging nettles into an electro-acoustic musical composition. The score was based on scientific observation of the chemical distress signal reactions of stinging nettle plants to being attacked by butterfly larvae. Collaborating with scientists, Odlund compressed a data set taken over a period of days into a musical composition lasting minutes. This underscored her intent to convey the slower timescale over which communication between plants takes place compared to human experience. Her integration of scientific research and sensory translation deeply inspired *Sun Eaters's* focus on making the hidden rhythms of plant life perceptible.[16]

Terike Häppöjä's installation *Inhale-Exhale* explores the vital role of carbon in the global ecosystem and its connection to life, death, and climate change. Three coffin-sized glass cases filled with soil and dead leaves simulate "soil respiration," where CO2 from decomposition is measured, sonified, and regulated by ventilation fans that mimic breathing. This artwork emphasizes the active, transformative nature of soil as a living process, drawing attention to its significance in the carbon cycle and its impact on global warming.

The data visualization techniques used in both Häppöjä's and Odlund's artwork, prompted the development of my own data-derived experimentation.[17]

Similarly, Agnes Meyer Brandis'*One Tree ID - How to Become a Tree for Another Tree* is meaningful to my exploration of plant individuality and interaction in *Sun Eaters*. *One Tree ID* transforms the volatile organic compound (VOC) identity of a specific tree into a wearable perfume, allowing a human to "wear" a tree's chemical characteristics. By applying the perfume, participants symbolically and biochemically align with the tree's communication system, imagining an invisible dialogue on the same chemical level that plants use to exchange information.[18]

Through these influences, *Sun Eaters* stands as an example of data visualization within the tradition of SciArt, using interdisciplinary methods to make plant bioelectric rhythms tangible and relatable. My practice draws on both scientific and artistic modes of inquiry, striving to foster new ways of seeing and sensing the unseen processes that unite all life on Earth.

15.4 Technical Description

Sun Eaters translates the bioelectric rhythms of trees into real-time visual changes through custom electronics I developed to measure, process, and visualize plant bioelectric signals. This section outlines the methods I used to capture and interpret these signals, but first I'll share a brief overview of what bioelectricity is.

Plant Bioelectrical Signal Rhythms: All living beings produce a bioelectrical current within their corpus and radiate a weak electromagnetic field. Bioelectricity is produced in cells by the cumulative action of ion channels, pumps, and transporters as they move ions within living tissue which generates small electrical currents and fields. This occurs both as intra-tissue signals to stimulate biological processes and as a by-product of biological processes.[19] In plants, these weak currents typically occur in the microvolt range. The strength and frequency of these signals reflect physiological responses to environmental and internal conditions.[20] In trees, bioelectric activity follows circadian rhythms, peaking twice daily, at sunrise and sunset, similarly to human biological cycles. Additionally, bioelectric signals fluctuate in response to immediate influences such as temperature, light levels, and environmental threats such as insects.[21] These variations occur on timescales ranging from seconds to minutes, reflecting plants'sensitivity and adaptability.[22]

As a result of all these factors, each plant exhibits unique bioelectric patterns, akin to how individual heartbeats vary in humans. For example, I have observed how plants under stress, such as a broken stem, exhibit higher bioelectrical microvolt readings than the same plant without stress. Human heart beats are variable as well. When we are stimulated by excitement, for example, they become more rapid, or when we are injured, as from surgery, the microvolt levels are elevated.[23] In addition, each person has a slightly different heartbeat as the next, and the same holds true for plants. They are all uniquely individual, just as we are. Though humans may exist in a different temporal scale as plants, shared biological rhythms, such as the diurnal cycle, underscore connections between plant and human life.

Electronics Overview: The system I used in *Sun Eaters* measures plant bioelectric signals, processes the data, and outputs it into light variations in LEDs. Electrodes affixed to the leaves and/or branches of the tree, detect the plant's bioelectric signals in the microvolt to millivolt range. These signals are amplified and filtered using an AD8232 module, designed for biopotential measurements.[24] They are then processed by an MCU, I used an Arduino Nano microcontroller.[25] The processed signals control LEDs via pulse-width modulation (PWM), translating the plant's bioelectric rhythms into a dynamic visual display.[26] This setup makes the invisible electrical activity of plants visible, offering an interactive representation of their biological processes, and I hope, highlighting their individuality. Below is a system diagram.

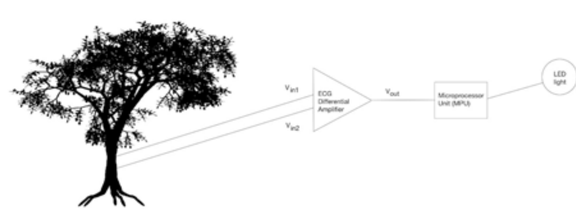


Figure 15.4: Functional diagram of Sun Eaters. (Diagram by the author, 2020).

I am using a AD8232 signal conditioning block to obtain, amplify, and filter the electrical differentials measured at time intervals across the electrodes. The chips built-in high and low-pass filters remove motion artifacts and baseline drift caused by environmental noise from the electrode wires and surrounding environment. The AD8232 was originally developed in a medical context for ECG (electrocardiogram) applications, but in *Sun Eaters* it works equally well to measure plant, not human microvolt signals.[27] The module's ability to operate in noisy conditions makes it well-suited for the challenges of capturing bioelectric signals in outdoor environments. Below is an open-source functional block diagram of the chip taken from the manufacturer Analog Devices:

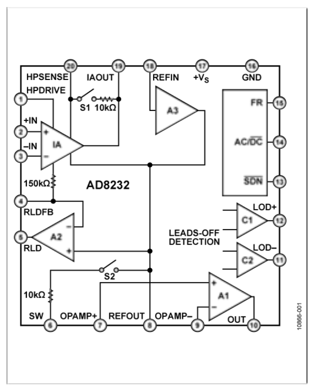


Figure 15.5: A functional block diagram of the AD8232 ECG module. (Diagram from https://www.analog.com/en/products/ad8232.html#product-overview.

The Code: In *Sun Eaters,* an Arduino Nano microcontroller serves as the processing unit, interpreting the filtered and amplified signals from the AD8232 module. The code can be found in appendix C.

Visualization: The processed bioelectric signals are mapped to LED light levels, creating a pulsing, fluctuating display. The LEDs I am using are ultra-bright daylight visible units affixed to large heatsinks. This visualization captures both the cyclical patterns, such as the diurnal peaks, and momentary fluctuations influenced by environmental factors.

Prosthetic limbs: The electronics are built into branches I designed and printed. As in nature, no two are the same, though visually similar. Below is a photo of the 3D print in software PrusaSlicer in preparation for printing and a finished limb from an installation at the Toronto Botanical Garden.[28]

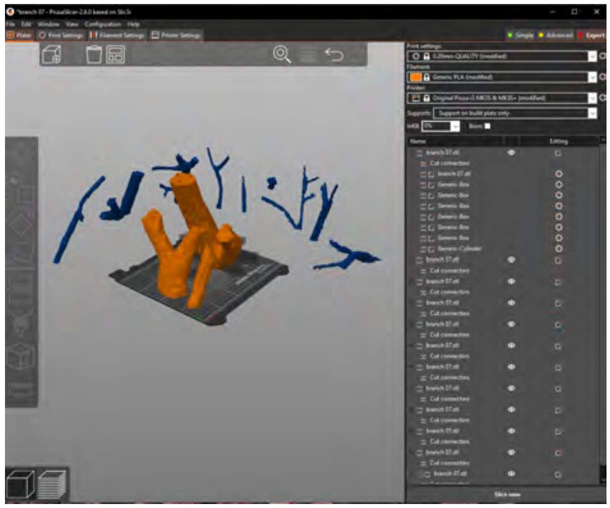


Figure 15.6: 3D model of a *Sun Eaters* branch in software PrusaSlicer in preparation for printing. (Screenshot by the author, 2023).

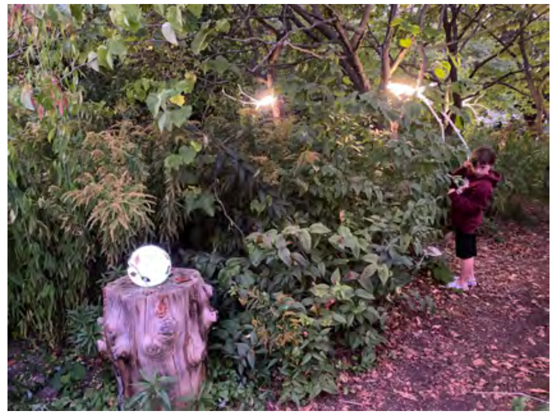
15.5 Documentation and Public Presentation

Sun Eaters remains my most exhibited artistic experiment. It has evolved in form and dimensions since its 2019 inception, in response to the unique attributes of each site and my ongoing investigations into plant biodata. I envision this process continuing to unfold in future years, potentially including iterations co-developed with more specialists including plant physiologists. Below is documentation of *Sun Eaters* from prior instantiations undertaken during my research period at York University including at the *Nuit Blanche*, *DesignTO*, and *Currents New Media* festivals, as well as the 2023 Congress of the Humanities and Social Sciences and 2022 exhibition *Sensoria: The Art & Science of Our Senses*.

Here is a link to *Sun Eaters* installed at the Toronto Botanical Garden: *Sun Eaters* at TBG, and here is a video of visitors interacting with *Sun Eaters*. Another presentation of *Sun Eaters* is Black Creek Walks, Talks, & Dances: click here for link to press. Afterwards, *Sun Eaters* was adapted for gallery exhibition and included in *Sensoria: The Art and Science of our Senses*: exhibition review here, and here. The showing at *Sensoria: The Art and Science of Our Senses* was followed shortly afterwards by inclusion of *Sun Eaters* into the *Forecast* group exhibition in the 2022 DesignTO Festival: Click here for press about the exhibition. Lastly, *Sun Eaters* was also curated into the 2022 Currents New Media Festival in Santa Fe at the Center for Contemporary Art.

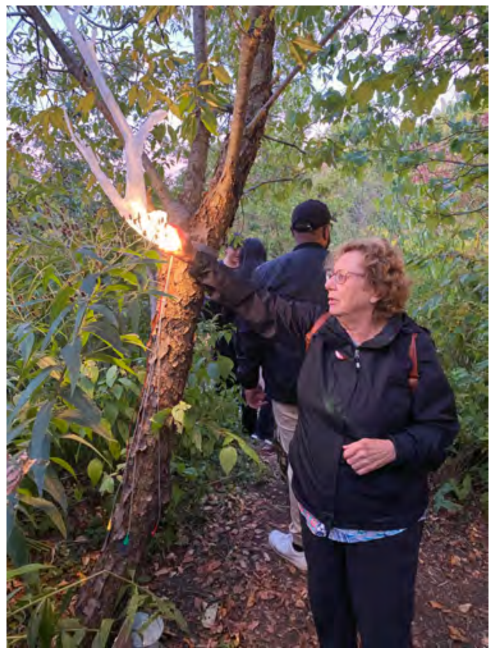
Here are a selection of views from the most recent installation for *Nuit Blanche* and the remainder of images can be found in Appendix C.

(a) *Visitors interacting with one of the branches.*



(b) *Globe for displaying visitors'heartbeats and branches.*

(c) *Young visitor interaction.*



(d) *Visitor holding a branch.*

Figure 15.7: Four views of visitors interacting with the *Sun Eaters* branches in the Nuit Blanche Festival at the Toronto Botanical Garden. (Photos by the author, 2023).

15.6 Acknowledgements

I am grateful to The Qualcomm Institute and ICA in San Diego for underwriting the initial development of *Sun Eaters*, as well as Citè Internationale des Arts in Paris, and York University and the City of Toronto, for their support in its iterative evolution. Special thanks go to professors Brett Stalbaum and Joel Ong, colleague Tjasa Crnigoj, and curator Nina Czegledy for their generosity in dialogue about the work and studio visits at critical junctures.

Sun Eaters has travelled to many exhibitions, thanks to an incredible amount of support. First, I would like to acknowledge scholarship support from by the University of California San Diego, where the research began and York University, where I carried it to its present state. Next, the Lux Art Institute in Encinitas, California for their initial support of its first installation in fall 2020. Additional thanks go to the California Institute for Telecommunications and Information Technology on the campus of the University of California San Diego who exhibited it in May 2021 as part of their Initiative for Digital Exploration of Arts and Sciences (IDEAS) performance series. At Cite Internationale des Arts, it was shared through an artist in residence in August 2021, as part of an artistic co-creation lab, Through the Eyes of the Others led by artists Tjasa Crnigoj, alongside Garance La Fata, Cristina Rosenberg, and Gethce Pierre. Thanks also to the generosity of the 2022 Currents New Media Festival organizers and volunteers who supported its installation at the Center for Contemporary Art in Santa Fe. I am grateful for curators Nina Czegledy and Joel Ong who made it possible to bring *Sun Eaters* indoors through exhibition and symposium *Sensoria: The Art & Science of our Senses* at Gales Gallery; to *DesignTO* for curating the work into their January 2023 festival and installation assistance by United Contemporary gallery's staff; to Raghad Shawky El-Shebiny, Brian MacLean, and Joel Ong for bringing *Sun Eaters* into their creative visions and the 2023 Congress of the Humanities and Social Sciences held at York University. Finally, I want to thank Gabrielle Johnson with the City of Toronto for her expert assistance and warmth during the readaptation of *Sun Eaters* to the breath-taking cherry grove at the *Toronto Botanical Garden* for the 2023 *Nuit Blanche* Festival's Independent Projects.

Chapter 16

Celestial Objects and Aeriform Masses

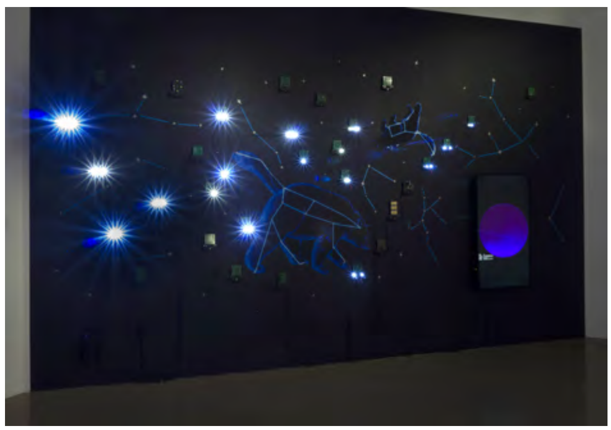


Figure 16.1: Installation wall (interactive light display on repurposed cube satellite electronics boards) and monitor displaying animation *Celestial Objects and Aeriform Masses.* Installed in the exhibition *The Life Cycle of Celestial Objects Pt. 2,* McIntosh Gallery, Western University in London, Ontario. (Photo courtesy curator Helen Gregory, 2023).

16.1 Introduction

Celestial Objects and Aeriform Masses, is a generative animation that visualizes a dataset amassed by Dr. Regina Lee's Nanosatellite Laboratory via satellite, while studying the phenomenon of human-produced space detritus, or trash, orbiting Earth.[1] This artwork was created to be exhibited as part of an interactive installation I helped design under the direction of artist Dr. Joel Ong for the exhibition *The Life Cycle of Celestial Objects Pts. 1 and 2* curated by Helen Gregory.[2] From the curatorial statement:

> Attempting to reach what Gregory Cajete calls a "participatory consciousness to the conception

> of the heavens", the exhibition focuses on artistic practices, community science, citizen engagement, and education... through multi-media artworks, scientific models, interactive projects, and a broader series of science engagement events, the exhibition locates decentred, diverse narratives of space exploration that propose forms of collaborative exploration in cosmic futurities. In this unprecedented time of access and democratization of tools, we consider a reframing of space not as a "new frontier" for appropriation and extraction, but as a critical site for considering how we can collectively participate in pioneering explorations in the skies above us.[3][4]

Acknowledging that access to space is not uniform, this animated data visualization and the other creative works developed from Dr. Regina Lee's dataset are components of a larger initiative, " Space Situational Awareness and Us" (SSA). Under the stewardship of Ong and Lee, this initiative uses art and science interdisciplinary communication to highlight the need to democratize access to space exploration, engaging communities traditionally marginalized in the history of space exploration alongside the general public of Toronto.[5] This work is ongoing, carried out through a series of innovative scientific expositions coupled with community-oriented science communication endeavours.

16.2 Artist's Statement

Sited at the intersection of art and space science, the artwork *Celestial Objects and Aeriform Masses* is a data visualization rendered through generative animation, and is best understood as an example of envirographic art. The data set used for it provided by Lee's lab was collected by a nanosatellite sent into near-earth orbit to learn about accumulating space debris. This material, left behind by earlier satellites and space missions, represents a growing threat to the stability of our planet's outer atmosphere. Through this piece, I aim to highlight the unseen impact of human activity in space, urging viewers to reflect on how even the far reaches of space are being affected by our presence. For me, this piece isn't just about interpreting data; it's about illustrating the delicate balance of life and geophysical cycles on our planet and the importance of protecting this, both on Earth and in the space surrounding our planet. It raises concerns about past and present use of outer space as an environmental sacrifice zone, similarly to how wetlands, the ocean, and precarious forests are treated here on Earth.

Working alongside the Nanosatellite Lab at York University, I used latitude, longitude, altitude, and pressure recordings to produce an evolving lunar landscape, visualized through TouchDesigner.[6] My goal is to interpret this scientific information not as raw data, but as something poetic, offering viewers a meditative look at our relationship with space and the unseen forces that govern it. The colours and movement in the piece reflect atmospheric and geospatial shifts, drawing inspiration from the redshift and blueshift phenomenon that astronomers use to map our universe.[7]

Through this data visualization I attempted to manifest a progression of waves, encapsulating periodic rhythms that subtly reference the dynamic shifts observed within atmospheric flux, stratospheric currents, and the Earth's geomagnetic field. Foregoing a direct analytical engagement with the dataset, I opted instead for an interpretative methodology, privileging an exploration into the poetic potentialities and multifaceted expressions inherent within datum. This approach underscores a deliberate shift towards embracing the aesthetic and conceptual dimensions of scientific data, aiming to foster connections between scientific inquiry and artistic communication.

16.3 Related Work and Methods

The development of *Celestial Objects & Aeriform Masses* was shaped by the collaborative research-creation project led by Joel Ong and influenced by several significant artworks exploring varied perspectives on space exploration and planetary concerns about space detritus. These include Refik Anadol's *AI Data Sculpture: ISS HUBBLE MRO* (2020 - 2021), Camille Turner's *Dream Room* (2022), and Joel Ong's *Aeolian Traces* (2019).[8][9][10]

At its core, the project employs a hybrid methodology, drawing on the traditions of SciArt, data visualization, and co-design. As an example of SciArt, Celestial Objects and Aeriform Masses is situated at the intersection of scientific research and artistic expression, transforming complex data about space debris and atmospheric phenomena into aesthetic forms. The use of data visualization is central, as a scientific dataset from a cube satellite is interpreted through generative animation, allowing viewers to witness the data as shifting patterns of light, colour, and movement. Co-design informs the collaborative process: the project was developed in close dialogue with research scientists and artists, integrating their expertise and feedback at each stage throughout the work's creation.

Refik Anadol's *AI Data Sculpture: ISS HUBBLE MRO* uses artificial intelligence to transform data from space missions into dynamic, large-scale digital projections. Exhibited at *Machine Memories: Space*, the work immerses viewers in vibrant, ever-shifting visuals that evoke the movement of celestial bodies. The artwork is created from datasets of images captured by Hubble, MRO, and the ISS, bridging art and science to reflect on humanity's relationship with the cosmos.[11]

Camille Turner's *Dream Room* presents a colourful installation of a lunar-like landscape and projection of Earth as seen from space. Accompanied by a soundscape, *Dream Room* explores "Afronautic methodology", offering visitors the opportunity to engage in meditation, blending personal reflection with planetary imagination, imagining futures shaped by diasporic knowledge, liberation and African cultural memory.[12] Quoting Turner, to use the imaginative space of world-making to dream of "African descended people who made their exodus from earth to create liberated worlds on other stars" and "call upon the travellers to return to earth to recover their sacred knowledge for the future."[13]

Joel Ong's *Aeolian Traces* transforms human migration data into an immersive multi-sensory experience through installation. Ventilators generate shifting air currents synchronized with spatial sound, while a screen visualizes migration patterns as interconnected nodes in 3D space. Each node represents countries of migrating populations. As the nodes move in the animation, connections between nodes are shown. The installation invites visitors to feel, hear, and see flows of migration, emphasizing the interconnectedness of people across the planet.[14]

Celestial Objects and Aeriform Masses draws on these works' shared focus on data visualization, planetary concerns, and the use of sensory engagement as communication aids. By blending SciArt methods, co-design, and complex data visualization, the project seeks to translate complex scientific knowledge into poetic, multisensory encounters— inviting viewers to contemplate humanity's impact on both Earth and its surrounding environments.

16.4 Technical Description

Celestial Objects and Aeriform Masses is a time-based animation, characterised by looping particle waves informed by an array of geospatial and atmospheric measurements, chiefly latitude, longitude, altitude, and pressure. These data points were collected during the experimental voyage of a Resident Space Object Near-Atmospheric Edge Reconnaissance (RSOnar) nanosatellite. This CubeSat was a principal component of the payload aboard the Canadian Space Agency's stratospheric balloon Gondola, launched from Timmins, Ontario in August 2023. The satellite was equipped with an integrated payload designed for data collection, intended for comprehensive subsequent analysis.[15]

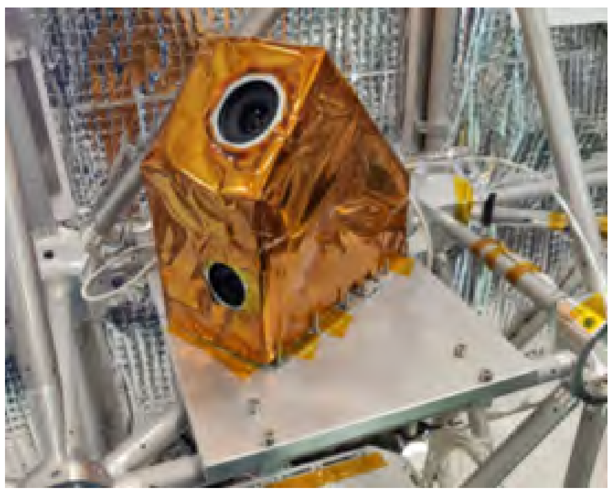


Figure 16.2: RSOnar Payload Integrated onto stratospheric balloon Gondola. (Photo from Dr. Regina Lee's lab).

Celestial Objects and Aeriform Masses animates via a customized generative algorithm, its motion informed by the RSOnar nanosatellite's latitude and longitude coordinates as it was released to into space, and the animation's colours are determined by its altitude and pressure measurements— "R" and "B" colour channels manifest a spectrum of evolving shades from deep reds to multi-hued purples and blues. Here I am drawing inspiration from the astronomical concepts of redshift and blueshift, techniques employed to ascertain the distance of celestial bodies from Earth.

The animation was crafted in Derivative's TouchDesigner software, wherein the RSOnar dataset is imported into a structured table, the values allocated to specific rendering attributes and mapped to ranges for optimized functionality. This choice of software evolves from a longer trajectory of my work in the visualization of environmental data, which includes preliminary explorations using Processing and Isadora. Click here to

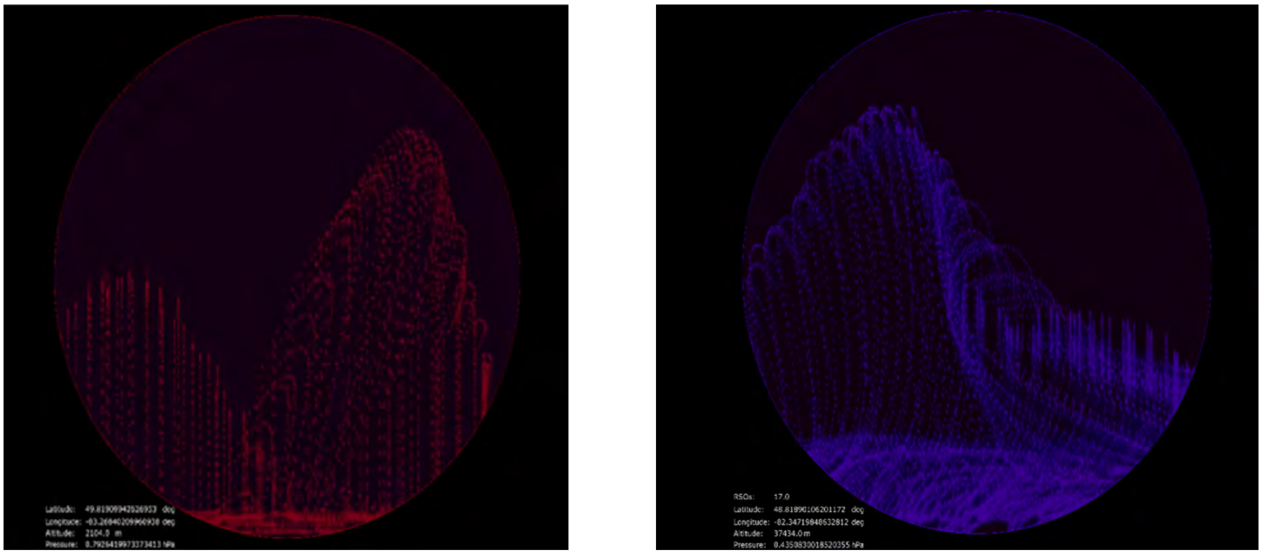


Figure 16.3: Still images of *Celestial Objects and Aeriform Masses* at two intervals within the animation cycle. (Screenshots by the author, 2024).

view.

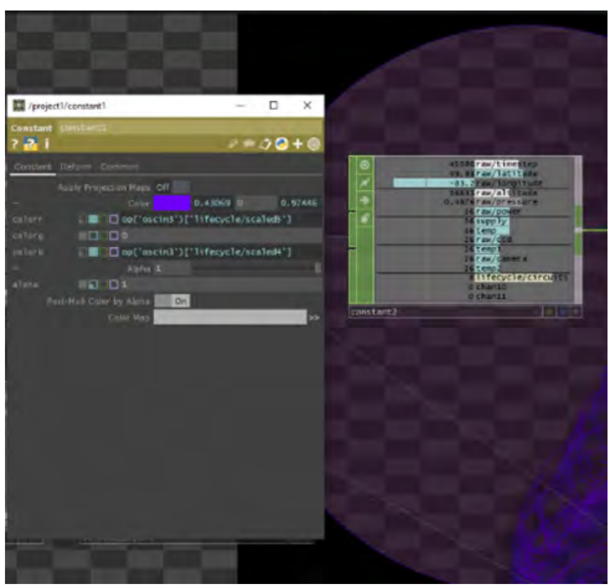


Figure 16.4: Screenshot in TouchDesigner. On left, altitude and pressure values assigned to red and blue colour channels, and on right, complete imported dataset. (Screenshot by the author, 2024).

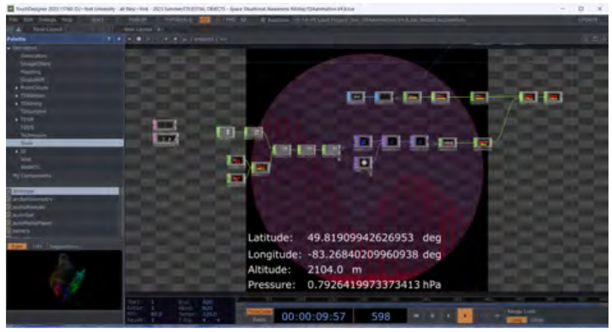


Figure 16.5: Screenshot of the generative programming underpinning *Celestial Objects and Aeriform Masses*. (Screenshot by the author, 2024).

16.5 The Team

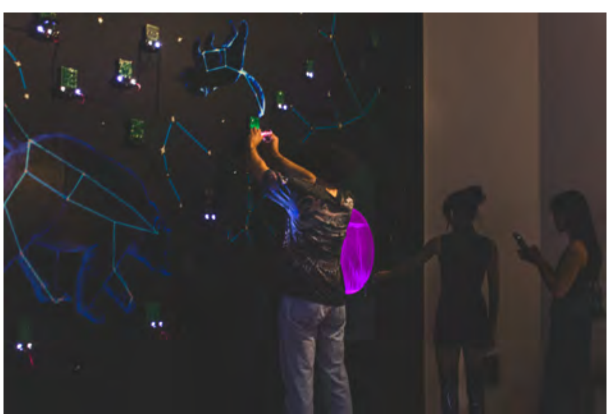
While the development of this artwork was largely a solo endeavour, it was created to complement work by other artists and jointly exhibited. The lead commissioning artist on this exhibition is Professor Dr. Joel Ong, BSc, Ph.D., a media artist whose works connect scientific and artistic approaches to the environment, particularly with respect to sound and physical space. His co-pi and the lab director with whom the dataset originated is Dr. Regina Lee, PEng, Ph.D., York University Nanosatellite Lab, in the Lassonde School of Engineering at York University. Lastly, the same data set was also used to create an audio soundscape by Kieran Maraj, MA Digital Media. He is a programmer, creative technologist, and machine learning and sound specialist concerned with environmental concerns such as the recent wildfires which ran unchecked across Canadian forests. His soundscape was inspirational to my creative process and hauntingly suffused the gallery in which *The Life Cycle of Celestial Objects Pt. 2* was exhibited.

16.6 Documentation and Public Presentation

Celestial Objects & Aeriform Masses was exhibited at the McIntosh Gallery as part of *The Life Cycle of Celestial Objects Pts. 1 & 2,* curated by Helen Gregory and Joel Ong from September to December 2023. It was shown as part of a larger installation titled *The Life Cycle of Celestial Objects Pt. 2*, which incorporates decommissioned satellite parts and prototype builds from prior research experiments and displays them as constellations on a backdrop of the sky. A sound artwork, a data sonification by Kieran Maraj utilizing the same RSOnar dataset, emanated from a multi-channel speaker system and was time synchronized to the data visualization through software MaxMSP.

Celestial Objects & Aeriform Masses was also shown in Rome, Italy at the Borrominian Hall of Biblioteca Vallicelliana from December 11 to December 13, 2023 as part of the 2023 XXVI Generative Art Conference during an artist talk.

Below are links to the exhibition announcements and related press, as well as published essays about the work in scholarly journals: (https://www.events.westernu.ca/events/mcintosh-gallery/2023-09/opening-reception-the-life.html, https://www.scienceopen.com/hosted-document?doi=10.14236/ewic/EVA2024.60), (https://computer-arts-society.com/evaarchive/documents/2024/330_Grothaus_EVA24.pdf), (https://generativeart.com/GA2023/papersDOC/OK/52_gracegrothaus.pdf). Additionally, here is a link to a video excerpt of the animation: (https://www.notion.so/IV-Chapter-16-Celestial-Objects-and-Aeriform-Masses-18851e007be181eb96f9d50d3042bf5f#18851e007be1816c821ff5131444547e) Below are two additional views of the installation, and the remainder of images can be found in Appendix C.



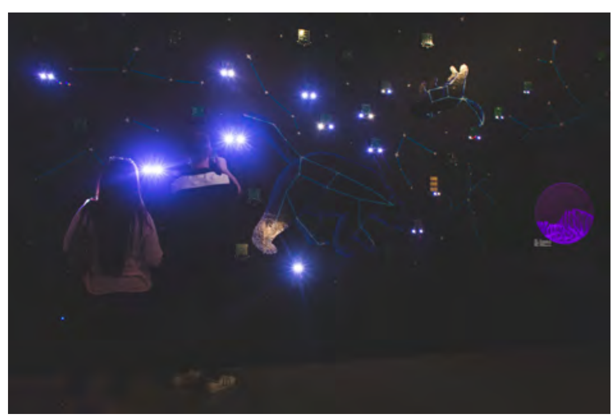


Figure 16.6: Visitors interacting with light display created from repurposed cube satellite electronics boards and monitor displaying animation *Celestial Objects and Aeriform Masses.* Installed in the exhibition *The Life Cycle of Celestial Objects Pt. 2,* McIntosh Gallery, Western University in London, Ontario. (Photo courtesy Helen Gregory, 2023).

16.7 Acknowledgements

Celestial Objects and Aeriform Masses was commissioned by Professor Joel Ong for exhibition *The Life Cycle of Celestial Objects Pt. 2* as part of a larger NFRF-E funded research project Space Situational Awareness and Us. This work has received support from Sensorium: Centre for Digital Arts and Technology, the School of the Arts, Media, Performance and Design, CRSH-SSHRC, the Ontario Arts Council, and the Canada Council for the Arts.

Chapter 17

AtmoSpheres 01

> *. . . no matter how rich you are, there is no way to hide from the "blanket" of toxic air.*
>
> –Li Bo (Director of Friends of Nature – oldest environmental organization in China)

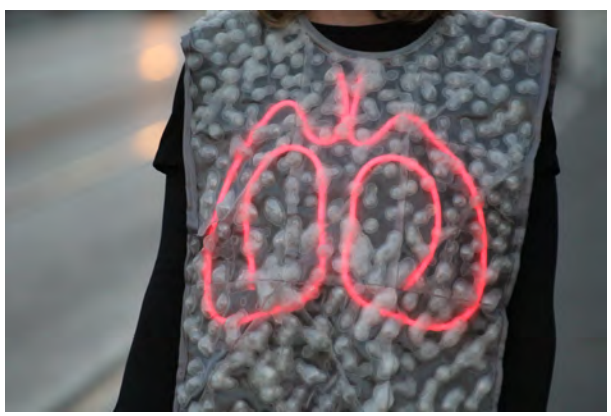


Figure 17.1: *AtmoSphere 01,* an air pollution sensing garment. Here the garment is red, representing an air quality index (AQI) reading of 150 to 200. (Photo by James Dunne, 2024).

17.1 Introduction

This chapter introduces the first of my *AtmoSpheres* wearables, a series of aesthetically arresting wearable critical art objects that incorporate an air pollution sensor developed as part of a larger research-creation project *We Are Air Aware*. These wearable critical art objects dynamically react to the environment, showing fluid transformations of LED light in response to air pollution— such as when cars pass by. For instance, the yellow, orange, and red of the Air Quality Index can indicate levels of toxic particulate matter in the air, notably black carbon (BC) particulate. Inspired by socially conscious and activist wearables created by artists Behnaz Farahi and Nick Cave, these garments aim to make visible the invisible threat of BC air pollution.[3][4]

The broader project *We Are Air Aware* that *AtmoSpheres* is a part of, is addressing a worldwide issue: particulate air pollution. This invisible threat, present in vehicle exhaust and wildfire smoke, is a contributor to global warming and a public health crisis.[5] Currently, air pollution is recognized as the leading environmental contributor to illness and death globally, with particulate matter (PM) being the most impactful of all assessed pollutants on health.[6] Almost everyone on earth is exposed to air pollution levels above WHO recommended safe levels.[7] Despite this, public awareness remains low, in part due to significant obstacles in obtaining accurate measurements of the most harmful type of airborne particulate matter (black carbon), and the invisibility of particles sized 2.5 micrometers and smaller. This project proposes to overcome these challenges by co-creating novel black carbon particulate sensors and deploying them in city streets, making the invisible threat visible, and facilitating understanding and public engagement.

The project has five objectives: 1) Design a sensor for isolating airborne black carbon particulate in real-time. 2) Integrate it into wearables logging real-time geolocated black carbon data. 3) Create a community-driven online database to publish findings. 4) Facilitate public art performances using these wearables. 5) Further knowledge dissemination through workshops, publications, and exhibitions. This large-scale project, which merges art, science, and engineering, aims to make substantial advancements in these fields and potentially yield significant public health benefits.

17.2 Detailed Description of Prototype

AtmoSpheres 01 was created in 2024 using an airborne particulate sensor, flexible LED strands, custom electronics, custom 3D printed TPU fabric, and nylon. This garment is programmed to sense and display particulate air pollution levels, revealing it as breathing lungs inflamed with colour corresponding to the Air

Quality Index (AQI). There are five colours in the index, each representing different quantities of particulate counts in micrograms per cubic meter of air (µg/m^3):

(1) Green. In this setting the garment represents PM 2.5 µm count from 0 to 50 µg/m^3 as green light in two lungs, slowly pulsing, or "breathing", on and off.
(2) Yellow. Representing PM 2.5 µm quantities from 51 to 100 µg/m^3, in this level the lungs pulse faster than in level 1.
(3) Orange. When PM 2.5 µm readings are between 101 and 150 µg/m^3, the lungs pulse orange, faster than in levels 1 and 2.
(4) Red. Level 4 represents PM 2.5 µm counts from 151 to 200 µg/m^3 as red lungs pulsing light on and off quickly.
(5) Purple. At this final level the lungs breath at their most rapid pace in bright purple LED light when PM 2.5 µm readings are at 201 µg/m^3 and above.

A brief video displaying all five possible display modes is available here: (https://graceful-mist-a8e.notion.site/IV-Chapter-17-My-Air-Wear-AtmoSpheres-01-18851e007be181f9871de02a9f64375c), and below is an AQI chart describing the colour codes ascribed to different levels of air quality measurements:

Air Quality Index		
AQI Category and Color	**Index Value**	**Description of Air Quality**
Good Green	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate Yellow	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups Orange	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Unhealthy Red	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy Purple	201 to 300	Health alert: The risk of health effects is increased for everyone.
Hazardous Maroon	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Figure 17.2: The Air Quality Index, a uniform colour coded index developed by the United States Environmental Protection Agency. (From https://www.epa.gov/wildfire-smoke-course/wildfire-smoke-and-your-patients-health-air-quality-index).

17.3 Related Work and Methods

This project is grounded in three mutually reinforcing methods: citizen science, co-design, and data visualization. Each of these approaches underpins my commitment to producing work that is both ethically attuned and socially impactful.

Citizen science lies at the heart of this project, enabling communities and non-specialists to directly participate in the gathering and interpretation of environmental data. This participatory mode is inspired by influential works such as Beatriz da Costa's *Pigeon Blog* (2006), which invited public engagement by equipping homing pigeons with air quality monitoring backpacks.[9] The project exemplifies how environmental sensing can be democratized: volunteers, pigeons, and artists collaboratively collected carbon monoxide, nitrogen oxide, and temperature data across Los Angeles, ultimately visualized through accessible maps. The team aimed to capture peak pollution episodes and spark public discourse about the need for more detailed sensing networks. Their choice to work with pigeons was strategic— these non-human collaborators naturally inhabit highly trafficked, polluted areas. This model of open, citizen-driven inquiry directly informs my own project's strategy of involving community members in both data collection and interpretation, making complex environmental phenomena more accessible and actionable.

Co-design is equally central to my methodology in this project. I draw inspiration from Natalie Jeremijenko's *Feral Robotic Dogs* (2002), where the public helped modify and deploy sensor-equipped robotic dogs to monitor radiation and air quality at contaminated urban sites.[10] Together with collaborators, she modified Sony Aibo toy robots with environmental sensors and all-terrain capabilities. The first iteration equipped "gamma dogs" to detect and transmit radiation levels exceeding EPA regulations in contaminated areas. Later versions expanded to monitor volatile organic compounds, carbon monoxide, methane, and air particulate levels. These enhanced robots surveyed various urban sites, including a former gas plant at East 173rd Street Works along the Bronx River and a former landfill at Baldwin Park in Orlando, Florida—notably, a proposed location for a middle school expansion. Through these community engagements, Jeremijenko created an accessible way to share real-time environmental data with the public while sparking discussions and gathering community perspectives.

Data visualization acts as the connective tissue between these participatory methods and the resulting public impact. Projects such as Mel Chin's *Fundred Project*— in which communities co-created "fundred" drawings to raise awareness and resources for combating lead poisoning— demonstrate how participatory art can transform otherwise abstract or technical data into vivid, relatable forms.[11]

> this is an ongoing collective art project made by people across America. Their hand-drawn interpretations of $100 bills are original works of art that together call attention to the danger of childhood lead poisoning and remind us that every child's future has value. Although lead poisoning is 100% preventable, it still puts millions of children at risk for lifelong brain damage and other health issues.[12]

Similarly, my project employs data visualization to translate complex environmental metrics into intuitive, engaging graphics that foster public understanding, empathy, and advocacy. This approach is also deeply informed by Sarah Williams' *Data Action: Using Data for Public Good*, which emphasizes transparency, fairness, and equity in all stages of data-driven work. By integrating Williams'methodologies, I strive to ensure that the visualized data is not only accessible, but also ethically mediated and inclusive, bridging the gap between abstract environmental phenomena and lived human experience.[13]

This framework draws additional threads of connection to other landmark projects such as Andrea Polli's *Particle Falls* (2015), Michael Pinsky's *Pollution Pods* (2017), and Grisha Coleman and Todd Ingalls'*Echo:system* (2010), all of which leverage citizen science, co-design, and data visualization to foster dialogue and collective action around environmental challenges.[14][15][16]

Common to all of these projects, and a main driver behind my own, is the effectiveness of employing an artistic framework to invoke a public response to environmental concerns.

In its ability to engender affective responses in viewers, art may be an especially effective tactic for disrupting social conventions because it can engage in consciousness raising. In my view it accomplishes this through cultivating empathy across different groups of people and perceived borders, helping participants to reimagine their role(s) in the world.[17] Culture affects us deeply, lingers in our minds, and changes our understanding of ourselves and one another. When our mindsets have shifted, our future actions change as well.[18]

17.4 Technical Description

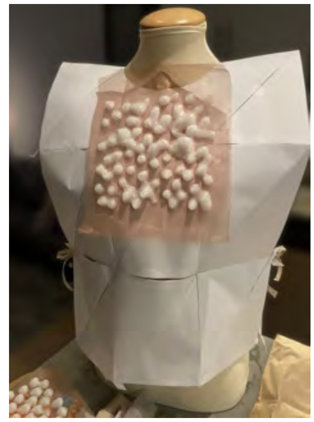
Data visualization of the particulate display: I considered several options for display of the black carbon particulate levels. Illuminated displays, either LED, screen, or custom fabricated LED screens were modes that seemed most promising and capable of being implemented in a garment through a variety of means. However, I also considered many less common possibilities as well including colour-changing thermally responsive fibre[19], Electroluminescent (EL) wire[20], electrically conductive paint[21], and even custom cast LED housings[22]. Ultimately I chose flexible silicon RGB LED strips for their visibility even in day-light conditions, flexibility, and their waterproof nature.[23]

Code: In coding the final prototype's functionality, I settled on incorporation of two different operating states toggled via the addition of a potentiometer to the circuit. When the potentiometer reading is half or less of its range (0-512) the garment is in exhibition mode, displaying the cycling of LED colour and speed settings. When the potentiometer is turned up higher (513-1024) alternate code is implemented and the garment is in sensing mode. In this mode PMS5003 sensor readings are taken, printed to serial and initiate the colour level designated for the readings of particulate matter sized 2.5 microns. This data visualization mode is the primary mode intended for the garment. Below is the code for both modes with comments throughout explaining the different functions and structure. This is processed by an Arduino Uno powered with 12V, 1600 mAh from rechargeable NiMh batteries. Final code written using Arduino Software (IDE). [24]

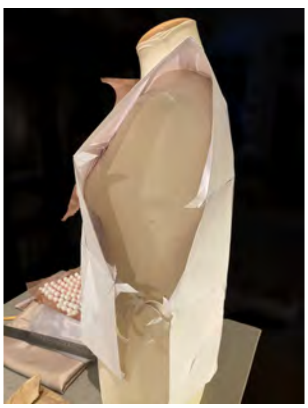
Code for wearable *AtmoSpheres 01* can be accessed via GitHub at https://github.com/GraceGrothaus/AtmoSphereshttps://github.com/GraceGrothaus/AtmoSpheres and in Appendix C.

Garment substrate: Substrate options for the LED data visualization are wide and varied. Wearable electronics options are no longer limited to fibre and fabric but also include microelectronics printed into layers of flexible, transparent polymers enabling the creation of nearly invisible wearable patches.[25] Right now I am experimenting with this via the use of a conductive ink printer and SMD micro-components, as well as varied bioplastics recipes, through materials tests.[26] However for this first prototype I settled on open weave fabric that offered transparency allowing for layering and further diffusion of the LED display. I printed into the fibre using flexible, translucent filament, adding another design element - meant to reference cloud-like atmospheric masses.[27]

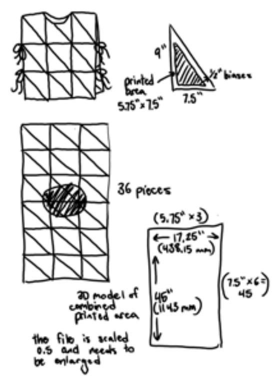
(a) *Clear TPU filament printed into non-stretch nylon with varied nozzle flow and temperature settings. Printed in the AMPD Fab Lab by technician Jacob Turola.*



(b) *Front view of paper mock-up of the garment; to-scale including seam allowances.*



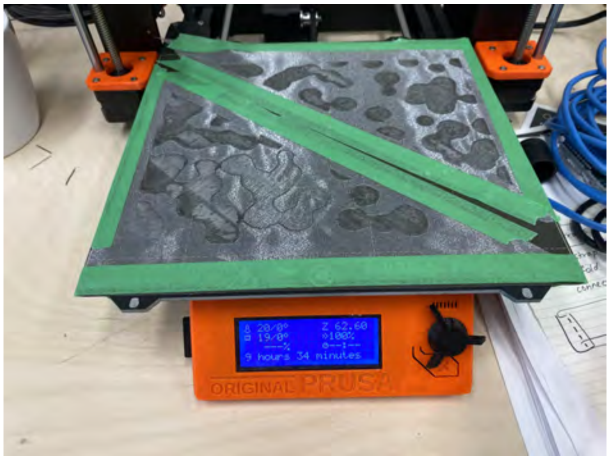
(c) *Side view of paper pattern.*



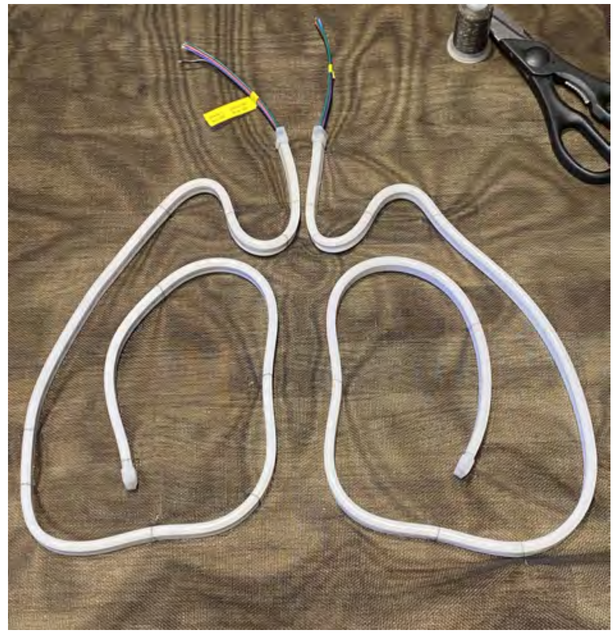
(d) *Notebook excerpt showing sketches of the final dimensions.*

Figure 17.3: Four process images showing various aspects of construction. (Photos and drawing by the author, 2024).

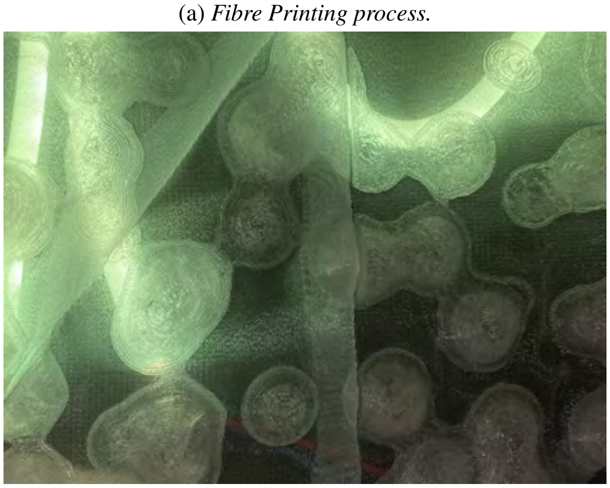
Production process: The fabrication of the garment involved 3D printing, sewing and wiring. Below are process images showing the 3D printing process, seam lines of sections hand-sewn together after printing, LED filament being sewn into place using clear nylon “Invisible Thread” sewn into vinyl mesh, and the final overlay of sewn TPU/nylon blocks on top of the LED/vinyl mesh interlayer.



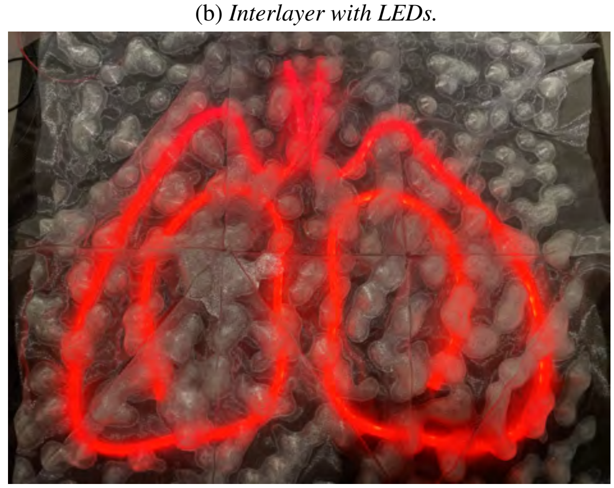
(a) *Fibre Printing process.*



(b) *Interlayer with LEDs.*



(c) *Detail view of display.*



(d) *Full front display.*

Figure 17.4: Four process images. (Photos by the author, 2024).

The particulate sensor: Low-cost, small-from sensors are desirable for my purposes of monitoring particulate exposure at the level of individual citizens, and they are potentially also suited for future research projects developing spatiotemporally dense sensor networks in cities. For this project, I began by experimenting with several low-cost sensors, including the SPS030 and PMS5003 by Plantower, both easily incorporated into wearables given their light weight and small size.[28].

Both sensors work via a light scattering measurement technique. A fan channels air into a cavity in the sensor through which a laser beam is cast. Measurements are generated through shadows cast by passing

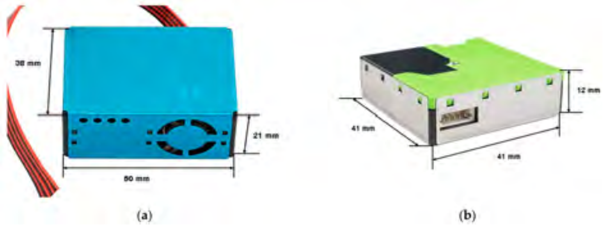


Figure 17.5: PMS5003 by Plantower with dimensions (left) and SPS030 by Senserion (right). (Photos from https://www.aqmd.gov/docs/default-source/aq-spec/resources-page/plantower-pms5003-manual_v2-3.pdf).

particulate matter.[29]

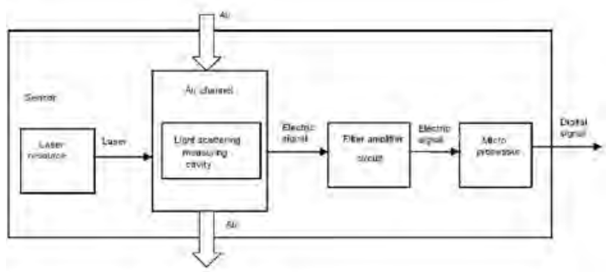


Figure 17.6: Functional block diagram showing how light-scattering particulate sensors work. (Photo from https://doi.org/10.3390/s20082219).

Further research was necessary for narrowing the options. I found that comparison studies indicated multiple benefits of the PMS5003 by Plantower over the SPS030. For example, in a 2020 study *Laboratory Comparison of Low-Cost Particulate Matter Sensors to Measure Transient Events of Pollution,* the PMS5003 by Plantower was found to exhibit no delay between the signal and sensor response, unlike other low-cost mobile particulate sensors like Honeywell's HPMA115S0 and the SDS018 by Novafitness. This capability is meaningful when measuring transient events of pollution such as car exhaust which can plume up to a high degree for <1 minute.[30]

In the box and whisker plot below comparing the PMS5003, SPS030 and other common particulate sensors against the known accuracy of a DustTrak, the horizontal lines show the 1st quartile (bottom), median (middle), and 3rd quartile (top). The vertical lines indicate data points within 1.5 times the interquartile range below the 1st quartile and above the 3rd quartile.

Regarding the lower limit of detection, the PMS5003 Plantower also performs far better than these peer sensors: Senserion SPS030, Novafitness SDS018, Alphasense OPCR1 and Honeywell HPMA115S0.[31]

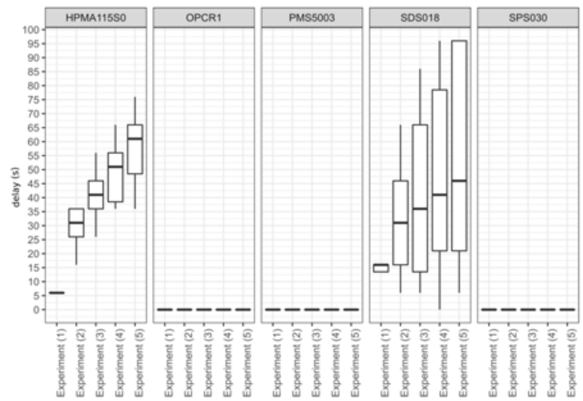


Figure 17.7: Comparison of sensor delay across different models, calculated by finding the maximum R squared with the DustTrak after applying time lags to the readings from each sensor. (Photo from https://doi.org/10.3390/s20082219).

The PMS50003 is not without issues. For example, it shows significant underestimations of particulate > 2.5 µm and greatest accuracy for 1 µm and below, see the following box and whisker plot graph.[32]

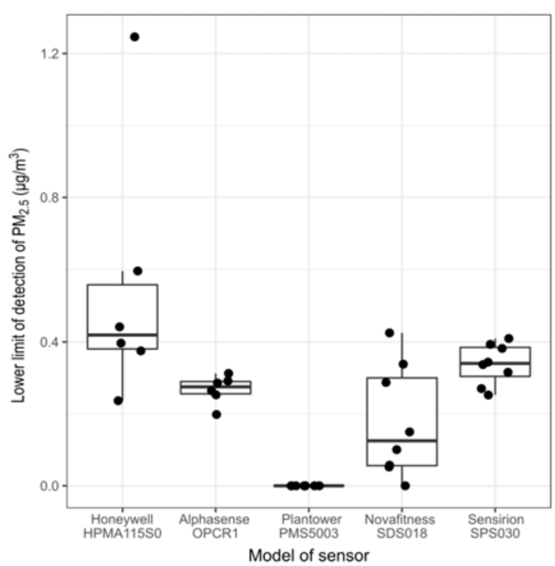


Figure 17.8: Lower detection limit across sensor models measured under blank conditions (PM2.5 µg/m^3). Boxplots indicate lower quartile, median, and upper quartile (horizontal lines); whiskers extend to data within 1.5 x the interquartile range. Dots represent individual sensor readings. (Graph from https://doi.org/10.5194/amt-13-2413-2020).

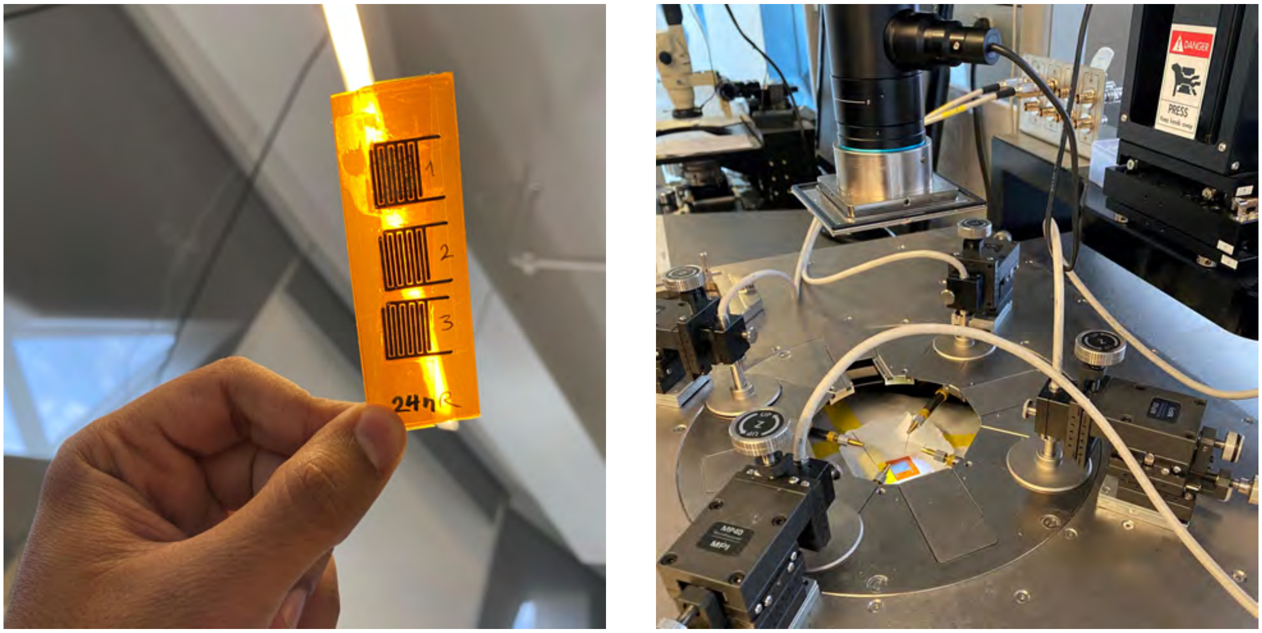
It is worth noting that all laser-scattering particulate sensing performed by low-cost mobile units underestimates black carbon particulate air pollution levels, as the laser light might vaporize some of the ultra-fine sized particles.[33] For this reason, a major component of the broader research project is to develop a better low-cost sensor. This work is in progress now and described more below in the following section.

17.5 The Team and Recent Developments

Our team is comprised of principal investigators and their lab members spanning expertise and leadership in the disciplines of electrical engineering, atmospheric science, and computational art. Working together, the engineers will contribute studies of the interaction of laser-induced graphene (LIG) with BC and then co-design a LIG-based BC sensor with the atmospheric scientists and the computational art team. Development of wearable electronics that include the sensor will be collaboratively developed through iterative input and testing with volunteer citizen scientist input. Jointly we are co-creating a scientifically viable instrument which is simultaneously an art object and an engineering advancement. The core team is strengthened by collaborators with expertise in database design, data visualization, and community engagement. The researchers will work closely together and bi-weekly meetings will ensure that the research is coordinated, and the results are integrated. The team thus far is comprised of the following faculty and student in addition to myself:

- Hosale, Mark-David - NPI. Associate Professor, York, Computational Arts
- Grau, Gerd - Co-Applicant. Associate Professor, York, Electrical Engineering & Computer Science
- Gordon, Mark - Collaborator. Associate Professor, York, Earth & Space Science
- Ranee Lee - Collaborator. Associate Professor, OCAD, Industrial Design
- Ong, Joel - Collaborator. Associate Professor, York, Computational Arts
- Prince, Enamul - Collaborator. Associate Professor, York, School of Information Technology
- Anvari Kohestani, Abolfazl - Engineer. Masters student, York, Electrical Engineering & Computer Science
- Basak Babadagi - Undergraduate student researcher, York, Earth & Space Science

Below are a series of images from June 2024 through January 2025, showing our sensor testing, co-design, and artwork development processes created together.



(a) Three prototype capacitors. (b) Capacitance testing of prototype in-plane capacitor.

Figure 17.9: Two images of the novel capacitor design, on the left three LIG capacitors held up to the light by Abolfazl Anvari and on the right, capacitance testing. (Photos by the author, 2024).

Next steps include the design and production of a series of other wearable works of art sensing and displaying air pollution in a variety of methods and visual strategies. Collectively these will be used together in objective four of the overarching research project *We Are Air Aware,* and public art performances in which citizens wear the sensor embedded into eye-catching wearables walking through their neighbourhood, visibly revealing their lived experience with air pollution.

(a) Basak Babadagi and Abolfazl Anvari testing the capacitor in an air chamber filled with a quantified amount of black carbon particulate at York University.

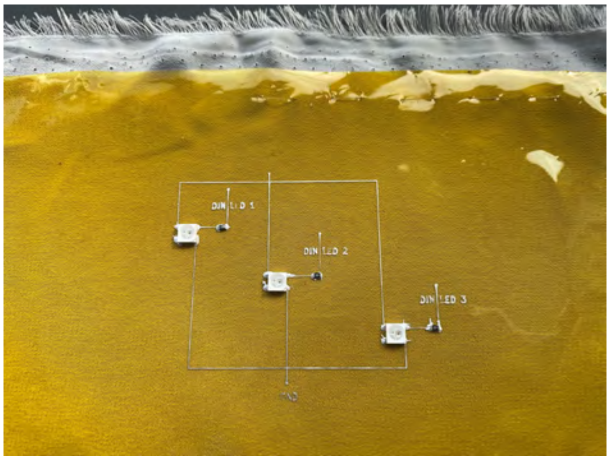
(b) Michael Weeler and Abolfazl Anvari cross-testing the capacitor at Environment Canada.

Figure 17.10: Capacitor testing. (Photos by the author, 2024-25).

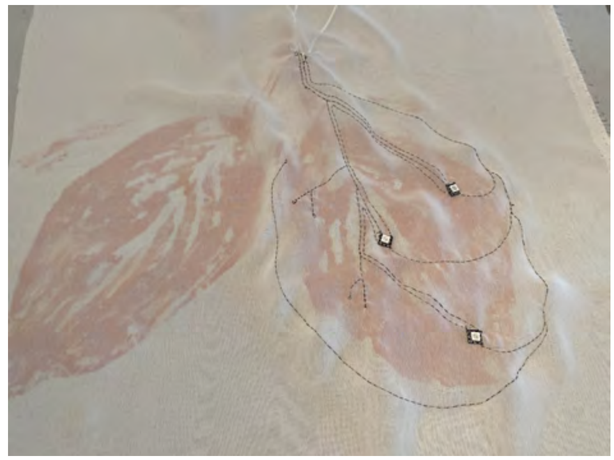
(a) Zoey Ji and Crystal Chan prepare fabric for embroidery.

(b) Lab director Ranee Lee displays the results.

Figure 17.11: Two images of mechanical embroidery experimentation at the DESIGNwith lab in the Eaton Centre. (Photos by the author, 2024).

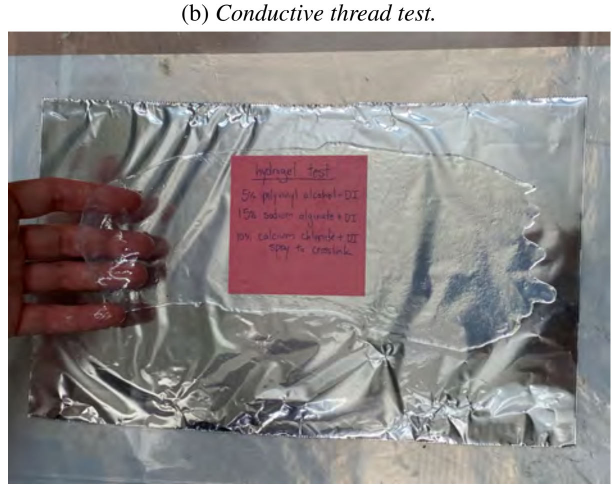


(a) *Conductive ink circuit test print.*



(b) *Conductive thread test.*

(c) *Bioplastic bracelet test.*



(d) *Bioplastic recipe.*

Figure 17.12: Four images of materials experiments in bioplastics, conductive ink printing, eco-printing and sewn electronics. (Photos by the author, 2024).

17.6 Documentation and Public Presentation

(a) AtmoSpheres 01 prototype in the streets of Toronto.

(b) Wide-angle shot.

Figure 17.13: *AtmoSpheres 01* prototype adjacent to air pollution emitting traffic on College Street in downtown Toronto. (Photo by James Dunne, 2024).

17.7 Acknowledgements

I am grateful to the New Frontiers Research Fund - Explore Stream for underwriting the development of this project and the team that makes it possible. Thanks go to Professors Joel Ong and Regina Lee for seeing value enough in the work to recommend this funding possibility to me. Special thanks go to Professors Mark-David Hosale, Gerd Grau, and Mark Gordon for believing in the work enough to submit the grant application with me. I would like to acknowledge the support of teammates Abolfazl Anvari Kohestani, Basak Babadagi, and collaborator Ranee Lee and her DESIGNwith incubator in the ongoing development of our novel sensor, calibration and testing, and the co-design process.

Part V

Conclusion and Future Directions

Chapter 18

Conclusion and Future Directions

18.1 Future Trajectories in My Practice

In my practice, integrating environmental data into art has increasingly come to represent a synthesis of empirical observation and emotional insight akin to uniting the mind with the heart— connecting intellectual comprehension with affective resonance. This combination grounds my creative approach in externally verifiable realities while fostering an expansive, fractal sense of interconnection between myself and the planetary. Recent envirographic artworks, including *Holonic Chorus* (2021-22), *Daily Chorus* (2022), *Dawning* (2023), *Sun Eater*s (2022-2023), *Celestial Objects and Aeriform Masses* (2023), and *AtmoSpheres 01* (2024), illustrate my consistent investigation into how data visualization can enhance ecological awareness and deepen collective engagement with environmental challenges.

My trajectory over recent years has evolved significantly— from initial collaborative co-design practices toward increasing public engagement. While co-design has been one of the most challenging aspects of my practice, requiring iterative negotiation and patience, it has also proven to be among the most rewarding, resulting in rich, multidimensional, and community-responsive artworks. This collaborative foundation now positions my practice to enter a new phase, emphasizing citizen science facilitation, and thereby further extending opportunities for public involvement and direct ecological advocacy.

Central to my current research-creation is *We Are Air Aware* (2025-27), a large-scale initiative designed to heighten public awareness and action around particulate air pollution. This work encompasses continued development (2025) and exhibition (2026-27). Drawing insights from my wearable artwork series *Atmo-Spheres*, this next phase will involve creating discrete, everyday air pollution sensors (*My Air Wear*) alongside elaborate artistic forms. Through public events, exhibitions, and interactive online archives, I aim to transform air quality data into compelling experiences, facilitating greater public understanding and engagement. Hopefully, this initiative will mature into a portable toolkit enabling global civic collaboration around air pollution awareness. This work is close to my heart and I feel deep gratitude to be working with an incredible team to make it a reality.

Parallel to this, ongoing work with plant biosignaling, initially explored in *Sun Eaters*, will involve continuing to learn about what biosignaling means in relation to tree and forest health, through expanded interdisciplinary collaborations with plant biophysiologists, forestry scientists and other researchers. This future work seeks to further investigate speculative yet meaningful dialogues between humans and plants, utilizing tangible, interactive interfaces to bridge perceptual divides and foster ecological empathy. This may potentially be the beginning of additional projects exploring connections between human heart beats and plant electrical rhythms, and possibly the early steps toward developing a speculative language between plant and human life.

I am also expanding my environmental data visualization efforts to include soil health and microbial life, with upcoming work in both an exhibition and a book co-organized by artist and curator Alexandra Toland and curator Patricia Lee Watts through Ecoartspace in Santa Fe (2025-26). The initial presentation of this work will occur at the Soil Factory in Ithaca, New York, in October 2025, with a potential subsequent exhibition at Biobat Artspace in 2026. This work emerges from ongoing dialogues with artists engaged in soil-based practices within Ecoartspace.

My initial experiment in this domain was cloth burial in the summer of 2023— a low-tech approach for visualizing soil microbial health. For the upcoming Soil Factory exhibition, I am beginning a series of conversations with a local soil scientist, citizens, and artists about how soil soil health might be characterized, and how soil sensors could be used to create live visualizations through which we might compare soil samples. Through a brief site visit, and a planned public invitation for visitors to bring soil samples to the exhibition space, I am looking forward to learning more about the diversity of soil health. This is a critical issue in relation to climate change, as the shifting ratio of carbon dioxide to oxygen and rising ambient temperatures are affecting the ability of soils around the world to support sustained crop growth and plant life more broadly.

Further, planned immersive envirographic video installations will document endangered ecosystems, starting with the Niagara Escarpment UNESCO Biosphere Reserve. Utilizing methods pioneered in Dawning, these installations will dynamically visualize real-time environmental conditions, emphasizing the fragile beauty and urgency of preserving vulnerable ecosystems. Collaborating with local experts where possible, I intend these videos to document fleeting moments in vulnerable ecosystems before they vanish. Displayed on immersive screens, these installations will dynamically visualize environmental changes using real-time data, calling urgent attention to the fragility and beauty of vulnerable ecosystems worldwide.

The fundamental questions driving my practice remain:

- Can environmental sensing and visualization artworks act as useful empirical interfaces for grasping complex, more-than-human ecologies?
- Might these works inspire novel methods of environmental engagement and ways of being?

Through continued integration of co-design, citizen science, and community collaboration, I aim to evolve my practice, continue to expand on the concept of envirographic art— artworks that use environmental data visualization to inspire new ways of understanding planetary systems, deepen ecological awareness, and promote collective planetary care.

18.2 The Role of Envirographic Art in The Great Transition

Cold War computation helped uncover climate change and catalyzed planetary-scale thinking. Today, computation itself is planetary in scope. Though born of systems rooted in surveillance, militarism, and control, artists have long subverted these tools, repurposing them to visualize environmental systems and foster connection and collective care across distance, and even across species.

If the project of modernity sought to use technology to separate humanity from nature— to buffer and control the perceived inconveniences, inconsistencies, and discomforts of weather, disease, and ecological interdependence— then the project I propose as a necessary counterpoint is The Great Transition.[1] Within this shift, I believe in the role of envirographic art is to reorient us toward new forms of relation. These are relations enhanced— not diminished— by the technological, making use of computational media to render visible the dynamic interrelations and invisible life processes that bind us to planetary ecologies.

Although tools may carry a degree of determinism embedded in their designed affordances, this determinism is not absolute. It remains critically important to resist simplistic notions of technological determinism, instead choosing to discard, hack, or reconfigure tools that cause harm and actively develop alternatives. Artists, in particular, are often well positioned for this work. They are frequently engaged in the imaginative and critical labour of envisioning and materializing alternative possibilities. Through the invention of new forms of media, tools, techniques, narratives, and modes of interaction, artists can open-up novel pathways toward coexistence, interspecies empathy, and ecological care. Many envirographic artists challenge dominant paradigms by embracing and expanding computational media's capacity to foster interconnectivity, wonder, and care rather than division and alienation.

Throughout this dissertation, I have articulated how technologies might be reimagined as instruments of ecological attunement. This includes augmenting perception, supporting distributed co-creation, and amplifying signals otherwise too subtle, distant, or temporally diffused to apprehend otherwise. I invite others to build on this work by extending envirographic methodologies into new domains, contexts, and collaborations. This may involve developing new sensor-based tools, speculative storytelling frameworks, or participatory protocols for engaging publics in interpreting environmental data. These strategies can counter narratives that frame computation as inevitably extractive or alienating, challenging instead the divisive logic of rationalist modernity. This vision points forward toward systems premised on collective and interspecies thriving.

I believe in art's capacity to catalyze connection, agency, and expanded possibilities for planetary care. The role of envirographic art in this context is not to resolve the climate crisis, but to change how we see it— to cultivate new habits of attention and new modes of relationality, imagining futures in which mutual flourishing is once again common-place. Much like the iconic Earthrise photograph helped ignite a sense of planetarity in the late 20th century, I believe that artistic engagements— especially those capable of working across species, across distance, and across time— hold similar potential today. Art offers not just metaphors, but methods: means of presenting alternate ontologies and opening pathways for value shifts that underpin broader cultural change.

The challenge lies in the nature of climate change itself. As Timothy Morton describes through the concept of hyperobjects, climate change resists immediate human perception due to its scale, duration, and distributed impacts. While technological advances such as satellite monitoring and environmental sensors can help make the invisible measurable, they cannot, on their own, bridge the perceptual and emotional gap between individuals and global phenomena. Art, however, can.

Consider, for instance, artworks like *Essay Concerning Human Understanding* and *Telegarden*, both of which demonstrate how electronic systems can mediate empathy across species. The former employs data sonification to explore interspecies communication, provoking reflection on what it means to understand or feel with another form of life. The latter, though mechanical, fostered genuine affective bonds between remote participants and a living garden, establishing a precedent for distributed care.

Digital media art, in particular, is uniquely positioned to meet this moment. Its structural resemblance to environmental systems— comprising interdependent modules, feedback loops, and responsive behaviour— mirrors the complexity of ecological networks. The capacity for interactivity allows users to engage with these systems experientially, collapsing temporal and spatial distance. And the computational nature of the medium makes it especially apt for translating environmental data into legible, affective, and embodied experience.

This potential is not hypothetical— it is already being realized. Envirographic artists today are resisting the divisive logics of rationalist modernity. Instead, they are advancing creative practices rooted in repair, reciprocity, and joy. Artists like Spela Petric, in works such as *PL'AI*, embrace the playful and the speculative, while also advancing serious questions about technological agency and multispecies entanglement. Similarly, in my own work *Sun Eaters*, prosthetic limbs invite human-tree interactions not because plants require enhancement, but rather because humans require assistance to bridge perceptual gaps and communicate more effectively across species boundaries.

Discussions surrounding mediation frequently highlight its capacity to attenuate relationships between people and their environment, as well as each other. However, mediation can equally connect and expand perceptual and conceptual possibilities. There is no single method for this; instead, there are multiple approaches, each offering different perspectives analogous to the concept of "umwelt"— the unique perceptual reality experienced by each species.[2] Mediation through technology can thus enable humans to glimpse the perceptual worlds of other organisms. For instance, butterflies and some birds can see the ultraviolet attributes of flowers, but without technological aids, we can only see visible light. Ultraviolet cameras make it possible for us to see an approximation of what the butterfly does. Through such mediations, new empathetic understandings and expanded forms of knowledge can emerge, both interspecies and within our own.

> This shared world is not flat, or singular. Many worlds— lively, noisy worlds— exist; many don't include us at all. . . . It is a beautiful illustration of the kind of decentring of ourselves and of human experience at which we much become adept in order to live better and more responsibly. . . [3]

In my own artworks, such as *Sun Eaters*, *Dawning*, and *Holonic Chorus*, I have sought to demonstrate how art can facilitate connection across spatial, temporal, and even species boundaries. These works use environmental data not simply to represent ecological conditions, but to generate embodied experiences of entanglement. They are not ends in themselves, but invitations to feel, to reflect, and to reimagine what relations might be possible. Indeed, technology functions as the interface through which we interact with both natural and cultural worlds. When existing technologies fail— as they frequently do— the imperative becomes to invent and innovate improved alternatives. This imperative underpins both the challenge facing envirographic artists and forms a central tenant guiding my own practice.

Looking ahead, the stakes are high. Escalating climate impacts demand cultural transformation. As calls intensify for societal shifts away from entrenched hyper-capitalist practices toward regenerative ways of living that respect planetary limits. It is my conviction that expanded support for artists who challenge dominant narratives, repurpose technologies, and invent novel tools and narratives can significantly contribute to achieving this "Great Transition".

Emerging technologies such as quantum computing may also offer new directions for this work. Quantum computing represents a potential Copernican shift. Unlike traditional computation, which is linear and binary, quantum computation operates through indeterminacy and entanglement— qualities resonant with ecological complexity. As these tools develop, artists will play a critical role in translating their potential into ethical, poetic, and relational forms.

An energy transition remains uncertain, as does humanity's ability to achieve the Great Transition toward sustainability. Whether or not these societal shifts occur, it is clear that climate change will continue to escalate in severity and impact in the near term. In this context, envirographic art increasingly emerges as an essential field for creatively mediating humanity's relationship with ecological and planetary realities.

Looking forward, my own future directions will further explore these intersections. By situating my practice within this broader context of artistic inquiry, I will contribute actively to shaping the trajectory of envirographic art and to envisioning pathways toward regenerative futures.

I call not only for awareness, but for attunement. Not only for representation, but for relation. Not only for seeing the world differently, but for being in the world anew.

Part VI

Bibliography

Annotated Bibliography

I. Introduction

I. Chapter 1 - Introduction

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III. Theoretical and Methodological Frameworks

III. Chapter 1 - Introducing Envirographic Research-Creation Methodologies

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III. Chapter 5 - In the Field, In the Code, In the Image: Reflections on my own Research-Creation Methodologies

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Physical computing refers to the use of tangible, embedded microcontroller-based interactive systems that can sense the world around them and/or control outputs such as lights, displays and motors.

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Comparative Genome Analysis." *Microbiome* 12, no. 1 (October 4, 2024). https://doi.org/10.1186/s40168-024-01916-8.

IV. Artworks

IV. Chapter 1- Six Envirographic artworks: 2021-25

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IV. Chapter 2: Holonic Chorus

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relating to biometeorology, a field of study of the interactions between the Earth's atmosphere and living organisms. Biometeorology is an interdisciplinary science that examines how weather and climate impact the health and well-being of living things, including humans, animals, and plants. In this artwork real-time wind data was derived from Foresta Inclusive: https://janetingley.com/foresta-inclusive/.

3. Graduate Program in Digital Media. "Our Alumni | About Us | Digital Media | Faculty of Graduate Studies (FGS) | York University." Accessed January 3, 2025. https://www.yorku.ca/gradstudies/digitalmedia/about-us/our-alumni/.
Kwame Kyei-Boateng is now an alumnus of the Digital Media Masters program at York University. With a BA in Theatre and Digital Media, Kwame explores the interdisciplinary nature of digital media at the intersection of performance and computational art. He is interested in exploring the body as a medium for human-computer interaction, connecting the physical to the digital in performance and interactive settings.

4. Toronto Metropolitan University (TMU). "Eyal Assaf." Accessed January 3, 2025. https://www.torontomu.ca/master-digital-media/the-mdm-network/2015-2016/Assaf_Eyal/. Eyal Assaf is a PhD candidate in the Digital Media Masters program at York University. He is a computer graphics animator and a Professor in the Applied Arts department at Seneca Polytechnic in Toronto. His work explores the boundaries of storytelling through game engines, 3D applications, and immersive technologies.

5. Graduate Program in Digital Media. "Our Alumni | About Us | Digital Media | Faculty of Graduate Studies (FGS) | York University." Accessed January 3, 2025. https://www.yorku.ca/gradstudies/digitalmedia/about-us/our-alumni/. Douglas Gregory is now an alumnus of the Digital Media Masters program at York University. He is a game designer and educator, with 14 years of experience developing commercial video games at both indie and AAA scale.

6. KAVI. "KAVI." Accessed January 3, 2025.https://www.ka-vi.com/. Ilze Briede [a.k.a. Kavi] is a Latvian/Canadian artist and researcher working across multiple disciplines, including visual art, interactive installation and live performance. Her creative practice and academic

research encompass working with live data sets and designing systems to turn data into visceral experiences.

7. Koestler, Arthur. *The Ghost in the Machine,* 48. New York: The MacMillan Company, 1968.

8. Overholt, Daniel, and Esben Bala Skouboe. “Perceptual Ecologies: MINE.” In *Worldmaking as Techne: Participatory Art, Music, and Architecture,* 90-113. Edited by Mark-David Hosale et al., vol. 1, Guelph, ON: Riverside Architectural Press, 2019.

9. Bennett, Jane. *Vibrant Matter: A Political Ecology of Things.* Durham, NC: Duke University Press, 2010. Barad, Karen. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* Durham, NC: Duke University Press, 2007. My conception of emergent materialism is shaped primarily by Jane Bennett’s *Vibrant Matter*, but to a lesser degree also by Karen Barad’s Meeting the Universe Halfway.

10. Noë, Alva. *Strange Tools: Art and Human Nature.* New York: Hill and Wang, 2016. I was initially introduced to embodied cognition by Alva Noë, notably through his text *Strange Tools* and also by my experiences as a teaching assistant in the Cognitive Science department at University of California San Diego.

11. Stiegler, Bernard. *Technics and Time, 2: Disorientation.* Stanford, CA: Stanford University Press, 1998. My definition of techne is taken from the writings of Bernard Stiegler and rooted in the Greek concept of techne, which refers to the art of making or doing. It is not only about computational technology, but is about the deeper and more fundamental relationship between humans and their tools, which Stiegler argues is what makes us human.

12. MoMA. “Kit Galloway, Sherrie Rabinowitz Hole in Space: A Public Communication Sculpture (Single-channel Documentation).” Accessed January 4, 2025. https://www.moma.org/collection/works/120330.

13. Digital Canon. “JODI (Joan Heemskerk & Dirk Paesmans) - DIGITAL ART (1960-2000).” Accessed January 23, 2025. https://www.digitalcanon.nl/?artworks=jodi-joan-heemskerk-dirk-paesmans#list.JODI. JODI is a collective of two internet artists, Joan Heemskerk and Dirk Paesmans, created in 1994.

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16. Douglas Gregory is the author of these two paragraphs, quoted from his programmer’s notes introducing *multiplayer.html*.

17. Shiftr. "shiftr.io." Accessed January 4, 2025. https://www.shiftr.io/.

18. Grothaus, Grace. “Holonic Chorus - Digital Media Gallery.” Accessed January 4, 2025. https://dmgallery.apps01.yorku.ca/holonic-chorus/.

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20. Wakefield, Graham. “The Alice Lab.” Accessed January 4, 2025. https://alicelab.world/.

IV. Chapter 3: Daily Chorus

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2. Teilhard de Chardin, Pierre. *The Phenomenon of Man.* New York: Harper Collins, 2008. Noosphere is a term popularized by Pierre Teilhard de Chardin to describe a planetary "sphere of reason" shaped by human thought and cultural production within the biosphere. Although finding this concept useful in the development of our artwork, the author would like to point out that the team does not espouse any of Teilhard de Chardin’s work which describes elements of scientific racism.

3. Tingley, Jane. *Foresta Inclusive.* Accessed January 23, 2025. https://janetingley.com/foresta-inclusive/. Live wind data was derived from Foresta Inclusive project, website above. Air particulate data was provided by the author.

4. Loreto, Vittorio, Muki Haklay, Andreas Hotho, Vito D. P. Servedio, Gerd Stumme, Jan Theunis, and Francesca Tria, eds. *Participatory Sensing, Opinions and Collective Awareness.* Cham, Switzerland: Springer, 2017.

5. West, Geoffrey B. *Scale: The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies.* New York: Penguin, 2017.

6. Dunne, Anthony, and Fiona Raby. *Speculative Everything: Design, Fiction, and Social Dreaming.* Cambridge, MA: MIT Press, 2013.

7. Arber, Werner. *Complexity of Life and Its Dependence on the Environment,* 3-9. In Springer eBooks. Cham, Switzerland: Springer, 2020. https://doi.org/10.1007/978-3-030-31125-4_1.

8. Gabrys, Jennifer. *Automatic Sensation: Environmental Sensors in the Digital City.* The Senses and Society 2, no. 2 (June 16, 2007): 189âĂŞ200. https://doi.org/10.2752/174589307x203083.

9. Coleman, Beth. "Let's Get Lost: Poetic City Meets Data City." In *Civic Media: Technology | Design | Practice*, edited by Eric Gordon and Paul Mihailidis, 267âĂŞ94. Cambridge, MA: MIT Press, 2015.

10. Manaugh, Geoff, ed. *Landscape Futures: Instruments, Devices and Architectural Invention.* Exhibition Catalogue. Barcelona: Actar, 2028.

11. Escobar, Arturo. *Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds.* Durham, NC: Duke University Press, 2018.

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V. Conclusion and Future Directions

V. Chapter 1- Conclusion and Future Directions

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Appendices

Appendix A: Supplemental Code and Documentation from Artworks

Holonic Chorus

Project code for Holonic Chorus in 5 main parts:

1. multiplayer.html:

```
<html>
  <head>
    <meta charset="UTF-8" />
    <link rel="apple-touch-icon" sizes="180x180" href="/apple-touch-icon.png">
    <link rel="icon" type="image/png" sizes="32x32" href="/favicon-32x32.png">
    <link rel="icon" type="image/png" sizes="16x16" href="/favicon-16x16.png">
    <link rel="icon" href="/favicon.ico">
    <link rel="manifest" href="/site.webmanifest">
    <link rel="stylesheet" type="text/css" href="styles.css">
    <script type="text/javascript" src="networkMessages.js"></script>
  </head>
  <body>
    <div id="avatar-customization">
      <div class="avatar-background">
        <h1>Avatar Customization</h1>
        <div class="color-grid">
          <div class="grid-item">
            <h2 style="color: red">Red</h2>
            <input type="range" min="0" max="255" value="255" id="red-slider"
 />
            <h2 style="color: green">Green</h2>
            <input id="green-slider" type="range" min="0" max="255"
 value="255" />
            <h2 style="color: blue">Blue</h2>
            <input id="blue-slider" type="range" min="0" max="255"
 value="255" />
          </div>
          <div class="grid-item">
            <div id="login-section">
              <label for="username">Username:</label><br />
```

```
          <input type="text" id="username" name="username" /><br
/><br/><br/><br/>
          <button id="login-button" type="button">Login</button>
        </div>
      </div>
    </div>
  </div>

 <script type="module">
  'use strict';

  import * as THREE from
'https://cdn.jsdelivr.net/npm/three@0.126.0/build/three.module.js';
  import { TransformControls } from
"https://cdn.jsdelivr.net/npm/three@0.126.0/examples/jsm/controls/TransformControls.js"
  import { World } from "./world.mjs";
  import { initializeReplication, updateUserReplica, replicatePoses,
disposeUserReplica, getOwnReplica } from "./replication.mjs";
  import { randomColourHex, colourHexToString, colourHexToTriplet,
colourTripletToHex, print, showReadout } from "./utility.mjs";
  import { connectToWorld } from "./connect.mjs";
  import * as MKControl from './mouseKeyboardControl.mjs';
  import * as VRControl from './vrControl.mjs';

  const form = document.getElementById('avatar-customization');
  const displayNameField = document.getElementById('username');
  const colourSliders = [
    document.getElementById('red-slider'),
    document.getElementById('green-slider'),
    document.getElementById('blue-slider')
  ];
  for (let i = 0; i < 3; i++) {
    const slider = colourSliders[i];
```

```
    slider.value = Math.floor(Math.random() * 256);
    slider.oninput = updateSwatch;
  }
  document.getElementById('login-button').onclick = logIn;

  function getFormColour() {
    return [
      colourSliders[0].value/255,
      colourSliders[1].value/255,
      colourSliders[2].value/255
    ];
  }

  function updateSwatch() {
    const colour = colourTripletToHex(getFormColour());
    document.getElementById('colour-swatch').style.backgroundColor =
colourHexToString(colour);
  }

  function logIn() {
    const readout = document.createElement('div');
    readout.style.position = 'absolute';
    readout.style.top = '0px';
    document.body.appendChild(readout);

    const world = new World();
    const colourTriplet = getFormColour();

    initializeReplication(world, colourTriplet);

    const app = connectToWorld({
      reload_on_disconnect: true,
      room: "/multiplayer",
```

```
          url: location.origin.replace(/^http/, 'ws'),
          userName: document.getElementById('username').value
        });

        form.style.display = 'none';
      }
    </script>
  </body>
</html>
```

2. world.mjs:

```
import * as THREE from
   'https://cdn.jsdelivr.net/npm/three@0.126.0/build/three.module.js';
import { VRButton } from
   'https://cdn.jsdelivr.net/npm/three@0.126.0/examples/jsm/webxr/VRButton.js';
import {print, vectorToString} from './utility.mjs';

// added ramp to floor; expanded plane and gridHelper

/**
 * Bundles up the boilerplate of setting up a THREE.js scene for VR,
 * and packs up the items we want to use most often into a "world" object
   with type information
 * for easier code completion when accessing it in other modules.
 */
class World {
    /** @type {THREE.Clock} */
    clock;

    /** @type {THREE.WebGLRenderer} */
    renderer;

    /** @type {THREE.Scene} */
    scene;
```

```
playerHeight = 1.5;

/**
 * Camera used for VR view and replication.
 * @type {THREE.camera} */
vrCamera;

/**
 * Camera used for mouse & keyboard use.
 * @type {THREE.camera} */
mouseCamera;

/** @type {THREE.Mesh[]} */
walkable;

/** @type {THREE.Group} */
clientSpace;

/** @type {THREE.material} */
defaultMaterial;

/** @type {THREE.Group} */
teleportTarget;

/** @type {THREE.Raycaster} */
raycaster = new THREE.Raycaster();

constructor(makeLights=true) {
    // Set up basic rendering features.
    this.clock = new THREE.Clock();

    const renderer = new THREE.WebGLRenderer({antialias:true});
```

```
this.renderer = renderer;

renderer.setPixelRatio(window.devicePixelRatio);
renderer.setSize(window.innerWidth, window.innerHeight);
renderer.xr.enabled = true;

document.body.appendChild(renderer.domElement);
document.body.appendChild(VRButton.createButton(renderer));

// Setup scene and camera.
const scene = new THREE.Scene();
this.scene = scene;

const vrCamera = new THREE.PerspectiveCamera();
vrCamera.position.set(0, this.playerHeight, 0);
this.vrCamera = vrCamera;

// Nest the VR camera in a local coordinate system for teleportation.
this.clientSpace = new THREE.Group();
this.#addSpaceReticle(this.clientSpace);
this.clientSpace.add(vrCamera);
scene.add(this.clientSpace);

// Create a second camera for mouse & keyboard use.
const mouseCamera = new THREE.PerspectiveCamera(
    75,
    window.innerWidth / window.innerHeight,
    0.05,
    100
);
mouseCamera.position.set(0, this.playerHeight, 0);
this.mouseCamera = mouseCamera;
scene.add(mouseCamera);
```

```
    // Handle resizing the canvas.
    this.#handleResize();
    window.addEventListener('resize', this.#handleResize.bind(this),
false);

    // Create a basic material.
    const material = new THREE.MeshLambertMaterial();
    this.defaultMaterial = material;

    // Set up an attractive fog in the distance.
    const fadeColor = 0x5099c5;
    scene.background = new THREE.Color(fadeColor);
    scene.fog = new THREE.FogExp2(fadeColor, 0.05);

    // Create a floor plane with a grid.
    const floor = new THREE.Mesh(new THREE.PlaneGeometry(200,200),
material);
    floor.receiveShadow = true;
    floor.rotation.x = -Math.PI / 2;
    scene.add(floor);
    this.walkable = [floor];

    const grid = new THREE.GridHelper(200,200, 0x333366, 0x666666);
    scene.add(grid);

    if (makeLights) {
        // Add lighting to the scene.
        const light = new THREE.HemisphereLight(0xfffcee, 0x202555);
        scene.add(light);

        const directional = new THREE.DirectionalLight(0xfff2dd, 1.0);
        directional.position.set(-1, 7, 0.5);
```

```
            renderer.shadowMap.enabled = true;
            renderer.shadowMap.type = THREE.PCFSoftShadowMap;
            directional.castShadow = true;
            scene.add(directional);
        }

        // Add a targeting reticle for teleportation.
        this.teleportTarget = new THREE.Group();
        this.#addSpaceReticle(this.teleportTarget);
        this.teleportTarget.visible = false;
        scene.add(this.teleportTarget);

        // Create reusable primitive geometries.
        this.primitiveGeo = {
            box: new THREE.BoxGeometry(),
            ico: new THREE.IcosahedronGeometry(),
            sphere: new THREE.SphereGeometry(0.5, 17, 9),
        }
    }

    /** Adds a circular reticle with a "forward" direction. */
    #addSpaceReticle(space) {
        space.add(new THREE.PolarGridHelper(1, 16, 1));
        space.add((new THREE.ArrowHelper(new THREE.Vector3(0, 0, -1), new
THREE.Vector3(0, 0, 0), 1.1, 0x0000ff, 0.2, 0.2)));
    }

    /** Handle resizing the canvas when the window size changes. */
    #handleResize() {
        if (!this.renderer.xr.isPresenting) {
            this.renderer.setSize(window.innerWidth, window.innerHeight);
            this.mouseCamera.aspect = window.innerWidth / window.innerHeight;
            this.mouseCamera.updateProjectionMatrix();
```

```
    }
}

/** Moves/rotates the client space for teleportation. */
teleportClientSpace(floorPositionUnderCamera, worldLookDirection) {
    const cameraOffset = this.vrCamera.position.clone();
    cameraOffset.y = 0;

    cameraOffset.applyQuaternion(this.clientSpace.quaternion);
    cameraOffset.multiplyScalar(-1);
    cameraOffset.add(floorPositionUnderCamera);

    this.clientSpace.position.copy(cameraOffset);
    this.clientSpace.updateMatrixWorld();
    this.vrCamera.updateMatrixWorld();
}

/** Rotates client space around the camera position. */
rotateClientSpace(radianDelta) {
    const cameraPosition = this.getFootPosition();
    this.clientSpace.rotation.y += radianDelta;
    this.clientSpace.updateMatrixWorld();
    this.teleportClientSpace(cameraPosition);
}

/** Updates the teleport target from a raycast. */
#updateTeleportTargetFromRaycast() {
    this.raycaster.firstHitOnly = true;
    const hit = this.raycaster.intersectObjects(this.walkable)[0];
    if (hit) {
        this.teleportTarget.position.copy(hit.point);
        this.teleportTarget.visible = true;
        return hit.position;
```

```
        }
        this.teleportTarget.visible = false;
        return null;
    }

    /** Tries to teleport to the current target. */
    tryTeleportToTarget() {
        if (this.teleportTarget.visible == false)
            return false;

        this.teleportClientSpace(this.teleportTarget.position);
        this.cancelTeleport();
        return true;
    }

    /** Cancels the teleport action. */
    cancelTeleport() {
        this.teleportTarget.visible = false;
    }
}

// Export world class.
export { World };
```

3. connect.mjs:

```
function connectToWorld(opt={}) {

  let options = Object.assign({
    url: location.origin.replace(/^http/, 'ws'),
    room: "/",
    reload_on_disconnect: false,

    userName: "Anonymous",
    userRGB: [Math.random(), Math.random(), Math.random()],
```

```
    log: console.log,
    onproject: function(projectData) {
      options.log ("Received project message, but ignored it since no
   'onproject' handler was provided.")
    },
    onuser: function(id, userData) {
      options.log (`Received user message for ${id}, but ignored it because
   no 'onuser' handler was provided.`)
    },
    onuserexit: function(id, userData) {
      options.log (`Received user exit message for ${id}, but ignored it
   because no 'onuserexit' handler was provided.`)
    },
  }, opt);

  let users = {
    self: {
      id: "",
      volatile: {
        poses: [new PoseData(0, 1.4, 2)],
      },
      user: {
        name: options.userName,
        rgb: options.userRGB
      }
    },
    others: []
  };

  function connect(users) {
    options.log(`connecting to ${options.url}${options.room}`)
    let server = new WebSocket(options.url + options.room);
    server.binaryType = "arraybuffer";
```

```
const reconnect = function() {
  server = null
  setTimeout(() => {
    if (options.reload_on_disconnect) {
      location.reload();
    } else {
      if (!server) connect(users)
    }
  }, 3000);
}

server.onerror = function(event, err) {
  options.log("WebSocket error observed:", err, server.readyState);
  server.close();
  reconnect();
}

server.onopen = () => {
  options.log( `connected to ${options.url}`)
  server.onclose = function(event) {
    options.log("disconnected")
    reconnect();
  }
  server.onmessage = (event) => {
    const msg = Message.fromData(event.data);

    switch (msg.cmd) {
      case "handshake":
        // Accept our new ID.
        users.self.id = msg.val.id;

        // Initialize replication for all other users already in the room.
```

```
          for (let o of msg.val.others) {
            users.others[o.volatile.id] = o.volatile;
            options.onuser(o.volatile.id, o.user);
          }
          break;
        case "user":
          // Accept notification of a new user joining,
          // or an existing user changing their persistent data.
          options.onuser(msg.val.id, msg.val.user);
          break;
        case "others":
          // Accept an update of all users’ volatile data. Prune out
information about ourselves.
          users.others = msg.val.filter(o=>o.id != users.self.id);

          break;
        case "exit":
          // Accept notification that a user has left the room.
          options.onuserexit(msg.val);
          break;
        case "reload":
          // Reload the scene on command from the server.
          location.reload();
          break;
        case "project":
          // Accept JSON representing the current state of the world
contents.
          if (options.onproject) options.onproject(msg.val);
          break;
        default:
          options.log("unknown message", msg);
      }
    }
```

```
      // send an update regarding our userdata:
      {
        const message = new Message("user", users.self.user);
        message.sendWith(server);
      }
    }

    return server
  }

  const server = connect(users);

  setInterval(() => {
    if (server && server.readyState==1 && users.self.id) {
      const message = new Message("pose", users.self.volatile);
      message.sendWith(server);
    }
  }, 1000/30);

  return {
    users,
    server
  };
}

export {
  connectToWorld
};
```

4. server.mjs:

```
const fs = require('fs');
const path = require("path")
const url = require('url');
```

```
const assert = require("assert");
const http = require("http");
const https = require("https");

const express = require("express");
const ws = require("ws");
const { v4: uuidv4 } = require("uuid")
const { Message, PoseData } = require('./public/networkMessages.js');
const dotenv = require("dotenv").config();

// this will be true if this server is running on Heroku
const IS_HEROKU = (process.env._ && process.env._.indexOf("heroku") !== -1);
// this will be true if there's no .env file or the DEBUG environment
   variable was set to true:
const IS_DEBUG = (!process.env.PORT_HTTP) || (process.env.DEBUG === true);
// use HTTPS if we are NOT on Heroku, and NOT using DEBUG:
const IS_HTTPS = !IS_DEBUG && !IS_HEROKU;

const PUBLIC_PATH = path.join(__dirname, "public")
const PORT_HTTP = IS_HEROKU ? (process.env.PORT || 3000) :
   (process.env.PORT_HTTP || 8080);
const PORT_HTTPS = process.env.PORT_HTTPS || 443;
const PORT = IS_HTTPS ? PORT_HTTPS : PORT_HTTP;

// allow cross-domain access (CORS)
const app = express();
app.use(function(req, res, next) {
  res.header('Access-Control-Allow-Origin', '*');
  res.header('Access-Control-Allow-Methods', 'GET, OPTIONS');
  res.header('Access-Control-Allow-Headers', 'Content-Type');
  return next();
});
```

```
// promote http to https:
if (IS_HTTPS) {
  http.createServer(function(req, res) {
        res.writeHead(301, { "Location": "https://" + req.headers['host'] +
   req.url });
        res.end();
    }).listen(PORT_HTTP);
}

// create the primary server:
const server = IS_HTTPS ? https.createServer({
  key: fs.readFileSync(process.env.KEY_PATH),
  cert: fs.readFileSync(process.env.CERT_PATH)
}, app) : http.createServer(app);

// serve static files from PUBLIC_PATH:
app.use(express.static(PUBLIC_PATH));

// default to index.html if no file given:
app.get("/", function(req, res) {
    res.sendFile(path.join(PUBLIC_PATH, "index.html"))
});

// add a websocket server:
const wss = new ws.Server({ server });

// start the server:
server.listen(PORT, function() {
  console.log("\nNode.js listening on port " + PORT);
});

// ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
```

```
const demoproject = {
  threejs: {
  geometries: [{ uuid: "geom_cube", type: "BoxGeometry" }],
  materials: [{ uuid: "mat_cube", type: "MeshStandardMaterial" }],
  object: {
    type: "Scene",
    children: [
      { type: "Mesh", geometry: "geom_cube", material: "mat_cube",
   castShadow: true, matrix: [
        0.8775825618903728, 0.22984884706593015, -0.4207354924039482, 0,
        0, 0.8775825618903728, 0.47942553860420295, 0,
        0.47942553860420295, -0.4207354924039482, 0.7701511529340699, 0,
        0, 1.5, 0, 1
      ]}
    ]
  }
  }
};

const clients = {}
const rooms = {}

// get (or create) a room:
function getRoom(name="default") {
  if (!rooms[name]) {
    rooms[name] = {
      name: name,
      clients: {},
      project: demoproject
    }
  }
  return rooms[name]
}
```

```
/**
 * Send a message to all users in a room.
 * @param {Room} room
 * @param {Message} message
 */
function notifyRoom(room, message) {
  if (!room) return;
  const clientsInRoom = Object.values(room.clients);
  message.sendToAll(clientsInRoom);
}

// generate a unique id if needed
function newID(id="") {
  while (!id || clients[id]) id = uuidv4()
  return id
}

// Handle incoming connections as a new user joining a room.
wss.on('connection', (socket, req) => {
  const requestedRoomName = url.parse(req.url).pathname.replace(/\/*$/,
   "").replace(/\/+/, "/")

  const id = newID()
  let client = {
    socket: socket,
    room: getRoom(requestedRoomName),
    shared: {
      volatile: {
        id: id,
        poses: [new PoseData()],
      },
      user: {}
```

```
  }
}
clients[id] = client
client.room.clients[id] = client;

function getOthersInRoom() {
  return Object.values(client.room.clients).filter(c =>
 c.shared.volatile.id != id);
}

console.log(`client ${client.shared.volatile.id} connecting to room
 ${client.room.name}`);

socket.on('message', (data) => {
  const msg = Message.fromData(data);

  switch(msg.cmd) {
    case "pose":
      client.shared.volatile = msg.val;
      client.shared.volatile.id = id;
      break;
    case "user":
      client.shared.user = msg.val;
      (new Message("user", {id: id, user:
 msg.val})).sendToAll(getOthersInRoom());
      break;
  }
});

socket.on('error', (err) => {
  console.log(err)
});
```

```
  socket.on('close', () => {
    delete clients[id]

    if (client.room) delete client.room.clients[id]

    notifyRoom(client.room, new Message("exit", id));

    console.log(`client ${id} left room ${client.room.name}`);
  });

  (new Message("handshake", {
    id: id,
    others: getOthersInRoom().map(o=>o.shared)
  })).sendWith(socket);

  (new Message("project", client.room.project)).sendWith(socket);
});

setInterval(function() {
  for (let roomid of Object.keys(rooms)) {
    const room = rooms[roomid];
    const clientlist = Object.values(room.clients);
    const message = new Message("others",
   clientlist.map(o=>o.shared.volatile));
    message.sendToAll(clientlist);
  }
}, 1000/30);
```

5. replication.mjs:

```
import * as THREE from
   'https://cdn.jsdelivr.net/npm/three@0.126.0/build/three.module.js';
import { World }    from './world.mjs';
import { colourTripletToHex, print, vectorToString } from './utility.mjs';

```

```
/**
 * Pseudo-enum to make magic numbers for indexing hands less magic/more
   readable.
 */
const HandID = {
    left: 0,
    right: 1,
    toSideSign: function(handID) {
        return 2 * handID - 1;
    },
    toPoseIndex: function(handID) {
        return handID + 1;
    }
}
Object.freeze(HandID);

/**
 * Gets the world space position and orientation of an object
 * and packs it into a PoseData struct to send to the server.
 */
function packWorldPose(source, pose) {
    let p = new THREE.Vector3();
    source.getWorldPosition(p);
    pose.pos[0] = p.x;
    pose.pos[1] = p.y;
    pose.pos[2] = p.z;

    let q = new THREE.Quaternion();
    source.getWorldQuaternion(q);
    pose.quat[0] = q.x;
    pose.quat[1] = q.y;
    pose.quat[2] = q.z;
    pose.quat[3] = q.w;
```

```
}

/**
 * Takes pose data from a network packet and applies it to a THREE.js object.
 */
function unpackLocalPose(pose, destination, scale = 1) {
    if (destination.visible) {
        const p = new THREE.Vector3(pose.pos[0], pose.pos[1], pose.pos[2]);
        destination.position.lerp(p, 0.2);
        const q = new THREE.Quaternion(pose.quat[0], pose.quat[1],
   pose.quat[2], pose.quat[3]);
        destination.quaternion.slerp(q, 0.2);
    } else {
        destination.position.set(pose.pos[0], pose.pos[1], pose.pos[2]);
        destination.quaternion.set(pose.quat[0], pose.quat[1], pose.quat[2],
   pose.quat[3]);
        destination.visible = true;
    }
    destination.scale.set(scale, scale, scale);
}

/**
 * World object to use in accessing camera, scene, shared primitives, etc.
 * @type {World} */
let world;

/**
 * Local replica to represent the client.
 * @type {Replica} */
let clientReplica;

// Load a font for displaying user names.
const loader = new THREE.FontLoader();
```

```
let font;
loader.load('fonts/Roboto_Regular.json', function (loadedFont) {
    font = loadedFont;
});
const textMaterial = new THREE.MeshBasicMaterial({color:0x000000});

/**
 * Array of the local user's controller objects.
 */
const controllers = [null, null];

class Replica {
    #head;
    #body;
    #hands = [null, null];
    #nameGeo;
    #material = null;
    #displayName;

    constructor(displayName, colour, customAvatar) {
        let material = world.defaultMaterial;

        if (colour) {
            material = new THREE.MeshLambertMaterial({color: new
   THREE.Color(colourTripletToHex(colour))});
            this.#material = material;
        }
        this.#head = new THREE.Group();
        world.scene.add(this.#head);
        this.#body = new THREE.Group();
        world.scene.add(this.#body);
        let makeAvatar = true;
        if(customAvatar){
```

```
        makeAvatar = customAvatar(this.#head,this.#body, material)
    }
    if (makeAvatar){
        const visor = new THREE.Mesh(world.primitiveGeo.box, material);
        visor.scale.set(0.2, 0.1, 0.12);
        this.#head.add(visor);

        const ball = new THREE.Mesh(world.primitiveGeo.sphere, material);
        this.#head.add(ball);
        ball.scale.set(0.24, 0.35, 0.24);
        ball.position.set(0, -0.052, 0.09);
        ball.rotation.set(Math.PI * 0.1, 0, 0);
        ball.castShadow = true;

        const torso = new THREE.Mesh(world.primitiveGeo.box, material);
        torso.scale.set(0.35, 0.65, 0.12);
        torso.castShadow = true;
        this.#body.add(torso);
    }
    if (displayName) {
        this.#displayName = displayName;
        const nameGeo = new THREE.TextGeometry(displayName, {font:font,
size: 0.3, height: 0});
        nameGeo.computeBoundingBox();
        const name = new THREE.Mesh(nameGeo, textMaterial);
        name.rotation.set(0, Math.PI, 0);
        name.position.addScaledVector(nameGeo.boundingBox.min, -0.5);
        name.position.addScaledVector(nameGeo.boundingBox.max, -0.5);
        name.position.y += 1.5;
        name.position.x *= -1.0;
        this.#body.add(name);
        this.#nameGeo = nameGeo;
    }
```

```
        this.#head.visible = false;
    }

    static createClientReplica(colour,customAvatar) {
        let replica = new Replica(undefined, colour, customAvatar);
        world.vrCamera.add(replica.#head);
        world.clientSpace.add(replica.#body);
        replica.#head.visible = true;
        return replica;
    }

    updateUserData(userData) {
        this.#material.color = new
THREE.Color(colourTripletToHex(userData.rgb));
        if (userData.name != this.#displayName) {
            this.#nameGeo.dispose();
            this.displayName = userData.name;
        }
    }

    dispose() {
        world.scene.remove(this.#head);
        world.scene.remove(this.#body);
        for (let hand of this.#hands) {
            if (hand && hand.parent) world.scene.remove(hand);
        }
        this.#nameGeo.dispose();
        if (this.#material) this.#material.dispose();
    }

    updatePose(userData) {
        const scale = userData.scale ?? 1;
```

```
        unpackLocalPose(userData.poses[0], this.#head, scale);
        this.poseBodyFrom(this.#head, scale);
        this.#tryReplicateHand(HandID.left, userData.poses[1], scale);
        this.#tryReplicateHand(HandID.right, userData.poses[2], scale);
    }
}

/** @type {Replica[]} */
let replicas = [];
let customAvatarFunction=undefined;

function initializeReplication(targetWorld, clientColour, customAvatar) {
    world = targetWorld;
    customAvatarFunction=customAvatar;
    controllers[HandID.left] = world.renderer.xr.getController(HandID.left);
    controllers[HandID.right] = world.renderer.xr.getController(HandID.right);

    clientReplica = Replica.createClientReplica(clientColour,
   customAvatarFunction);
}

function createReplicaForUser(id, userData) {
    const replica = new Replica(userData.name, userData.rgb,
   customAvatarFunction)
    replicas[id] = replica;
}

function replicateUserPose(userData) {
    const replica = replicas[userData.id];
    if (replica) replica.updatePose(userData);
}

function replicatePoses(self, others) {
```

```
    packWorldPose(world.vrCamera, self.volatile.poses[0]);
    for (const other of others) {
        replicateUserPose(other);
    }
    clientReplica.poseBodyFrom(world.vrCamera);
}

function updateUserReplica(id, userData) {
    const replica = replicas[id];
    if (!replica) {
        createReplicaForUser(id, userData);
    } else {
        replica.updateUserData(userData);
    }
}

function disposeUserReplica(id) {
    const replica = replicas[id];
    if (replica) {
        replica.dispose();
        delete replicas[id];
    }
}

function getOwnReplica() {
    return clientReplica;
}

export {
    initializeReplication,
    updateUserReplica,
    replicatePoses,
    disposeUserReplica,
```

```
    getOwnReplica
}
```

Daily Chorus Documentation

Supplemental documentation images of *Daily Chorus* and its process of development:

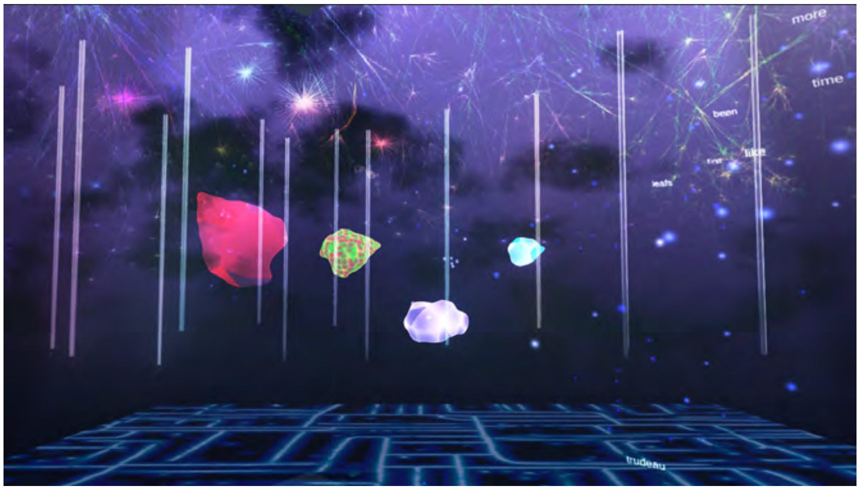

Figure 18.1: Projection mock-up created in Unity, still image by Douglas Gregory, 2022.

Figure 18.2: Installation view of *Daily Chorus* with co-creator Douglas Gregory. (Photo by the author, 2022).

Figure 18.3: Installation view of *Daily Chorus* with viewer interaction. (Photo by the author, 2022).

Dawning Documentation

The following link is to the installation and maintenance document provided to the gallery for *Dawning*: https://graceful-mist-a8e.notion.site/IV-Chapter-14-Dawning-18851e007be181a4a7dde4b135d4a464. It is a guide to proper installation and daily operating instructions. Below are the required material list and venue requirements.

Material list:

- Set of braided steel hanging cables and fasteners
- Projection screen: 1.2m x 2.4m x 0.006m [4'H x 8'W x 1/4"D], 22.5 kg [50 lbs]
- Epson LS300 ultra short throw laser projector, 3600 lumens
- Mac preloaded - Touch Designer.TOE audio/visual projection file
- Hanging microphone with 5m XLR cable
- Triton-A08 mixer
- Edifier MR4 powered monitors 10 cm
- Floor cushion, navy blue: 140 x 180 cm

Installation requirements:

- Space: Minimum of 10' ceiling clearance and 12' wide by 8' deep floor footprint
- Power: 120/220 AC
- Load: ceiling rated for hanging weight of 85 lbs/39 kgs
- Lighting: medium to low lighting. no spots
- Ladder: 2.5-3 m
- Walls painted Pantone 303 C

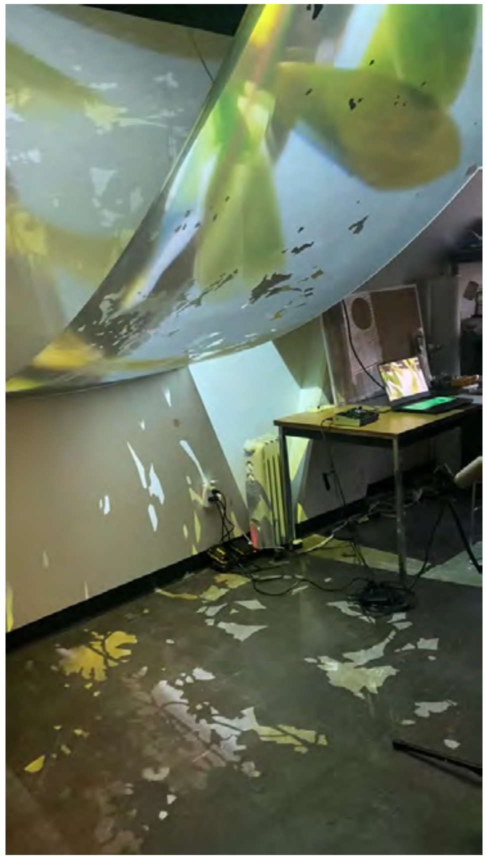

Figure 18.4: Documentation from the development process of *Dawning,* showing early studio testing of the projection screen hanging system, documentation by the author, 2022.

Figure 18.5: Flyer advertising exhibition *more-than-human,* in which *Dawning* was installed Onsite Gallery in Toronto, flyer provided by Onsite Gallery.

Sun Eaters Code

```
int led = 9;
 int motor1 = 8; const int biodataPin = A1;

 void setup() \{ \\
 Serial.begin(115200); \\
 pinMode(LED\_BUILTIN, OUTPUT); \\
 pinMode(motor1, OUTPUT); \\
 pinMode(led, OUTPUT); // declare pin 9 to be an output:
 \} \\
 \\
 void loop() \{ \\
 int bioValue = analogRead(biodataPin); \\
 delay(50); \\
 Serial.println(bioValue); \\
   if (bioValue >=500) \{ \\
       analogWrite(led, 255); \\
       analogWrite(motor1, 255); \\
   \} \\
   else if (bioValue >=400 \&\& bioValue <500) \{ \\
       analogWrite(led, 175); \\
       analogWrite(motor1, 175); \\
  \} \\
else if (bioValue >=300 \&\& bioValue <400) \{ \\
       analogWrite(led, 75); \\
       analogWrite(motor1, 75); \\
  \} \\
  else if (bioValue >=200 \&\& bioValue <300) \{ \\
       analogWrite(led, 15); \\
       analogWrite(motor1, 15);  \\
  \} \\
  else if (bioValue >=100 \&\& bioValue <200) \{ \\
       analogWrite(led, 15); \\
```

```
        analogWrite(motor1, 15); \\
  \} \\
  else \{ \\
        analogWrite(led, 0); \\
        analogWrite(motor1, 0); \\
  \} \\
\} \\
\\
```

Sun Eaters Documentation

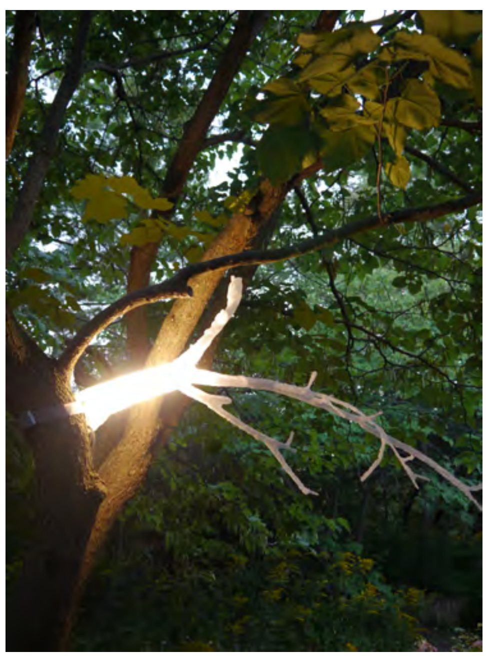

Figure 18.6: Close-up view of one of the *Sun Eaters* prosthetic branches exhibited in the Nuit Blanche Festival at the Toronto Botanical Garden. (Photo by the author, 2023).

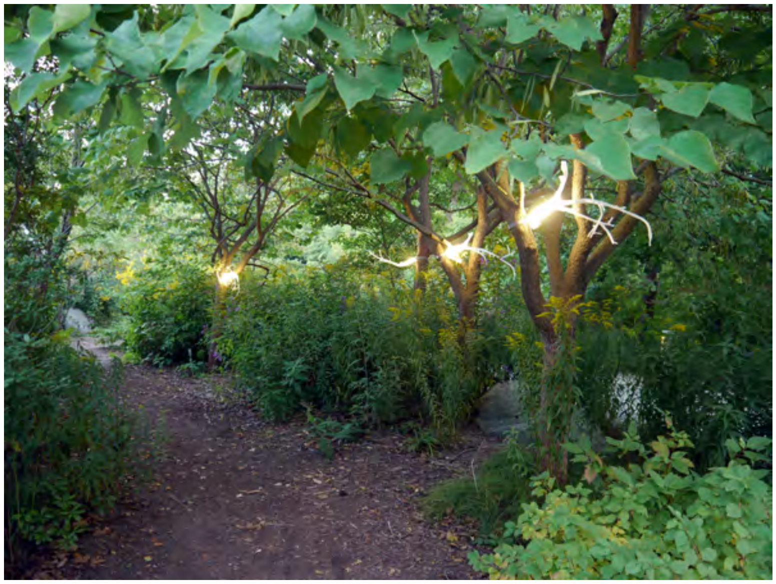

Figure 18.7: Installation view of *Sun Eaters* in the *Nuit Blanche Festival* at the Toronto Botanical Garden. (Photo by the author, 2023).

Figure 18.8: Participants engaging with *Sun Eaters* in art walk *Black Creek Walks, Talks, & Dances* co-organized by Raghad Shawky El-Shebiny, Brian MacLean, Grace Grothaus, and Joel Ong as part of the 2023 Congress of the Humanities and Social Sciences held at York University. (Photo by James Dunne, 2023).

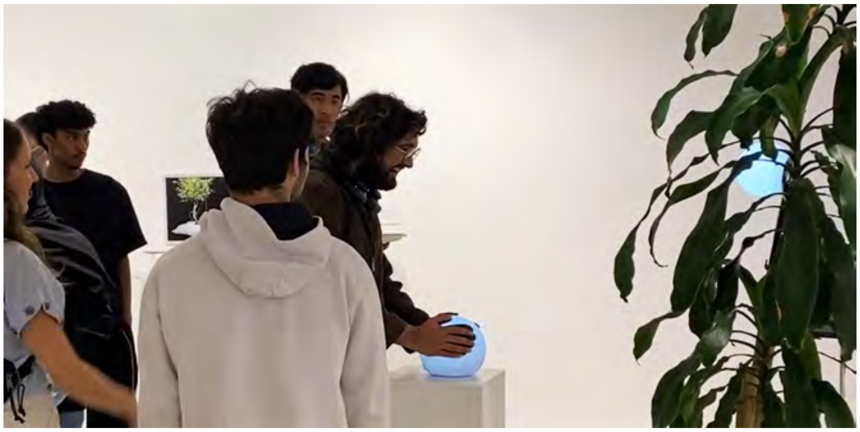

Figure 18.9: Visitors interacting *Sun Eaters*, viewing their own heartbeat and the tree's bioelectrical rhythm. (Photo by the author, 2022).

Figure 18.10: Installation view of *Sun Eaters* in the exhibition *Sensoria: The Art & Science of Our Senses* at the Gales Gallery, York University. (Photo by the author, 2022).

Figure 18.11: Exhibition poster for group exhibition *Sensoria: The Art & Science of Our Senses,* in which *Sun Eaters* was exhibited at the Gales Gallery of York University. (Poster courtesy curators Nina Czegledy and Joel Ong, 2022).

Figure 18.12: Installation view from indoors of *Sun Eaters* in the *DesignTO* Festival at a group exhibition organized at the United Contemporary gallery titled *Forecast*. (Photo by the author, 2023).

Figure 18.13: Installation view of *Sun Eaters* from outdoors in the *DesignTO* Festival at a group exhibition organized at the United Contemporary gallery titled Forecast. (Photo by the author, 2023).

(a) Installation view of *Sun Eaters.* (Photo by the author, 2022).

(b) Visitors viewing their heartbeat alongside that of the trees in *Sun Eaters. (Photo by Brian Brandes, 2022).*

Figure 18.14: Three views of *Sun Eaters* in the *Currents New Media* Festival in July 2022. (Photos by the author, 2022).

Celestial Objects and Aeriform Masses Documentation

Figure 18.15: Installation view of interactive light display on repurposed cube satellite electronics boards and monitor displaying animation *Celestial Objects and Aeriform Masses.* installed in the exhibition *The Life Cycle of Celestial Objects Pt. 2,* McIntosh Gallery, Western University in London, Ontario. (Photo courtesy Helen Gregory, 2023).

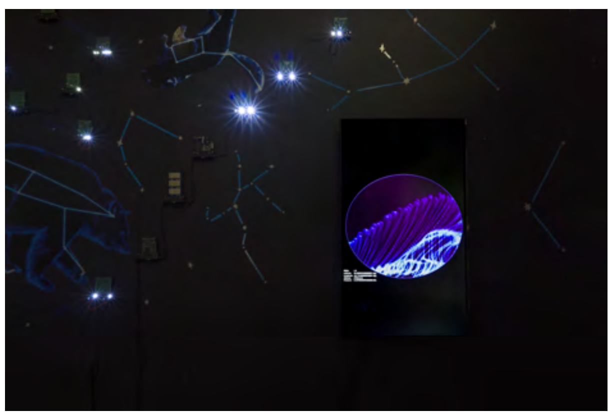

Figure 18.16: Cropped view of installation wall and monitor displaying animation*Celestial Objects and Aeriform Masses.* installed in the exhibition *The Life Cycle of Celestial Objects Pt. 2,* McIntosh Gallery, Western University in London, Ontario. (Photo courtesy Helen Gregory, 2023).

AtmoSpheres 01 Code

```
// Include the SoftwareSerial library for serial communication
#include <SoftwareSerial.h>

// Define pin numbers for RGB LED
#define REDPIN 5
#define GREENPIN 6
#define BLUEPIN 3
// Define the pin number for the potentiometer
#define POTENTIOMETER_PIN A0

// Declare a variable to store sensor values
int sensorValue = 0;

// Initialize SoftwareSerial object for communication, using pins 8 and 9 for
   RX and TX
SoftwareSerial pmsSerial(8, 9);

// Create a structure to hold data from the PMS5003 sensor
struct pms5003data {
  uint16_t framelen;
  uint16_t pm10_standard, pm25_standard, pm100_standard;
  uint16_t pm10_env, pm25_env, pm100_env;
  uint16_t particles_03um, particles_05um, particles_10um, particles_25um,
   particles_50um, particles_100um;
  uint16_t unused;
  uint16_t checksum;
};

// Declare an instance of the pms5003data structure
struct pms5003data data;

void setup() {
```

```
  // Set the RGB LED pins as output
  pinMode(REDPIN, OUTPUT);
  pinMode(GREENPIN, OUTPUT);
  pinMode(BLUEPIN, OUTPUT);

  // Start the SoftwareSerial communication at 9600 baud rate
  pmsSerial.begin(9600);

  // Start the Serial communication at 9600 baud rate
  Serial.begin(9600);
}

void loop() {
  // Read the value from the potentiometer
  int potValue = analogRead(POTENTIOMETER_PIN);

  // Check if potValue is less than or equal to 512
  if (potValue <= 512) {
    // Execute a series of color fade functions on the RGB LED representing
   the five different levels of particulate
    fadeColor(GREENPIN, 15);
    fadeTwoColors(GREENPIN, REDPIN, 10);
    fadeOrange(10);
    fadeColor(REDPIN, 5);
    fadeTwoColors(BLUEPIN, REDPIN, 3);
  } else {
    // If potValue is greater than 512, check if PMS5003 sensor data is
   available
    if (readPMSdata()) {
      // Print the PMS sensor values to the serial monitor
      // Print sensor values to the serial monitor
      Serial.println("---------------------------------------");
      Serial.println("Concentration Units (standard)");
```

```
  Serial.print("PM 1.0: "); Serial.print(data.pm10_standard);
  Serial.print("\t\tPM 2.5: "); Serial.print(data.pm25_standard);
  Serial.print("\t\tPM 10: "); Serial.println(data.pm100_standard);
  Serial.println("---------------------------------------");
  Serial.println("Concentration Units (environmental)");
  Serial.print("PM 1.0: "); Serial.print(data.pm10_env);
  Serial.print("\t\tPM 2.5: "); Serial.print(data.pm25_env);
  Serial.print("\t\tPM 10: "); Serial.println(data.pm100_env);
  Serial.println("---------------------------------------");
  Serial.print("Particles > 0.3um / 0.1L air:");
Serial.println(data.particles_03um);
  Serial.print("Particles > 0.5um / 0.1L air:");
Serial.println(data.particles_05um);
  Serial.print("Particles > 1.0um / 0.1L air:");
Serial.println(data.particles_10um);
  Serial.print("Particles > 2.5um / 0.1L air:");
Serial.println(data.particles_25um);
  Serial.print("Particles > 5.0um / 0.1L air:");
Serial.println(data.particles_50um);
  Serial.print("Particles > 10.0 um / 0.1L air:");
Serial.println(data.particles_100um);
  Serial.println("---------------------------------------");

  // Get sensor value data.particles_25um
  sensorValue = data.particles_25um;

  // Determine LED color and fade sequence based on sensorValue
  if (sensorValue >= 0 && sensorValue <= 50) {
    fadeColor(GREENPIN, 15);
  } else if (sensorValue >= 51 && sensorValue <= 100) {
    fadeTwoColors(GREENPIN, REDPIN, 10);
  } else if (sensorValue >= 101 && sensorValue <= 150) {
    fadeOrange(10);
```

```
      } else if (sensorValue >= 151 && sensorValue <= 200) {
        fadeColor(REDPIN, 5);
      } else {
        fadeTwoColors(BLUEPIN, REDPIN, 3);
      }
    }
  }
}

// This function handles the fading effect for a single color LED
void fadeColor(int pin, int fadeDelay) {
  int cycles = 20000 / (256 * 2 * fadeDelay); // 20 second cycles

  for (int i = 0; i < cycles; i++) {
    for (int j = 0; j <= 255; j++) {
      analogWrite(pin, j);
      delay(fadeDelay);
    }
    for (int j = 255; j >= 0; j--) {
      analogWrite(pin, j);
      delay(fadeDelay);
    }
  }
}

// This function combines red and green to create an orange fade effect
void fadeOrange(int fadeDelay) {
int cycles = 20000 / (256 * 2 * fadeDelay); // 20 second cycles

  for (int i = 0; i < cycles; i++) {
    for (int j = 0; j <= 255; j++) {
      analogWrite(REDPIN, j);
      analogWrite(GREENPIN, j / 2); // Less intensity on green for orange
```

```
      delay(fadeDelay);
    }
    for (int j = 255; j >= 0; j--) {
      analogWrite(REDPIN, j);
      analogWrite(GREENPIN, j / 2);
      delay(fadeDelay);
    }
  }
}

// This function handles the fading effect for two LEDs at the same time
void fadeTwoColors(int pin1, int pin2, int fadeDelay) {
  int cycles = 20000 / (256 * 2 * fadeDelay); // 20 second cycles

  for (int i = 0; i < cycles; i++) {
    for (int j = 0; j <= 255; j++) {
      analogWrite(pin1, j);
      analogWrite(pin2, j);
      delay(fadeDelay);
    }
    for (int j = 255; j >= 0; j--) {
      analogWrite(pin1, j);
      analogWrite(pin2, j);
      delay(fadeDelay);
    }
  }
}

// This function reads and processes the data from the PMS5003 sensor
boolean readPMSdata() {
  if (!pmsSerial.available()) {
    return false;
  }
```

```
// Read a byte at a time until we get to the special '0x42' start-byte
if (pmsSerial.peek() != 0x42) {
  pmsSerial.read();
  return false;
}

// Now read all 32 bytes
if (pmsSerial.available() < 32) {
  return false;
}

uint8_t buffer[32];
uint16_t sum = 0;
pmsSerial.readBytes(buffer, 32);

// get checksum ready
for (uint8_t i=0; i<30; i++) {
  sum += buffer[i];
}

// The data comes in endian'd, this solves it so it works on all platforms
uint16_t buffer_u16[15];
for (uint8_t i=0; i<15; i++) {
  buffer_u16[i] = buffer[2 + i*2 + 1];
  buffer_u16[i] += (buffer[2 + i*2] << 8);
}

// put it into a nice struct :)
memcpy((void *)&data, (void *)buffer_u16, 30);

if (sum != data.checksum) {
  Serial.println("Checksum failure");
```

```
    return false;
  }
  // success!
  return true;
}
```

Appendix B: Draft Course Syllabus

Course Overview: *Signs and Signals: Eco Art Experiments in Environmental Sensing*

Signs and Signals is an interdisciplinary undergraduate seminar that explores environmental sensing as both a scientific and artistic practice. The course engages students in critical discussions on climate change, multispecies ethics, and communication through data, while also building technical skills in sensor design, solar-powered systems, and computational media. Artists such as Beatriz da Costa, Nathalie Jeremijenko, and Tomas Saraceno frame the practice-based components, culminating in a final self-directed art project that synthesizes theory and technique.

The course is designed for students in ICAM, Speculative Design, and related fields, though others may join with instructor permission. Structured around a growth mindset and backward course design, it scaffolds learning through small assignments, hands-on labs, and community critique. A full syllabus, including weekly topics, grading criteria, and detailed learning outcomes, is available online at the following link: https://graceful-mist-a8e.notion.site/Appendix-B-Draft-Course-Syllabus-18851e007be18048bc18c3b10e647882.

Appendix C: Example Workshop Materials

Workshop Summary: *Low-Barrier Environmental Sensing Instructions*

This hands-on workshop introduces participants to accessible, low-cost techniques for building and deploying environmental sensors. Designed with inclusivity and interdisciplinary collaboration in mind, the workshop emphasizes minimal technical prerequisites and leverages readily available microcontrollers, sensors, and open-source tools. Participants learn to assemble, program, and power basic sensing systems to capture real-time environmental data such as temperature, humidity, or light.

The workshop demystifies environmental sensing through clearly sequenced steps and visual aids, enabling a broad audience— including artists, students, and community members— to engage in environmental monitoring and data-driven creative practice. The full instructional guide, including parts lists, wiring diagrams, sample code, and troubleshooting tips, is available online at the following link: https://graceful-mist-a8e.notion.site/Appendix-C-Low-Barrier-Environmental-Sensing-Instructions-18851e007be18183b776d26a99b75063.