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Klimatické (ne)viditelnosti: Data o Zemi mezi uměním a vědou
Climate (in)visibilities: Earth data between art and science

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- language correction and stylistic editing of parts of the text,
- suggestions for structure and formulation of research questions,
- summarization of notes, which I provided in the form of uploaded documents,
- brainstorming, assistance in the formulation of definitions, syntheses, and connections between theoretical concepts (e.g., the digital twin of Earth, planetary thinking, climate data visualization),
- formatting of citations

The resulting thesis is my own intellectual work – all generated content was reviewed, edited, and finalized by me as the author. The AI tool was used as an assistive aid, not as a content creator.

Klíčová slova (česky)

klimatická krize, data, digitální dvojče, umění, věda, viditelnost, neviditelnost, vizualizace, estetika, afekty, infrastruktura vědění, planetární

Keywords (in English)

climate crisis, data, digital twin, art, science, visibility, invisibility, visualisation, aesthetics, affects, knowledge infrastructure, planetary

Abstrakt (česky)

Klimatické (ne)viditelnosti zkoumají digitální dvojče Země jako technologickou infrastrukturu i kulturní artefakt, který přetváří současné přístupy ke klimatické krizi. Práce čerpá z teorií médií, estetiky a planetárního myšlení a zkoumá, jak digitální repliky Země, vyvíjené například v rámci iniciativy Destination Earth Evropské komise, zprostředkovávají percepci, poznání a emocionální vztah k planetárním procesům. Digitální dvojče Země je chápáno jako reprezentanční systém, který redefinuje způsoby, jakými planetu vnímáme, představujeme si ji a reagujeme na její proměny.

Prostřednictvím teoretických rámců komparativní planetologie (Likavčan) a planetary mattering (Waag Futurelab) tato práce kriticky nahlíží na to, jak technologické systémy upřednostňují fakta a kontrolu, zatímco přehlíží péči, spravedlnost a naději. Práce je strukturována do tří částí – Dvojčení, Estetika, Afekty – které sledují, jak digitální dvojče externalizuje Zemi do strojově předpovídaného objektu, jak ji činí viditelnou skrze hyperestetické vizualizace dat a jak vyvolává emocionální stavy od techno-optimismu po melancholii. Skrze příklady z platforem dálkového průzkumu Země, vizuální kultury a uměleckého výzkumu je digitální dvojče zasazeno do širších režimů viditelnosti a vládnutí, přičemž se ptá, jaké obrazy Země se nám zpřístupňují.

Nakonec práce navrhuje attunement (vyladění, naladění) jako alternativní etickou orientaci. Volá po propletených infrastrukturách, které umožňují péči a spolužití, a po planetárních imaginacích, které zůstávají otevřené komplexitě, nejednoznačnosti a situované odpovědnosti.

Abstract (in English)

Climate (in)visibilities investigates the digital twin of Earth as both a technological infrastructure and a cultural artifact that reshapes contemporary approaches to climate crisis. Drawing from media theory, aesthetics and planetary thinking, it explores how digital replicas of Earth, developed under initiatives like the European Commission's Destination Earth, mediate perception, knowledge and emotional engagement with planetary processes. The digital twin of Earth is a representational system that reframes how we sense, imagine and respond to environmental change.

Through the theoretical frameworks of Comparative Planetology (Likavčan) and Planetary Mattering (Waag Futurelab), this work critiques how such technological systems prioritize matters of fact and control, while neglecting care, justice and hope. The thesis follows a tripartite structure - Twinning, Aesthetics, Affects - to trace how the digital twin externalizes Earth into a machinic object of prediction, renders it visible through hyperaesthetic data visualizations, and induces emotional states from techno-optimism to melancholy. Engaging with examples from Earth Observation platforms, visual culture, and artistic research, it situates the digital twin within broadened regimes of visibility and governance, interrogating what kinds of Earth are made perceptible.

Ultimately, the thesis proposes attunement as alternative ethical orientation. It calls for entangled infrastructures that invite care and coexistence and for planetary imaginaries that remain open to complexity, ambiguity, and situated responsibility.

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Introduction

What is the Earth as seen through its digital twin? This thesis explores how the digital twin of Earth emerges not only as a progressively more intricate technological infrastructure, but more seriously as an epistemological and affective figure that reshapes how we perceive, imagine, and emotionally inhabit the planetary. As planetary-scale environmental sensing and predictive data visualisations increasingly structure contemporary climate science, they reshape both political imaginaries and mediated planetary perceptions, ultimately crystallising into affective responses to both the climate crisis and its technological representations. The thesis asks: What kind of Earth is being made visible, governable, and feelable through its digital twin and at what cost to our ways of sensing, knowing, and caring for the planet?

The thesis approaches this question from a hybrid position that is simultaneously critical, artistic, and reflective. It attends to the cultural logics and visual regimes that inform the twinning of Earth. It traces how simulation grows beyond being just a technical tool to embody the condition for experience, where what is sensed, seen, and acted upon is increasingly mediated by algorithms, platforms, and models. In this landscape, perception itself becomes programmable.

Doubled, troubled

The primary concern here is the individual subject living through an atmospheric saturation of political unease, algorithmic mediation, and ecological collapse. We navigate smart cities engineered for efficiency yet often devoid of lived community; encounter metaverses and synthetic interfaces that promise escape while entrenching commodified realities; face a daily feed of climate forecasts, extinction reports, and computational predictions of futures we increasingly struggle to imagine ourselves within. We are asked to make sense from within a condition of entangled urgencies, where the very frameworks we once relied on, such as scientific rationalism, liberal democracy, and cultural narratives of progress, begin to fracture under the weight of their own contradictions.

In this disorientation, the digital twin of Earth arrives as a powerful figure among its infrastructural kin of techno-political imaginaries: smart cities, predictive AI systems, immersive social metaverses. Once experimental and speculative, these systems now mature with startling speed, with narratives of optimisation, crisis response, and planetary management. They emerge without clear collective reflection and consent, offered as solutions to problems we have not yet articulated, implemented top-down before we even have the language to ask what it is we are being asked to live with.

We find ourselves surrounded by infrastructures of simulations that appear inevitable, while remaining epistemologically under-examined and emotionally unprocessed. Technologies have always shaped, extended, and externalised human ways of knowing and projected perceptions across distance, time and scale. From the telescope to the satellite, from the weather map to the climate model, they have rendered the imperceptible graspable. But as these machinic infrastructures scale to match the planetary, they begin to exceed the boundaries of human sense and orientation.

The meticulously complex infrastructure of Earth's digital twin exemplifies this shift. Its simulations reconfigure temporality, compressing uncertain futures into scrollable presents; its data visualisations turn complexity into beautiful gradients; and its feedback systems enact a mode of governance where prediction substitutes deliberation. How do we make sense from within such conditions? Where do we go when our inherited epistemological frameworks begin to crack under the weight of planetary complexity?

The world made visible by climate science and simulation no longer centres us. It is distributed, entangled, and operates on scales that exceed human comprehension. As we come to recognise the enormity of the systems we inhabit (and disrupt) the scaffolding of the human-centric worldview begins to fall down. Technologies that once promised mastery now expose our dislocation. The digital twin mirrors a world in which we are peripheral, partial.

The bruise on our collective ego is deepest for those who still dream of mastery and try to fight the planetary, tackle it, and control it. It is hardest for those whose imaginaries remain bound to colonial legacies, heroic stories of conquest and triumph, capitalist extractivism, and masculine fantasies of command. Techno-optimism is a cruel optimism, a promise of resolution without the demand for reflection.

For many, it is anxiety about the uncertainty and vastness the planetary brings, that makes us restless. Other times, the encounter with the weird world increasingly sensed and modelled through algorithms and not really quite fitting the scale of life, evokes something uncanny and strange. Beneath it all, we are all thoroughly sad.

To stay with the planetary is to begin questioning the technical, political, and social architectures that make certain ways of sensing and acting possible, and others unthinkable. It is questioning the desires that animate our infrastructures, the historical narratives we decide to focus on, and what imaginations are turned into stories we use to find our place in the world.

As thinkers like Donna Haraway and Isabelle Stengers remind us, it matters what matters we use to think other matters with. If we continue to build from the same myths, we will only reproduce their consequences. Rethinking the digital twin of Earth does not mean just updating once again its interfaces, algorithms, and feedback, but taking the time to collectively reflect on the cultural assumptions that shape what we think Earth is, and what kind of world continues to make such tools necessary.

What is required is a reorientation toward the planetary as something not to be solved, but lived with. A shift away from designing for command-and-control, toward infrastructures of care, attunement, and shared vulnerability.

This thesis is written from the position of an artist and critical coder working with environmental data. Working with satellite imagery platforms, weather forecast APIs, extreme event alerts, and quantum experiment databases, it began in fascination with the

visuality of Earth as rendered through computational infrastructures. There was an attraction to the pure magic of making the invisible visible. The very idea of the digital twin of Earth, a world that could be seen, simulated and perhaps even understood, felt compelling, even seductive.

Immersed in the aesthetics of these systems, I became increasingly attuned to the way they pull thought, feeling, and representation into particular forms. As I traced the architectures of sensing, prediction, and abstraction, my position shifted. The overwhelming scale and logic of the systems that form the digital twin of Earth confronted my own anthropocentric habits of seeing, feeling, and knowing from the position of an observer. This thesis, then, became not only a critical study of planetary-scale technologies, but a reflective investigation into the desires, imaginations, and narratives, my own included, that give rise to them.

It is written from a position that is both implicated and unsettled. I do not stand outside the systems I critique. I have been drawn to their promises and aesthetics. I have worked with their tools. And through that proximity, I have come to ask different questions: What kind of world do these systems render visible? What forms of knowledge do they prioritise? And what relationships to the Earth do they make possible or foreclose? This work is, in part, an effort to slow down, to stay with these questions, and to imagine other ways of perceiving and relating to a world in crisis.

I. Situated methodologies

This thesis brings together conceptual analysis, situated observation, and speculative critique through an interdisciplinary methodology, situated in artistic research, media theory, infrastructure studies, aesthetics, and affect theory. It does not seek to evaluate digital twins as engineering solutions, but rather to interrogate their cultural, epistemological, and affective significance that shapes contemporary understandings of planetary crisis.

The work is grounded in observing, analysing and engaging with the emerging digital twin platforms, while drawing from a vast constellation of theoretical texts. Destination Earth and its embedding within broader European infrastructures, such as the European Space Agency's Copernicus satellite programme, serve as a primary site of investigation. This platform is approached as an engineering artefact and a mediated environment with a visual interactive interface through which planetary processes become scrollable, adjustable and narratable. Alongside, the investigation traces the technical substrata that support such visualities, including the functioning of orbital satellites, sensor types, spectral bands and data-processing techniques. This research was also enriched by conversations with designers and coordinators involved in digital twin initiatives, offering additional insight into how these systems are imagined and implemented.

Parallely, the thesis emerges through conceptual and philosophical research into the epistemologies and imaginaries that shape the digital twin. The framework is distributed across three interrelated domains: twinning, aesthetics, and affects. Each draws on distinct but overlapping constellations of thinkers. In twinning, the work engages with media theories of contemporary Benjamin Bratton and Orit Halpern and foundational works by Jean Baudrillard, Bernard Stiegler, and Marshall McLuhan. Their contribution helps frame the digital twin as an extension of vision, cognition, control, and the very idea of Earth. Aesthetics is shaped by theoretical engagements with Nicolas Mirzoeff, Orit Halpern, Johanna Drucker, Eyal Weizmann, and Matthew Fuller. Their work grounds the analysis of the twins' visual regimes and the spectral, machinic, forensic aesthetics through which planetary processes are rendered visible and the transformation of vision into visualisation. The third part, focused on affects, draws on Naomi Klein, Timothy Morton, Lauren Berlant, Eugene Thacker and Dominic Pettman, whose writing helps map the affective terrain shaped by planetary crisis and its technological mediation.

The methodological orientation is grounded in two key interwoven frameworks: comparative planetology and planetary mattering. The first, developed by environmental philosopher Lukáš Likavčan, offers a lens for examining how different aesthetic imaginaries of Earth (such as Globe, Terrestrial, and Planetary) shape political and technological responses to climate change. The second draws on feminist and posthumanist scholarship

and foregrounds entanglements of epistemologies, technologies and affective investments, asking what matters, for whom, and through what representational apparatus. Planetary Mattering is conceptualised by Waag Futurelab's More-than-Planet project, where I undertook an internship under the guidance of Miha Turšič. The critical conversations and conceptual orientations encountered there have been foundational in shaping the thesis.

Taken together, this methodology enables a reading of the digital twin as a complex epistemic structure that shapes planetary perception, political imaginaries and emotional responses. The central question guiding this inquiry is: How does the digital twin of Earth mediate our perception, governance, and emotional experience of planetary crisis, and what are the epistemological, aesthetic, and affective consequences of this mediation?

I. I. Attunement as orientation

This thesis follows a trajectory across scales—technical, visual, affective—and across modes of thinking. It begins with asking what the Earth is and what Earth matters to describe the frameworks. From there, it traces the historical development and continues into the planetary-scale architectures of twinning. The work then turns to the aesthetic formations of the twin: colour gradients, rotating globes, seamless composites, predictive dashboards. These images abstract the Earth and shape how we feel about it. In its final movement, the thesis dwells in these feelings: the uncanny, the overwhelming, the comfortable, the anxious, the melancholic. It maps the affective terrain of a subject living within planetary crisis mediated through technological systems it did not ask for but must now learn to live with.

In place of a singular research outcome, this thesis proposes a mode of orientation: attunement. This form of inquiry resists closure not out of vagueness, but in recognition of the planetary condition it attempts to think-with. To attune to data, technologies, more-than-human temporalities, and the Earth is not to solve the planetary, but to stay with its complexity, ambiguity, and scale. If the digital twin enacts a logic of prediction, optimisation, and abstraction, then attunement insists on the opposite direction, not as rejection, but as remainder. What persists when we shift our focus to matters of care, of justice, of shared vulnerability and uncertain hope?

The structure of this thesis is intentionally layered, at times circling back, at times disoriented. This is part of the method, part of the condition it describes. You are invited to read it as such: not for resolution, but for resonance.

II. Frameworks for sensing, knowing and caring for the Planetary

Before diving into the core analysis of the digital twin of Earth, I would like to contextualise the central research question through two theoretical frameworks, comparative planetology and planetary mattering, that guide my investigation and shape my understanding of what it means to “twin” the Earth. These frameworks help me to move beyond technical and computational critique and instead situate the digital twin within broader planetary imaginaries, epistemologies, and political stakes.

Comparative planetology, developed by environmental philosopher Lukáš Likavčan, provides a method for analysing the evolution of our understanding of the planet and

environment.¹ Likavčan, inspired by Latour, introduces the methodology of cosmograms to picture and interpret different “Earths”.² Comparative planetology inspires me to situate the digital twin of Earth within planetary imaginations and their historical, social, and political underpinnings.

Mattering explores our values and how things become significant through their entanglements, relations, and intra-actions within complex networks. The concept challenges the artificial separation between facts and values, asking what is made to matter, by whom, and to what ends. I apply this framework through the work of Planetary Public Stack (PPS) developed by the More-than-Human Research group at Waag Futurelab, which examines how infrastructures shape planetary imaginaries and what “matters” motivate technological developments such as the digital twin of Earth.³

These two frameworks serve as critical tools for analysis and speculation on where this logic of datafication of Earth leads us and what futures it constructs. As many proclaim the end of alternatives to capitalism, Comparative Planetology and Planetary Mattering provide tools to think beyond the current paradigm toward new technological and environmental imaginaries.⁴ Both of these frameworks invite us to consider our imaginaries and values in designing new infrastructures. It should become apparent throughout this thesis that the development and implementation of digital twins of Earth as governing systems should be problematized through this ethical and theoretical grounding.

Before considering speculative alternatives, I must understand the complexities of planetary-scale computation, algorithmic governance, climate science and its visualities, and the affective responses to climate change. These frameworks act as a mirror to confront the twin revealing its foundations, limitations, and implications for how we conceptualize Earth itself.

1 LIKAVČAN, Lukáš. *Introduction to Comparative Planetology*. Moscow: Strelka Press, 2019. ISBN 9781916283002.

2 Bruno Latour, a key figure in science and technology studies, redefined how we think about nature, politics, and science by treating nonhumans as active participants in social and ecological systems. His ideas on cosmograms—representations of world-making—influence Likavčan’s method in *Comparative Planetology*, where planetary imaginaries are analysed as both political and epistemological constructions. See, for example: LATOUR, Bruno. *Facing Gaia: Eight Lectures on the New Climatic Regime*. Cambridge: Polity Press, 2017. ISBN 9781509519743.

3 The More-than-Planet project, coordinated by Waag Futurelab, brings together artists, scientists, and theorists to reimagine planetary imaginaries in light of ecological and technological crises. It critiques dominant visual and conceptual representations of Earth, aiming to develop more inclusive, transdisciplinary approaches to understanding the planet. See: Waag Futurelab. *More-than-Planet* [online]. [cit. 2025-04-02]. Available from: <https://waag.org/en/project/more-planet/>

4 Cultural theorist Mark Fisher famously described the contemporary condition as one in which it is “easier to imagine the end of the world than the end of capitalism.” In *Capitalist Realism*, he argues that neoliberal ideology has so thoroughly permeated culture and consciousness that alternatives to capitalism appear not only unattainable but unthinkable. See: FISHER, Mark. *Capitalist Realism: Is There No Alternative?* Winchester: Zero Books, 2009. ISBN 9781846943171.

II. I. What is the Earth? Thinking-with Comparative Planetology

How is the Earth known? *What is the planet?*⁵ And what planet is going to have its twin? Comparative planetology by Lukáš Likavčan aims to study and compare different kinds of imaginations of the planet. He pictures three central Earth figures of our present: Globe, Terrestrial, and Planetary. He does so to explore the *politics-to-come* in the *New Climatic Regime* that departs from the abstractions created within these figures.⁶ The Globe is the figure of a *perfectly smooth sphere* that “*can be clearly segmented or easily unified*.”⁷ It was formed by the territorial approach to land that led to colonial and imperial acts. It is an Earth figure that can be casually transcribed as zeroes and ones because everything is closed and predictable. There is a system running in feedback loops of decisions with different probabilities.

Perhaps we need more space for fuzziness, uncanniness, blurriness, and vagueness. Likavčan introduces The Terrestrial, following Latour, focusing on the Earth’s entangled dynamics and resisting their abstraction by highlighting the planet’s material and political realities.

As a third figure, he presents The Planetary, describing the Earth in its astronomical context as one of the many planets. He further proposes, similarly to Chakrabarty, adopting a cosmic perspective in environmental thought.⁸ The Planetary perspective on Earth attunes to the astronomical becoming of Earth and the outer and inner, material and energetic happenings that the Earth evolves through.

As Likavčan explains, different planetary conceptualizations are useful for different communities and contexts.⁹ From Ursula Le Guin, followed by Donna Haraway and other feminist scholars, we know that “*it matters what matters we use to think other matters with*.”¹⁰ And so it matters what Earth we are imagining when constructing its digital twin because of what futures it enfolds.

II. II. What Earth matters? Thinking-with Planetary Mattering

The Planetary Public Stack (PPS), introduced by the More-than-Planet research group of Waag Futurelab, is “*a stack of socially inclusive technological components that contrib-*

5 Likavčan, *Introduction to Comparative Planetology*.

6 New Climatic Regime is a term by which Bruno Latour describes the changing climate and its politics. More in: LATOUR, Bruno. *Down to Earth: Politics in the New Climatic Regime*. Cambridge: Polity Press, 2018.

7 Likavčan, *Introduction to Comparative Planetology*. p. 70

8 LIKAVČAN, Lukáš. “Another Earth: An Astronomical Concept of the Planet for the Environmental Humanities.” *Distinktion: Journal of Social Theory* [online]. 2024, vol. 25, no. 1, pp. 17–36 [cit. 2025-04-04]. DOI: 10.1080/1600910X.2024.2326448. Available from: <https://doi.org/10.1080/1600910X.2024.2326448>

9 Ibid.

10 HARAWAY, Donna J. *Staying with the Trouble: Making Kin in the Chthulucene*. Durham: Duke University Press, 2016. p. 12.

ute to our image of the earth”.¹¹ The PPS should be a tool to explore what matters in the infrastructures of planetary phenomena and what “matters” motivates their development. It is based on the Public Stack, also developed by Waag Futurelab, that aims “towards open, democratic and sustainable digital public spaces” by analysing technology’s underlying complexity. PPS functions as a tool for discussion about enviroing technologies and infrastructures that form our planetary imaginaries. From researching conceptual foundations (matterings, concepts, cosmologies) through testing technical capacities (tools, data, skills), it aims to develop new cases of public imaginaries. Throughout the thesis, I use concepts and tools of the PPS to analyse the imagination and development of the digital twin of Earth.

Mattering is rooted in works by scholars like Karen Barad, Bruno Latour, Donna Haraway and Isabelle Stengers, which explore the dynamic processes through which things become significant through their interactions, relations and intra-actions within complex networks.¹² It deconstructs the traditional dichotomy between facts and values and forces us to take responsibility for the kinds of facts we produce and the values they promote. Planetary Public Stack introduces six forms of mattering: matters of fact, matters of control and risk, matters of concern, matters of justice, matters of care, and matters of hope. These help us to recognise the relational, dynamic, and ethical dimensions of the existence of different tools. Here, I investigate and ask *what matters* when we imagine and develop the digital twin of Earth.

The digital twin of Earth is, at its core, grounded in matters of fact - objective data points, scientific measurements, and empirical evidence. The twin is built through the collection of vast amounts of data about physical processes on Earth: atmospheric conditions, wind patterns, ocean currents, temperatures, carbon cycles, and so on. These facts are quantified, measured, and processed into data grids that represent the Earth in increasingly high temporal and spatial resolutions. Simply, the Earth is divided into grids, and its phenomena (wind patterns, ocean currents, temperature) are dissected, processed, archived, and reassembled into the digital twin. As a matter of fact, the Earth is a thing to explain.

This data postproduction is not objective at all - it matters what data are collected, how

11 TURŠIČ, Miha; WAAG FUTURELAB. *Planetary Public Stack* [online]. 2023 [cit. 2025-04-04]. Available from: <https://ars.electronica.art/who-owns-the-truth/en/events/planetary-public-stack/>

12 The idea of *mattering* draws on Karen Barad’s agential realism, where matter is an active participant in meaning-making and world-forming. Bruno Latour calls for a shift from *matters of fact* to *matters of concern*, highlighting the entangled nature of knowledge. Donna Haraway emphasizes *situated knowledges* and relational responsibility, and Isabelle Stengers urges us to rethink how we collectively engage with what is at stake, what is made to matter, and how to resist technocratic fatalism. See: BARAD, Karen. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press, 2007. ISBN 9780822339175.
LATOUR, Bruno. “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern.” *Critical Inquiry*. 2004, vol. 30, no. 2, pp. 225–248. ISSN 0093-1896. DOI: <https://doi.org/10.1086/421123>.
HARAWAY, Donna J. *Staying with the Trouble: Making Kin in the Chthulucene*. Durham: Duke University Press, 2016. ISBN 9780822362142.
STENGERS, Isabelle. *In Catastrophic Times: Resisting the Coming Barbarism*. London: Open Humanities Press, 2015. ISBN 9781607853070.

it is processed, and what is considered factual. Many subjective decisions are made in such a process, and it matters who makes them. Moreover, decisions are made on these data-driven insights, often leaving out lived experiences and other forms of knowledge. The digital twin, built primarily on matters of fact, risks reducing the complexity of the Earth to a manageable set of variables, ignoring the messiness of real-world ecological and social entanglements.

Control and risk are other factors that matter when constructing a digital twin. One of its primary functions is to help manage uncertainties and mitigate risks associated with a changing climate. By simulating future climates, the digital twin becomes a tool for preemptive governance—allowing policymakers, corporations, and states to model different risk scenarios and plan for disaster preparedness, resource allocation, and crisis management. For example, the twin can model the impact of rising sea levels, extreme heat waves, or changing precipitation patterns, enabling authorities to prepare for these eventualities. However, this focus on control and risk obscures deeper structural causes of environmental crises, such as global inequality or the extraction of natural resources.

The matters of concern, initially explained by Latour, are things we care about and debate.¹³ They expand facts with entanglements, values, and stakes that they bring with them, involve ethical and social questions, and reflect a more complex understanding of reality. While the digital twin of Earth brings attention to ecological crises—deforestation, ocean acidification, mass species extinction—it presents these concerns in a detached, abstract way without addressing the root causes. Matters of concern prompt us, instead of taking them as pure facts – +2°C, 1029ppm – to keep asking what this data means for the communities affected by these changes.

Climate change is a justice issue. Its causes, impacts, and responses are uneven, with wealthier Western countries contributing the most to the crisis while marginalized communities bear its worst consequences. The legacies of colonialism, capitalism, and racial inequality shape the unequal distribution of environmental benefits and burdens, deepening existing global injustices. The digital twin of Earth reinforces these power structures through disparities in access to technologies and control over data, such as ownership of satellites and access to surveillance data—tools that determine what is seen, measured, and prioritized. Within the framework of planetary mattering, matters of justice compel us to recognize that climate governance cannot be separated from questions of historical responsibility, equity, and reparations. “*tackling climate change*”¹⁴ requires more than technological solutions; it demands systemic, transformative change and the redistribution of agency and resources.

Matters of care emphasize the relational, affective, and interdependent connections between human and nonhuman life, as articulated by María Puig de la Casa.¹⁵ She calls for

13 Latour, “*Why has critique run out of steam?*”

14 *Destination Earth*, a main initiative behind building the digital twin of Earth and that is discussed throughout this thesis, uses the slogan “Tackle climate change,” reflecting a technocentric framing of planetary challenges. See: European Commission. *Destination Earth* [online]. [cit. 2025-04-04]. Available from: <https://destination-earth.eu/>

15 See: PUIG DE LA BELLACASA, María. *Matters of Care: Speculative Ethics in More Than Human Worlds*. Minneapolis: University of Minnesota Press, 2017. ISBN 9781517900632.

attention to maintenance, dependency, and the overlooked labours and attachments that sustain both human and nonhuman life—challenging technocratic ideals of control and efficiency. Earth’s digital twin operates in efficiency, optimization, and control, sidelining lived experiences, emotional ties, and cultural meanings attached to environments.

All that remains is hope. The digital twin of Earth is an optimistic project but not so much a hopeful one. Its optimism lies in faith in technological progress: better data, finer simulations, faster models. This confidence is grounded in prediction and control—tools for mitigating the crisis, not transforming the systems that produce it. Yet this form of optimism often comes at the expense of hope, which is less about certainty and more about imagination, resistance, and the possibility of otherwise. A hopeful future resists linear progress and invites rupture, speculation, and care. The digital twin of Earth, as currently imagined, functions within frameworks of efficiency, extraction, and computational governance. It rarely leaves room for ambiguity, indeterminacy, or radically different planetary futures. Matters of hope call to imagine alternative, hopeful futures beyond. A hopeful digital twin of Earth could be a platform for speculative design and experimentation with new modes of planetary coexistence.

The notion of mattering here serves as a useful tool for revealing the problematics of Earth’s digital twin. The digital twin of Earth, as imagined by major scientific and commercial institutions now, is based on the idea of Earth as The Globe, constructed primarily through matters of fact, concern, and risk. It is the same conceptualization of the planet based on the logic of control and domination that led to the climate crisis in the first place. The Earth is represented in a flat and detached manner as a resource to be managed, optimized, and exploited. The environment is a dataset to be surveilled.

The various projects of the digital twin of Earth fail to engage with critical and interpretative social sciences. Its ontology is not questioned, and its epistemology is not explored. Mattering serves as one of the frameworks for considering the essential societal aspects of this socio-technical imaginary.¹⁶ The DT projects are based on the underlying metaphor of “nature as a machine,”¹⁷ an out-of-date dream of prediction and control of man over nature that went through deep critique and revision in the 21st century by critical thinkers and scholars across disciplines - including feminist theorists, decolonial philosophers, science and technology studies (STS) scholars, systems theorists, ecologists and cyberneticians.¹⁸ The modern scientific conception of “nature” takes into account interconnectedness, self-organisation, complexity, nonlinearity, emergence, adaptability, and the relational dynamics between human and nonhuman systems. The projects of the

16 SALTELLI, Andrea; GIGERENZER, Gerd; HULME, Mike; KATSIKOPOULOS, Konstantinos V.; MELSEN, Lieke A.; PETERS, Glen P.; PIELKE, Roger; ROBERTSON, Simon; STIRLING, Andy; TAVONI, Massimo; PUY, Arnald. “Bring Digital Twins Back to Earth.” *Wiley Interdisciplinary Reviews: Climate Change* [online]. 26 August 2024 [cit. 2025-04-04]. Vol. 15, no. 6, e915. Available from: <https://doi.org/10.1002/wcc.915>

17 The idea of nature as a machine emerged in early modern science, particularly through thinkers like Descartes and Newton, who framed the natural world as a rational, predictable system governed by mechanical laws. This metaphor underpins many technoscientific projects, including digital twins. Feminist theorists, STS scholars, and decolonial thinkers for obscuring complexity, relationality, and situated knowledge have since challenged it.

18 Saltelli et al., “*Bring Digital Twins Back to Earth.*”

digital twin of Earth ignore this critical shift.¹⁹

III. The twin made thinkable

Twins, mirror-selves, doppelgängers, and doubles have fascinated humanity from ancient mythology to contemporary psychoanalysis. “Twinning” seems to be a significant fascination for humans, leading us to imagine parallel worlds and construct our avatars on social media, deepfakes, and digital twins. Today, humanity’s pursuit of the ultimate twin of the Earth underscores the complexity of our relationship with technology, the planet, and ourselves. This chapter explores the digital twin of Earth as a focal point for ontological, epistemological, ethical, and existential inquiry, unpacking the tensions, aspirations and contradictions in twinning the Earth.

III. I. Setting the mood for twinning

The collective state of mind in the second half of the 20th Century was characterised by a growing obsession with digital replication, simulations, and virtual representations. This fascination was driven by the technological advances in computing, led by cybernetic ideas of systems, feedback loops and control mechanisms. Cybernetics envisioned the world as an interconnected network of machines, humans, and ecosystems, all regulated by flows of information. Reality was understood as information, and the boundaries between humans and machines became blurry.²⁰

Simulations and precursors to digital twins first emerged in aerospace and engineering, motivated by the Space Race. NASA’s Gemini and Apollo programs relied on “twin” replicas of spacecraft to simulate and troubleshoot problems in space. Already using advanced telecommunications technology, it is believed to be the first digital twin²¹. Initially physical, their simulators later evolved into virtual simulations.

In the post-war Cold War era, cybernetics was embraced not just as a technological framework but as a governance and military tool.²² Facing the complexities of global politics, technological competition, and environmental crises, cybernetic ideas inspired strategies such as game theory, early computer models, and simulated scenarios. Initially

19 Ibid.

20 Hayles describes how the boundaries between humans and machines became increasingly blurred through cybernetic discourse, emphasizing that humans and technology are interconnected and mutually defining. She argues that this redefinition shifted perceptions of human identity and embodiment, positioning humans as information-processing entities analogous to computational systems. This convergence challenged traditional distinctions between the organic and mechanical, reshaping what it means to be human. See: N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 1999).

21 Ferguson, Stephen. “Apollo 13: The first digital twin.” *Siemens Blog* [online], 14 April 2020 [cit. 2025-04-02]. Available from: <https://blogs.sw.siemens.com/simcenter/apollo-13-the-first-digital-twin/>.

22 Cybernetics, first articulated by Norbert Wiener, is the interdisciplinary study of regulatory and control processes in biological, technological, and social systems. See Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (1948).

used in nuclear strategies, it laid the ground for the development of digital twins: using simulation to model, predict, and control.

At the same time, the proliferation of television, cinema, and video games sparked a cultural curiosity about representations and simulations of reality. Works like *2001: A Space Odyssey* (1968) captured society's growing engagement with artificial worlds, serving as both a philosophical exploration and a reflection of the era's technological ambitions. The emergence of personal computers and computer graphics further advanced the possibility of creating realistic digital replicas, making the abstract idea of virtual worlds tangible.

Meanwhile, the visible effects of industrialisation and population growth gave rise to environmental awareness and the development of environmental sciences. The environmental movement adopted cybernetic systems thinking to better understand the planet's interconnected ecosystems.²³ Early modern climate models, developed by figures like John von Neumann, used simulations of atmospheric processes, aiming to understand and predict the Earth's future.²⁴ These efforts were early steps towards solving climate change with the digital twin of Earth.

In 1998, US Vice President Al Gore described a digital future for Earth, envisioning access to Earth's multidimensional, multi-scale, multi-temporal, and multilayered visual representation with georeferencing and connection to scientific knowledge.²⁵ Building on an earlier vision of the Geoscope²⁶, a spherical display for geographic phenomena imagined by Buckminster Fuller, it crystallised in contemporary projects like Google Earth and continues to influence our imagination of the digitalised world. Smart cities from Songdo to The Line are offsprings of such ideas.

The first actual articulation of the digital twin technology was in David Gelernter's publication *Mirror Worlds* (1991), where he envisions a mirrored, real-time represented

23 The term *ecosystem* was coined in 1935 by ecologist Arthur Tansley, roughly contemporaneous with the development of cybernetic thought, emphasizing similar concepts of interconnectedness, feedback loops, and self-regulation in natural systems. For a critical perspective, see Tega Brain, who argues that treating the environment strictly as a system oversimplifies its inherent complexity and unpredictability, often leading to inadequate environmental interventions. BRAIN, Tega. "The Environment Is Not a System." *A Peer-Reviewed Journal About RESEARCH VALUES* [online]. 2018, vol. 7, no. 1 [cit. 2025-04-02]. ISSN 2245-7755. Available from: <https://doi.org/10.7146/aprja.v7i1.116062>

24 John von Neumann was instrumental in envisioning the use of digital computers for weather and climate prediction. In the late 1940s and early 1950s, he led one of the first major efforts to apply numerical methods to atmospheric modeling at the Institute for Advanced Study in Princeton. His team developed early simulations of atmospheric dynamics using one of the first programmable electronic computers (the ENIAC), laying the foundation for both numerical weather prediction and later climate modeling. Von Neumann saw these models not only as scientific tools but as strategic instruments for managing large-scale environmental and even geopolitical processes. See: VON NEUMANN, John. "Can We Survive Technology?" *Fortune* [online]. 1955; and EDWARDS, Paul N. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press, 2010. ISBN 9780262290714, esp. Chapter 3.

25 GORE, Al. 1998. "The Digital Earth: Understanding Our Planet in the 21st Century." Speech at the opening of the California Science Center, Los Angeles, CA.

26 Geoscope, proposed by Buckminster Fuller in the 1960s, was supposed to be a 61-meter-big globe with color lights that served as a large spherical display connected to computers to display data.

future to better understand and manipulate complex systems.²⁷ The formal application of the concept in manufacturing is credited to Dr. Michael Grieves. When developing a conceptual model for improving the design, production and operation of products in manufacturing systems, in 2002, he proposed a framework with three core components: physical product, virtual product, and flow of data between them. The actual term “digital twin” was given only in 2010 by John Vickers, a NASA technology strategist.²⁸

The complexities of the modern world, driven by the rapid growth of information enabled by advancing technology and a societal shift toward individualization, created an increasing need to globally organise and visualise data. This process itself has become a feedback loop - technology produces information, and information drives the need for more technology. First, new technologies enable the production and collection of more information. This increase in information created a demand for better tools to organise, analyze and visualise it. In response, more new technologies are being developed that generate even more information. This cycle accelerated the production and management of knowledge at a global scale.

The growing reliance on digital replication and simulation was not without critique. Philosophers such as Martin Heidegger and Jean Baudrillard questioned how these technologies redefine reality, knowledge and truth.²⁹ While digital twins are developed as tools to manage complexity, they also challenge us to consider whether these simulations enhance our connection to reality or risk reducing the world to data-driven abstractions. These critiques, which are explored throughout the thesis, highlight the importance of philosophical reflection on digital replication alongside its practical use.

Together, these cultural, technological, and environmental dynamics planted the seed of digital twins. They represent not only technological progress but also reflections of the era’s desire to understand, predict, and control an increasingly interconnected and uncertain world.

27 GELERTNER, David. *Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox... How It Will Happen and What It Will Mean*. New York: Oxford University Press, 1991. ISBN 9780195079067.

28 See LAWTON, George. “Grieves and Vickers - the history of digital twins.” *Diginomica* [online]. 13 September 2023 [cit. 2025-04-02]. Available from: <https://diginomica.com/grieves-and-vickers-history-digital-twins>

29 Both Martin Heidegger and Jean Baudrillard offer foundational critiques relevant to digital replication. Heidegger, in *The Question Concerning Technology*, warns that modern technology enframes the world as a “standing-reserve” (*Bestand*), reducing beings—including nature and humans—to resources to be ordered and optimized. Baudrillard, in *Simulacra and Simulation*, argues that in the postmodern era, representations can become more real than reality itself—what he terms “hyperreality”—where simulations no longer reflect but replace the real. These perspectives provoke essential questions about whether digital twins and similar technologies deepen our understanding of reality or contribute to its abstraction and commodification. HEIDEGGER, Martin. *The Question Concerning Technology and Other Essays*. Translated by William Lovitt. New York: Harper & Row, 1977. ISBN 0061319694. BAUDRILLARD, Jean. *Simulacra and Simulation*. Translated by Sheila Faria Glaser. Ann Arbor: University of Michigan Press, 1994. ISBN 9780472065219.

III. II. Earth's twins

Finally, what are digital twins? Although there is still no universally accepted definition, they are usually described as having three key interacting components: a physical asset, a virtual model, and data connectivity. A digital twin is a virtual replica of a physical system that is continuously updated with real-time data. Sensors on the physical object quantify and transcribe it into the virtual model that simulates the physical asset. In between, there is a continuous two-way exchange of real-time data, enabling automatic self-modulation and self-updating, permanent management of the digital twin system.

The demand for perpetual optimization is central to today's "smart" digital infrastructures. Systems are expected to address crises by optimizing themselves in real-time, ending up in a cycle of never-ending improvement without a clear endpoint, as Orit Halpern notes in *Smartness Mandate*. It is also this software logic that creates a distinction between digital twins and simulations.

Simulations replicate real-world systems or processes, with one simulation typically studying one particular process. Simulations don't directly link to a physical system through real-time updates. One type of simulation can be climate models. Climate models are mathematical equations to represent Earth's climate system. They use historical scientific data and are based on known physical principles, such as thermodynamics, fluid dynamics, and radiation. Their purpose is to study long-term climate processes and trends.

The term "digital twin" is being used loosely today, and digital twins take multiple different forms in different sectors, which complicates its definition. To understand the defining features of the digital twin (of Earth), I analysed four projects, engaging with their definitions and platforms through conferences and discussions with their developers and scientists. Here, I offer a brief introduction to each of the projects, which will be complemented by more insights throughout the thesis, especially in Part Two: *Aesthetics*, where I describe more precisely how the Earth is sensed and visualised through these projects. I categorize the projects in three cases - initiatives, solutions, and infrastructures - based on their role and scale, whether they operate more on a global or local scale, and whether they are led by corporate or scientific institutions.

III. II. I. Case One: Destination Earth, global scientific policy-driven initiative

European Commission's Destination Earth, launched in 2022, is the leading European initiative for creating a highly-accurate digital replica of Earth, integrating real-time environmental, social and physical data.³⁰ Its purpose is to allow scientists and policymakers to tackle complex environmental challenges by simulating Earth's processes in high resolution. Their initiative is made of three components: virtual environment, data space, and digital twins. DestinE platform is a cloud-based computing infrastructure that provides users with tools, applications and services for evidence-based decision-making. Data Lakes integrates data from different sources (ESA, EUMETSAT, ECMWF, Copernicus, etc.) with data from their digital twins. Destination Earth develops several digital replicas for different aspects of the Earth system based on their advanced high-resolution simula-

30 European Commission. *Destination Earth* [online]. [cit. 2025-04-02]. Available from: <https://destination-earth.eu/>

tions and observations. The first two digital twins are for climate change adaptation and weather-induced extremes. By 2030, they aim to have a “full” digital replica of the Earth.

Destination Earth’s main focus is to provide real-time, actionable insights into climate adaptation, environmental policy, and disaster risk management. Motivated by global challenges such as climate change, natural disasters, and environmental degradation, they provide scientists and policymakers with a tool for scenario testing and predictive analysis. Using high-performance computing (HPC) and AI infrastructure to process and visualise environmental, satellite, and socioeconomic data across multiple scales, it aims for seamless collaboration throughout the system. Dealing with climate change, its main challenges are technical - the integration of diverse datasets and running multiscale simulations requires advanced HPC systems with high computational power.

III. II. II. Case Two: NVIDIA, IBM, tech-company solutions

IBM, which has been at the forefront of developing and implementing digital twin technologies across various industries (manufacturing, healthcare, energy), defines digital twins as dynamic virtual environments for running multiple simulations with a real-time connection to the physical system.³¹ This framing as a “virtual environment” emphasises their interactive and dynamic nature, connecting them more closely with “metaverses” that are being developed in the social media industries. Further, they focus on the implementation of machine learning and reasoning to help make decisions. Its objective is to obtain knowledge and improve the original physical entity by optimising efficiency.

NVIDIA’S Earth-2 is defined as a digital twin of Earth’s climate system, focused on simulating climate phenomena with unprecedented precision using its own computational infrastructure.³² Combining AI, GPU acceleration, physical simulations, and computer graphics, it focuses on simulation and visualization in higher-resolution and interactivity.

III. II. III. Case Three: LTER-LIFE, local scientific infrastructures

A smaller-scale project, LTER-LIFE, is a long-term ecological research initiative that uses digital twin technology to study long-term environmental changes and ecosystem dynamics.³³ Instead of building the ultimate digital twin, they create a virtual research environment (VRE), a cloud-based computing space for data analysis, to support ecologists in developing their own digital twins. Their philosophy takes into account the complexity of the ecosystem and, therefore, aims to provide resources and modules to split workflow and workload in digital twin development. Their definition of a digital twin is closer to the one of models and simulations. With LTER-LIFE, the aim is to standardise data, simplify workflows, and provide infrastructure for simulations for better research of the consequences of climate change on ecosystems.

31 IBM. “What is a digital twin?” [online]. 5 August 2021 [cit. 2025-04-02]. Available from: <https://www.ibm.com/think/topics/what-is-a-digital-twin>

32 NVIDIA. “Earth-2 Platform for Climate Change Modeling” [online]. [cit. 2025-04-02]. Available from: <https://www.nvidia.com/en-us/high-performance-computing/earth-2/>

33 LTER-LIFE. “LTER-LIFE: Towards Building Digital Twins of Ecosystems” [online]. [cit. 2025-04-02]. Available from: <https://lter-life.nl/en/>

III. III. Digital twin of Earth, who are you?

This thesis does not seek to establish a singular, fixed definition of the digital twin of Earth, as I believe such an approach would be both misleading and counterproductive. Instead, I propose a working definition that is situated within the objectives of this research: a digital twin of Earth is a high-resolution computational model that integrates real-time environmental, social, and physical data to simulate, predict, and optimize planetary processes. It functions as both an instrument for data-driven governance and a cultural artefact that reconfigures how we see, feel, and act in relation to climate crises.

The case studies—Destination Earth, IBM, NVIDIA Earth-2, and LTER-LIFE—demonstrate that digital twins are complex systems shaped by technological, political, and epistemic choices. They rely on high-performance computing, AI, and diverse data sources to construct multi-scale, multi-temporal simulations. As models, they are inherently selective, emphasizing certain variables while omitting others. This selectivity raises crucial questions: Do digital twins enhance our understanding of Earth, or do they produce a new, simulated version of it? Are they tools for seeing the invisible? Or are they tools for avoidance “to stay with the trouble”?³⁴

It is important to note here that the full digital twin of Earth is still a speculative figure.³⁵ While advances in computation bring us closer to increasingly detailed models, a complete and total digital replica of Earth, as promised by initiatives like Destination Earth, is unachievable and recently started to be understood as conceptually problematic. For Reinecke, Pianosi, and Wagener (2024), the problem is that all digital representations are inherently models, and none would be able to fully encapsulate the complexity of reality.³⁶ This fact makes it even more urgent for theoretical exploration: what is really aimed for through the digital twin of Earth?

In this thesis, the digital twin of Earth is understood as an evolving process that is as much about representation, perception, and governance as it is about technological precision. This perspective allows for an inquiry not only into how these models function but also into how they shape our relationships with the Earth and its unfolding crises.

34 This reflection echoes Donna Haraway’s call to “stay with the trouble”—to resist the urge to resolve complexity through oversimplification or technofixes, and instead remain engaged with the messiness of real-world entanglements. Haraway critiques escapist narratives and emphasizes the importance of situated, responsible ways of knowing and relating. Applied here, her perspective challenges us to question whether digital twins help us grapple with ecological and planetary crises, or whether they risk replacing lived reality with controllable simulations. See: Haraway, *Staying with the Trouble*.

35 RUBEIS, Giovanni. “Hyperreal Patients. Digital Twins as Simulacra and their impact on clinical heuristics.” In: LOH, Janina; GROTE, Thomas, eds. *Medizin – Technik – Ethik*. Berlin; Heidelberg: Springer, 2023, pp. 193–207. ISBN 9783662658680. Available from: https://doi.org/10.1007/978-3-662-65868-0_10

36 REINECKE, Robert; PIANOSI, Francesca; WAGENER, Thorsten. “How to use the impossible map – Considerations for a rigorous exploration of Digital Twins of the Earth.” *Socio-Environmental Systems Modelling* [online]. 2024, vol. 6, 18786 [cit. 2025-04-02]. ISSN 2397-7140. Available from: <https://doi.org/10.18174/sesmo.18786>

1. TWINNING

The first part of the thesis's trilogy, *Twinning-Aesthetic-Affects*, traces the conceptual and infrastructural lineage through which the digital twin of Earth comes into being. In the gesture of mirroring, simulating, and externalising the Earth, the double is made. It is grounded in the desire to see, model and manage the world. This section follows the evolution of this desire, from tools that extend sensing to infrastructures that simulate global systems. It documents the longer trajectory of technologies that stretch perception and displace knowledge into networked architectures of sensing and control. Through the act of twinning, the new planetary condition begins to take shape.

1. 1. From Extension to Simulation

To discuss the phenomenon of twinning in-depth, I will turn to the philosophy of technology, interrogating the ways in which externalisation, extension, projection, simulation, performance, and partitioning manifest in the ambitious contemporary initiative of the digital twin of Earth and, more broadly, within the practice of doubling in general. Twinning here is not reduced merely to a technical operation but is explored as a comprehensive phenomenon, a new existential mode that arises from our pervasive interactions with digital media and computational tools. This chapter investigates the philosophy of twinning through the lens of media, technology, and simulation theories, tracing a path from the foundational insights of Marshall McLuhan through the concepts of Jean Baudrillard and Bernard Stiegler to the contemporary perspectives of Benjamin Bratton.

Externalisation is the process of taking something internal - like thoughts, perceptions, or qualities - and rendering it visible or tangible outside oneself. As the concept developed across multiple disciplines, from psychology through sociology to cybernetics, externalization has become a classical concept in media studies, framing our understanding of the transformation of communication, memory and social interactions through new media. Novel technologies are following the tradition of written texts, photography, print and sound recording, the means that enable us to express, remember, make real, or make sense of complex topics. Bernard Stiegler describes the externalisation by technics (tools and technologies) as the defining feature of human existence.³⁷ As social structures became more complex, the limitations in human cognitive, social and cultural capacities required adaptation and development of more sophisticated methods to communicate and organise.

Through datafication, we externalize complex systems and dynamics into quantifiable

37 STIEGLER, Bernard. *Technics and Time, 1: The Fault of Epimetheus*. Stanford, CA: Stanford University Press, 1998. ISBN 9780804730419.

data representations. Datafication is a derivative of externalization. It inherently depends on externalized human experience to quantify it and allow for computational manipulation, automation and detailed analysis. The derivative then actively reshapes the way externalisation occurs. For example, social media platforms, influenced by datafication, encourage specific types of behaviour to generate data and create work for algorithmic amplification of commercialisation and monetization.³⁸

The quantification of the self has become a relatable phenomenon in an era where digital identities are carefully curated and performed on social media platforms. As individuals, we selectively externalise our identities and attributes as curated data points. The deliberate selection, organization, and presentation of externalised aspects of the self results in a double that does not necessarily reflect reality but only an idealised or aspirational version that we are back confronted with.³⁹ Moreover, multiple digital shadows and traces are to be managed - “person is not a whole”. This “multiplication of partial simulations” is something intrinsic to contemporary doubling.⁴⁰

Many of our doubles are the result of automatic, unconscious datafication of our traces. For example, artist Trevon Paglen discusses unconscious, unintended externalization by surveillance mechanisms (as movements tracked by cameras) that capture traces of human (and nonhuman) life.⁴¹ Similarly, Hito Steyerl in *Duty-Free Art* explores how the translating of cultural artefacts into data streams makes them susceptible to commodification and erasure and further raises questions about agency, resistance, and the political economy of visibility.⁴² Automation and datafication increasingly take control of externalised processes, leading to Automatic Society (Stiegler) and the shift of power. This new mode of governance by algorithms is further discussed in the next section on planetary-scale computation and governance.

Technologies are also understood, in the tradition of media studies, as “extensions of man”, expanding human capabilities, such as extending vision with telescopes. For McLuhan, the wheel extended the foot, the telescope extended the eye, and electronic media

38 This logic is discussed by Shoshana Zuboff in her analysis of how digital platforms commodify human experience through processes of datafication and behavioral modification. She describes this as a new economic logic where human action is rendered as data for predictive and commercial purposes. See: ZUBOFF, Shoshana. *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*. New York: PublicAffairs, 2019. ISBN 9781610395694.

39 Naomi Klein explores the idea of the *doppelgänger* as a metaphor for the fragmented, curated, and often alienated digital self. In her book, she reflects on how the digital age enables the creation of alternate selves—distorted reflections shaped by algorithms, performance, and ideological mirroring. This curated double can escape our control and act in ways disconnected from our intentions or identity. Klein’s analysis highlights the affective and political dimensions of living with this split self, a theme that will be revisited in Part 3 in relation to emotional entanglements with digital representations. See: KLEIN, Naomi. *Doppelgänger: A Trip into the Mirror World*. New York: Farrar, Straus and Giroux, 2023. ISBN 9780374279290.

40 BRATTON, Benjamin. “Simulations and Doubling.” YouTube [online], 20 February 2022 [cit. 2025-04-02]. Available from: https://www.youtube.com/watch?v=Z0-lj_ACL0U

41 PAGLEN, Trevor. “Invisible Images: Your Pictures Are Looking at You.” *The New Inquiry* [online]. 8 December 2016 [cit. 2025-05-01]. Available from: <https://thenewinquiry.com/invisible-images-your-pictures-are-looking-at-you/>

42 STEYERL, Hito. *Duty Free Art: Art in the Age of Planetary Civil War*. London: Verso, 2017. ISBN 9781786632449.

extended the nervous system.⁴³ Similarly, digital twins extend our ability to perceive and interact with externalized data. The technological and data-driven progress in sciences has allowed us to gaze far away into the depths of black holes, discover the smallest living species, and delve even further into the micro world to observe the invisible realm of quantum mechanics. Much of our scientific knowledge is the result of technological sensing.⁴⁴ In climate sciences, these advancements have made it possible to model and predict the future with increasing precision. The digital twin of Earth is anticipated to further extend our capabilities, enabling weather predictions on a meter-scale resolution to calculate effective strategies for environmental management.⁴⁵

This extension also enhances our ability to interact with and control what has been externalised. Extension and externalisation operate in dynamic feedback loops: the externalisation of environmental data through sensors enables the creation of models that extend our ability to analyse climate systems. These models, in turn, shape how we externalise future data by highlighting previously overlooked variables and relationships. This iterative process is an essential feedback loop in the scientific sense-making.⁴⁶

Throughout, projection plays a crucial role through which we impose interpretations, expectations and meaning onto data. In scientific modelling, projection, serving as an act of externalised sense-making, plays out as assumptions, frameworks, and simplifications become encoded into the data and models themselves—impacting how the world is understood. Projection operates as an active mechanism that creates simulations out of representations, gradually shifting the focus from the original referent to the modelled abstraction. In this way, projection enables what Jean Baudrillard describes as simulacra, where the boundary between the real and its representation blurs, and the simulation becomes a substitute for reality itself.⁴⁷ This process is evident in climate modelling, where projections influence data selection, policy decisions, and public discourse, gradually replacing empirical complexity with an operationalised reality.

43 McLuhan, Marshall. *Understanding Media: The Extensions of Man*. New York: McGraw-Hill, 1964. ISBN 9780262631593.

44 Fuller and Weizman introduce *investigative aesthetics* as a practice where sensing technologies and visual methods are used to uncover and communicate hidden or complex truths. Their work, which links apparatuses to aesthetics and epistemology, is explored further in Part II in the context of sensing and sense-making. See: FULLER, Matthew; WEIZMAN, Eyal. *Investigative Aesthetics: Conflicts and Commons in the Politics of Truth*. London: Verso Books, 2021. ISBN 9781788739085.

45 European Commission. *Destination Earth*.

46 The concept of feedback loops as essential to scientific sense-making originates in cybernetics, where feedback enables systems to self-regulate and adapt. Bruno Latour emphasizes the iterative nature of scientific knowledge production through cycles of inscription and reinterpretation, while N. Katherine Hayles highlights how feedback shapes the co-evolution of human understanding and intelligent systems. These dynamics frame how externalised data and models influence each other in evolving loops of interpretation. See: WIENER, Norbert. *Cybernetics: Or Control and Communication in the Animal and the Machine*. Cambridge, MA: MIT Press, 1948. ISBN 9780262537840.
LATOUR, Bruno; WOOLGAR, Steve. *Laboratory Life: The Construction of Scientific Facts*. Princeton: Princeton University Press, 1986. ISBN 9780691028323.
HAYLES, N. Katherine. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press, 1999. ISBN 9780226321462.

47 Baudrillard, *Simulacra and Simulation*.

Baudrillard presented his theories on simulations in the 1980s, so as Benjamin Bratton explains in his lecture on simulations, “the oscillation between the model and the real is not new.”⁴⁸ However, the interplay between the real and the simulated has evolved significantly with advancements in datafication and computational modelling and the theory of simulations requires updating.

For Bratton, the interaction between the model and the real is not inherently problematic but must be critically examined. “*Simulations do more than represent; they are also active and interactive. “Recursive” Simulations refers to simulations that not only depict the world, but act back upon what they simulate, completing a cybernetic cycle of sensing and governing.*”⁴⁹ Our current condition, which Bratton describes as simulationism, where simulations become part of the governmental apparatus, requires proper theoretical reflection. Otherwise, we have “practice without theory”.⁵⁰

Antikythera, a think-tank led by Bratton, distinguishes between two types of simulations based on their intended purpose in relation to reality. Scientific simulations are designed to model reality with precision, with the intention of getting access to otherwise inaccessible knowledge and acting as extensions of our cognitive capacities. In contrast, VR and social media simulations (Meta, etc.) often prioritise distortion of reality, engagement, spectacle, or subjective experience, leading to the hyperreal world, as Baudrillard conceptualised it. Does the digital twin of Earth challenge this distinction? It embodies a tension: while it is a powerful tool for scientific investigation, enabling predictive modelling of Earth’s systems, its role in shaping real-world policies introduces subjective biases of its creators, potentially transforming it into a hyperreal projection. It is not merely a representation of the planet but an active participant in shaping our understanding and interaction with reality. It reconfigures what we consider significant by emphasizing certain variables while neglecting others.

This twin becomes a projected reality, where the externalized data from sensors, satellites, and other technics is curated and modelled to simulate Earth’s systems in detail. As the simulation grows in complexity and utility, it begins to influence how we perceive and engage with the real Earth. For instance, the predictive capabilities of the twin extend our ability to model future scenarios, but they also introduce a new form of governance, where decisions are increasingly based on the outputs of these simulations. In Baudrillard’s terms, the twin risks becoming a hyperreality—a version of Earth that prioritizes quantifiable metrics and algorithmic outputs over unquantifiable, lived realities, such as cultural or ecological nuances.

To take this further, Benjamin Bratton introduces a new tendency in confronting our twins: the “inverse uncanny valley.”⁵¹ Traditionally, the uncanny valley describes the unsettling feeling we get when confronted with a simulation that seems to be real but is not real enough. The inverse uncanny valley, however, describes the phenomenon of seeing

48 Bratton, “Simulations and Doubling.”

49 Antikythera, Benjamin Bratton’s research think tank, explores how recursive simulations shape the systems they model. See: Antikythera. “Recursive Simulations” [online]. [cit. 2025-04-02]. Available from: <https://research.antikythera.org/#recursive-simulations>.

50 Ibid.

51 Bratton, “Simulations and Doubling.”

ourselves from an external, alien perspective and feeling unsettled—not quite recognizing ourselves. As simulations become more embedded in daily reality, do we risk detaching from “the real” entirely?

This question becomes especially relevant in the context of Earth’s digital twin. By modelling and controlling planetary systems through externalized simulations, do we gradually alienate ourselves from the planet itself? Rather than engaging directly with the world, we interact with its mediated, optimized, and computed double. This concern mirrors broader anxieties about technological mediation, where the tools designed to enhance our understanding may ultimately create a cognitive and experiential gap between us and the phenomena they depict.

By weaving together insights from the philosophy of technology, it becomes evident why digital twins resonate so deeply: they offer us means to see a “better” reality, optimized by human intervention yet fundamentally shaped by the assumptions embedded in its design. This process of optimization encodes specific values of specific developers about what is essential, what should be measured, and what can be acted upon. As digital twins become more integrated into decision-making, their predictive models actively shape governance, influencing political, economic, and environmental policies. The authority of these simulations transforms them from tools of representation into instruments of control. This raises critical questions about agency, power, and the extent to which digital twins construct the very futures they claim to predict. The next chapter explores this new reality of technology: planetary-scale computation and its entanglement with contemporary governance systems.

1. 2. Towards planetary infrastructures

1. 2. 1. Planetary consciousness

The most significant application of massive-scale simulations is in the study of climate change.⁵² Indeed, climate change was not “discovered” through direct human perception but primarily through the very processes of externalization, extension, and projection that technological simulations enable. Climate models have allowed scientists to conceptualize long-term planetary transformations that would otherwise be imperceptible within human lifetimes, fundamentally reshaping how humans perceive the Earth as an interconnected planetary system.

Climatology, as a scientific discipline, evolved significantly from the 17th century onwards. Early observations were rooted in direct human perception, tracking seasonal patterns, weather variations, and atmospheric conditions. Precise climate measurements began with the invention of instruments such as the thermometer and barometer, and the conceptualisation of atmospheric phenomena by scientists including Robert Hooke, Edmund Halley, and John Dalton. Wind patterns, atmospheric pressure and gas behaviours were the first measured phenomena. By the early 19th century, Jean-Baptiste Fourier introduced the foundational idea of the greenhouse effect, suggesting that Earth is a system capable of trapping heat. This notion was further elaborated upon in the late 19th

52 Bratton, “Simulations and Doubling.”

century, with scientists identifying carbon dioxide and water vapour as critical actors shaping global climate.

However, it was not until the mid-20th century, with the emergence of computational modelling, that climate science truly became planetary in scope. Guy Stewart Callendar linked increased CO₂ concentrations from fossil fuel combustion to rising global temperatures. In the 1950s and 1960s, early climate simulations introduced the concept of the “butterfly effect”, which demonstrates that small perturbations in one part of the system can have far-reaching consequences and unpredictable global outcomes. It was a foundational concept in early climate modelling. The advent of computers in the mid-20th century allowed for the creation of sophisticated climate models.

Climate models are computational tools that simulate the Earth’s climate system by computing how energy is absorbed, stored, moved, and released across the planet. They begin with the calculation of Earth’s energy balance - the exchange between incoming solar radiation and outgoing infrared radiation - and simulate how heat moves between the equator and the poles. The most advanced are General Circulation Models (GCMs). Based on physical equations of fluid dynamics, they simulate three-dimensional complex simulations and interactions between the atmosphere, oceans, land, and ice over time. GCMs cut the Earth into a 3D grid, with each cell representing a portion of the planet’s surface, atmosphere, or ocean. Every few minutes of simulated time, the model calculates variables like temperature, humidity, wind, and energy flow at every grid point.

Over time, these models have become increasingly detailed. Modern GCMs include dozens of layers and simulate processes such as cloud formation, ocean circulation, aerosols, albedo, and parts of the carbon cycle. These additions have led to the development of Earth System Models (ESMs), which aim to represent the climate system in its full biological, chemical, and physical complexity. Momentary weather being chaotic, climate models focus on predicting rather long-term patterns. To simulate climate, the models are run for decades or even centuries of simulated time, often beginning in a “spin-up” phase where the model gradually stabilizes into its own internal climate. Once stable, scientists evaluate whether its simulated climate matches real-world observations.⁵³

GCMs and ESMs require massive computing power, contain various parameters for processes that can not be directly observed (like small-scale cloud behaviour) and vary in accuracy across different climate variables. Still, they remain essential for understanding climate dynamics, testing scientific hypotheses, and informing policy decisions about future climate scenarios.

Computational models are essential tools for contemporary climate science, revealing the necessity of viewing Earth as an integrated planetary system rather than a collection of isolated environments. Global view on Earth is further supported by international efforts into standardisation and institutionalization. The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 marked a turning point, systematising climate science globally and reinforcing the idea of planetary-scale governance informed by large-scale models and simulations.

53 For a detailed account of the development and structure of computational climate models, see: Edwards, *A Vast Machine*.

1. 2. 2. Climate Infrastructure

To make sense of the climate, global structures and coordinated efforts are required. Here, I follow researcher Paul N. Edwards and his analysis of climate science as a vast machine, along with Benjamin Bratton's conceptualisation of planetary-scale computation and other theorists of the "planetary", to describe how climate science and technological infrastructure development have shaped each other throughout the 20th and 21st centuries and continue today.

Science and Technology Studies (STS) provides a critical framework for understanding how scientific knowledge, technological systems, and society mutually shape one another.⁵⁴ Rather than viewing science as an objective and neutral endeavour, STS highlights that scientific practices are embedded within broader sociopolitical, economic, and historical contexts. In the case of climate science, the development of sophisticated computational models, satellite observation systems, and global data-sharing infrastructures did not emerge in isolation. These advancements were driven by geopolitical concerns, economic imperatives, and institutional frameworks that sought to standardize and regulate the production of knowledge on a global scale.

Early recognition of climate change as a global threat began gaining prominence in the early 1980s. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established to assess scientific research on climate change, publishing its first report in 1990 and its sixth report in 2023. Throughout, it has established itself as the authoritative source of global climate knowledge and has become a cornerstone for international climate negotiations, shaping policy discussions, and international agreements focused on reducing greenhouse gas emissions and mitigating global warming.

The supporting global climate knowledge infrastructure, which Paul N. Edwards calls a Vast Machine, is dependent on standardisation, institutionalisation and international collaboration. This vast machine - the sociotechnical system comprising people, artefacts, and institutions - generates and maintains a widely shared understanding of weather and climate by collecting, creating, and organising data. As the world came to be understood as a single physical system, the need for global knowledge of weather and climate implemented, for example, universal time coordination (UTC), global telecommunication system (GTS) established by the World Meteorological Organization (WMO), and data homogenisation techniques to standardise climate data from diverse sources. Institutions like the World Meteorological Organization (WMO, founded in 1950) or the Intergovernmental Panel on Climate Change (IPCC, founded in 1988) play critical roles in maintaining standards, facilitating data exchange, and coordinating collaborative research.⁵⁵

The development of these infrastructures was not merely technical but was shaped by global politics. During the Cold War, meteorological collaborations like the Global Atmospheric Research Program (GARP) or international satellite programmes (World Weather

54 Many of the references throughout this thesis are grounded in Science and Technology Studies (STS), which critically examines how scientific knowledge and technological systems are produced and embedded within social, cultural, and political contexts. STS provides a crucial framework for understanding digital twins as socio-technical constructs. See: JASANOFF, Sheila. *The Science and Technology Studies Reader*. London: Routledge, 2008. ISBN 9780415403290.

55 Edwards, *A Vast Machine*.

Watch, by WMO) were partly driven by geopolitical motivations and national security, surveillance, and international influence. Decolonization movements and global economic shifts further impacted how these infrastructures were formed and used, embedding climate knowledge production within complex global power dynamics.

Edwards terms this interconnected and mutually constitutive relationship between data infrastructures and global geopolitics as “infrastructural globalism”, explaining how data infrastructures were made global and how the global world was made by data infrastructures. This history, which was initiated by observing and modelling climate, now underpins fields ranging from international commerce to global governance. Globality needs complex infrastructures, standardizations, and interoperable systems that facilitate the seamless exchange of information, resources, and governance mechanisms on a planetary scale.

Through these processes, globality transformed from an abstract idea into a tangible reality. Complex, standardised, interconnected structures not only enabled the global exchange of scientific knowledge and policy coordination but also redefined the way technological advancements are developed and implemented, specifically to address planetary-scale challenges such as climate change. One process continuously shaped the other, leading to a new reality of planetary technology.

1. 2. 3. Planetary-scale computation

Since McLuhan’s time, technological progress has transformed the nature of technological extensions. They have shifted from being mere prostheses that augment human capabilities to autonomous systems that simulate, predict, and act upon the world, often independently of direct human control. This evolution marks a transition from externalising the mind to forming parallel cognitive and operational infrastructures - what Benjamin Bratton describes as a planetary-scale computation - that mediate the world rather than just reflecting or extending it.⁵⁶ Bratton’s concept of the “stack,” an accidental megastructure of interconnected computer systems, offers detailed analysis and insight into how these systems reconfigure societal, spatial, and political orders, creating new forms of governance and control at a planetary scale.

The Stack operates through layers of technology: Earth, Cloud, City, Address, Interface, and User. The Earth layer consists of the material substrates, such as raw materials, mineral extraction, energy infrastructures, and terrestrial hardware. The Cloud includes data centres, servers, computing platforms, and storage facilities responsible for data processing and management. Constituted by urban spaces, the City layer is where infrastructure and human activity intersect, including smart cities and intelligent infrastructures. Identification systems such as IP addresses and DNS systems constitute the Address. In the Interface, users engage and interact through dashboards and augmented reality systems. Users are humans and non-human actors who interact and are governed by this system.

From satellite networks, fibre-optic cables, and sensors to data centres and software systems, the Stack provides a systematic analysis of planetary computation that enables

56 BRATTON, Benjamin H. *The Stack: On Software and Sovereignty*. Cambridge, MA: MIT Press, 2016. ISBN 9780262029574.

global sensing and management of Earth. As manifestations of the stack we can see digital twins, along with smart cities, social media, and metaverses. All are based on the above-mentioned globally distributed material infrastructures, often forming whole cities, so-called “shadow” or even “ghost cities,” that are made for and occupied by only machines.⁵⁷ As, Bratton explains, today, whole cities are being built to curate and cater for our doubles. Smart urban infrastructures and metaverses that often seem invisible and seamless to us in our surrounding environments actually manifest materially elsewhere, often at the regional shades of anonymous capitals, as whole fields of data centre buildings, cooling systems, and surveillance cameras. These are the places where the digital twin of Earth, together with our digital doubles (avatars), live.

Smart cities reimagine our urban environment by collecting data from citizens, buildings, vehicles, and other objects to manage and operate services. One example of one of the largest private real estate developments in history is the city of Songdo, built by reclaiming land in South Korea, part of the Incheon Free Economic Zone. It was supposed to be a sustainable, high-tech future city without cars, pollution and overcrowded venues, and the technical implementations were successful. However, the developers forgot about people and other citizens, who describe their experience living there as lonely, cold and deserted.⁵⁸

This sad experience of living in a smart city is not at all reflected in the visions. European Commission notes on smart cities: “*A smart city goes beyond the use of digital technologies for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.*”⁵⁹ We can read that smart means upgraded, efficient, interactive, responsive, and safer. Perhaps we forget about a city that is livable.

1. 2. 4. Algorithmic governance

As we shift towards algorithmic governance, operational efficiency, surveillance, and data-driven management, Orit Halpern, in “Smartness Mandate”, critically analyses this logic of “smartness”.⁶⁰ According to her, smartness represents governance characterised by perpetual optimisation, continuous updates, and adaptive responsiveness. Instead of

57 Benjamin Bratton uses the terms *ghost cities* and *shadow cities* to describe aspects of urban environments shaped by planetary computation. *Ghost cities* may function as full-scale, 1:1 models—urban spaces designed as testbeds or optimized environments for machines, logistics, and autonomous systems. *Shadow cities* refer to the hidden layers of computation, regulation, and infrastructure that shape cities from within and below the surface of visibility. See: Bratton, “Simulations and Doubling.”

58 KIM, Heejin. “Songdo, South Korea’s Smartest City, Is Lonely.” *Bloomberg* [online]. 22 June 2018 [cit. 2025-04-02]. Available from: <https://www.bloomberg.com/news/articles/2018-06-22/songdo-south-korea-s-smartest-city-is-lonely>

59 European Commission. “Smart Cities” [online]. [cit. 2025-04-02]. Available from: https://commission.europa.eu/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en

60 HALPERN, Orit; MITCHELL, Robert. *The Smartness Mandate*. Cambridge, MA: MIT Press, 2023. ISBN 9780262544511.

seeking political consensus through discussions and negotiations, smartness constantly manages uncertainty through algorithms and anticipation. This “demo culture”, that is endlessly provisional, always updating, functions as a strategy for postponing political and ethical accountability. These processes do not seek closure or resolution, but instead emphasise flexibility, iteration, and real-time adaptation. This logic of endless testing is further explored in Part 2 on Aesthetics, particularly in relation to how it reshapes our perception of time.

Keller Easterling’s concept of “extrastatecraft” complements this critique by highlighting how modern governance increasingly occurs outside traditional state institutions.⁶¹ According to Easterling, governance today often takes place through logistical arrangements, standardized protocols, and infrastructural design rather than explicit political discourse. As such, systems like smart cities and digital twins embed control mechanisms not through visible policy, but through the very material and operational fabric of daily life. Governance becomes infrastructural, built into the pipes, codes, buildings, and networks that organise our environments.

The digital twin is a particularly vivid manifestation of this infrastructural governance. Designed as a large-scale, high-resolution simulation of the Earth, it enables scenario testing to anticipate and mitigate future environmental crises. But this ambition to know and manage the planet in totality introduces a different mode of political authority. Following Bernard Stiegler’s concept of the “Automatic Society,”⁶² the digital twin automates decision-making about Earth’s systems, shifting power from human deliberation to algorithmic governance. This shift reflects a broader trend in which computational models increasingly dictate policy, resource allocation, and risk management strategies.

As we can see, this shift is deeply political. Scientific simulations of the future are used today to legitimate governing decisions in the present. Bratton sees the prioritisation of governance by large-scale, long-duration simulations of climate as an “attempt to refocus government from the role of mediation of voice (democratic sense), to the administration of ecologies (human or non-human)”⁶³ and terms it simulationism – as a consequent to neoliberalism. The simulation becomes sovereign.

Even technologically, this logic is problematic. As Saltelli et al. argue, the extreme complexity of these models often undermines their effectiveness. In many cases, heuristic strategies - simpler, more intuitive models - often outperform big-data models in modeling dynamic and uncertain situations, such as climate change. Not only can simpler models do a better job, but they are also much easier “to implement and understand, facilitating open and constructive deliberations among policy-makers and citizens and reinforcing democracy.”⁶⁴ In this way, heuristic approaches can strengthen democratic processes at precisely this troubling moment when they are being bypassed by algorithmic governance.

Ironically, the very systems designed to manage planetary complexity often end up

61 EASTERLING, Keller. *Extrastatecraft: The Power of Infrastructure Space*. London: Verso Books, 2014. ISBN 9781781685877.

62 STIEGLER, Bernard. *Automatic Society, Volume 1: The Future of Work*. Translated by Daniel Ross. Cambridge: Polity Press, 2016. ISBN 9781509506309.

63 Bratton, “Simulations and Doubling.”

64 SALTELLI, et al., “Bring Digital Twins Back to Earth.”

oversimplifying it. The digital twin tends to perform the Earth as a knowable, measurable, governable system flattening diverse epistemologies into technocratic abstraction. As a result, it privileges managerial perspectives over more nuanced, local, relational, or Indigenous ways of understanding environmental change. Complexity becomes something to control rather than live with.

Together, the concepts of the Stack, smartness, and extrastatecraft provide a critical, theoretical framework for understanding how smart “twin” systems alter the relationship between technology, governance, and society. They highlight how these infrastructures construct a new planetary reality.

1. 2. 5. Planetarity

Technologies converge with global governance and philosophy through planetary-scale computation, as articulated by philosopher Yuk Hui. Hui is a contemporary philosopher of technology, and his latest work, “Machine and Sovereignty: for planetary thinking”, seeks to create philosophy for the planetary - an effort central to many, including Bratton.⁶⁵ For both Bratton and Hui, technology actively governs life, social systems and thought. Technology structures the world, determining what is visible and enabling or constraining certain actions. Technology also structures our thoughts, and as Bratton claims, we are way behind with our theory and reflection on how our world is changing in such a context.⁶⁶ As he claims: “*Human agency exceeds human wisdom*,”⁶⁷ the process of building a digital twin of Earth calls for a different philosophical framework before its implementation.

What is important for this thesis is the new reality of technology—described by concepts of computational sovereignty, technophilosophy, and planetary-scale computation—and the limited reflection with which we introduce new technologies into reality. While promising attractive scenarios, they are often based on the distorted realities these technologies produce. The imaginations and desires that fuel the development of a digital twin of Earth are progressing in parallel with technologies and the growth of their interconnected infrastructures. In the age of digital twins, we cannot base our analysis only on 20th-century theory, as technology progressed from “mere objects to interact with” to autonomously interacting ecosystems.

Coming back to the frameworks of this thesis, this chapter has shown how the digital twin is entangled with matters of fact, risk, and control—but it is within the neglected dimensions of care, justice, and hope that its political potential must be re-evaluated. These neglected forms of mattering invite us to question not only the epistemological foundations of the twin but also its ontological assumptions: Who defines the Earth that is being twinned? Whose futures are modelled, and whose are ignored?

Applying the mattering framework makes it clear that the digital twin does not only describe the world, it configures it. It performs a particular Earth: legible, optimized, and administratively coherent. But in doing so, it risks foreclosing other Earths, those that are

65 HUI, Yuk. *Machine and Sovereignty: For a Planetary Thinking*. Minneapolis: University of Minnesota Press, 2024. ISBN 9781517917418.

66 Antikythera. “Research Overview” [online]. [cit. 2025-04-02]. Available from: <https://research.antikythera.org/>

67 Ibid.

lived, felt, contested, and cared for. To imagine otherwise, we must ask not just how we design for the Earth but which Earth we allow to matter.

This opens a crucial line of inquiry for the next part of this thesis: if the twin is a performative act, how does it sense and make sense of the planet? What aesthetic and perceptual regimes does it rely on, and how do these shape the ways we come to know and not know the Earth? Moving from infrastructures and governance to the realm of visibility, representation, and affect, the next chapter turns to the aesthetics of planetary sensing and the politics of computational perception.

2. AESTHETICS

The first part of this thesis explored twinning as a way of mirroring, projecting, and externalising, as an act of simulation through which Earth is rendered computationally knowable and manipulable. The digital twin of Earth is more than just a technical object; it is a system of perception, a machine of sense-making, translating planetary processes into data, images, and interactive environments. This part focuses on aesthetics, not only as “making beautiful” but as a process of sensing and structuring knowledge.

I draw on the work of Eyal Weizman and Matthew Fuller, who expand aesthetics beyond human perception, incorporating the sensing capacities of machines, digital infrastructures, and planetary-scale computation. “*To aestheticise something ... [is] to render it more attuned to sensing,*”⁶⁸ and involves both sensing - detecting and registering phenomena, and sense-making - turning those registrations into knowledge. The digital twin of Earth operates as a planetary-scale sensing system, with data flowing through satellites, climate sensors, computational models, and interactive simulations, transforming planetary processes into structured, visualised, and governable objects.

Specific epistemologies, technological infrastructures, politics and design choices shape the way Earth is sensed, processed, and visualised through the digital twin. What is measured, and what is left out? What is visualised, and what remains invisible? As the digital twin of Earth increasingly entangles into governance, it is necessary to investigate the ways it aestheticises Earth in both ways - how the technological apparatus senses Earth and how it makes it “sensible” - sense-able, Earth becoming a sensor.

This second part centres around three interrelated aesthetic regimes through which the digital twin of Earth is constructed and experienced. Each regime speaks to a particular mode of mediation in how the Earth is sensed, rendered, and interfaced, and together, they reveal the layered infrastructures and perceptual logics that govern planetary simulation.

First, I examine its material sensibilities, the planetary-scale sensory apparatus of satellites, climate monitoring systems, and data networks that track and transcribe planetary processes. It investigates the material objects - orbiting satellites, undersea cables, radio waves, and their material implications - emissions, air pollution, space waste, extracted landscapes, et cetera. The digital twin of Earth is made perceptible through this architecture of measurement.

Second, I research its computational rendering, the algorithms and models that process the signal stream, recognise patterns, visualise planetary changes and simulate futures. This section considers the epistemological aesthetics of computational vision. What becomes visible and what does not is shaped through layers of code, calibration and design.

68 Fuller and Weizman, *Investigative Aesthetics*, p. 33.

Here, Earth becomes an image, a model, a simulation.

The third chapter moves to the interface, the front end, tracing how the digital twin is accessed, explored, and interacted with. The Destination Earth platform is navigated through here, following the ways in which the planet is presented as a scrollable, zoomable, modular environment. This chapter investigates how interface logics organize perception and transform Earth into a game-like, programmable space.

Though presented in three sections, sensing, rendering, and interfacing modalities do not function discretely. In practice, they are deeply entangled. How we visualise climate patterns depends on how we sense them, and how we interact with models reshapes what gets sensed in the first place. This structure reflects how digital twins themselves are often designed, through the layered architecture of data input, processing, and interface output. Yet, it also draws attention to the limitations of this triadic model. As Laura Tripaldi argues in *Parallel Minds*, reducing intelligence to human-like cognition obscures other ways of sensing, responding, and organising knowledge.⁶⁹ In reality, perception, processing, and interaction are entangled, occurring across multiple scales and agencies, human, nonhuman, and machinic.

This section explores how aesthetics shape what is sensed, what is visualised, and how we interact with the digital twin of Earth. The next sections first analyse specific aesthetic mechanisms before delving into examining the historical transformation of planetary perception—from the Blue Marble photograph, through satellite imagery, to the algorithmic optics of the digital twin. In this part, I find it necessary to understand how vision itself has been transformed—how planetary knowledge has shifted from direct observation to computational perception, from seeing Earth to processing it as data.

2. 1. The Earth measured: material sensing

2. 1. 1. Sensing Earth

Aesthetics, etymologically, pertains to aisthesis - sensory perception, the act of sensing the world. Before being concerned with beauty or subjective taste, it covers how sensory perception is structured and enabled. Perception requires a body; there is no such thing as thought without a material medium.⁷⁰ Today, this body is a hybrid, extended through vast planetary-scale infrastructures. The distributed machinic body of the digital twin spans from satellite constellations in orbit to deep-sea cables, seismic sensors, and atmospheric monitoring sensors. It is through this material infrastructure that the planet is rendered

69 Laura Tripaldi is a materials scientist and writer whose book *Parallel Minds* explores intelligence beyond human cognition, drawing from biology, chemistry, and nanotechnology to question dominant metaphors of mind and machine. See: TRIPALDI, Laura. *Parallel Minds: Discovering the Intelligence of Materials*. Translated by Heather McRae. London: Urbanomic, 2022. ISBN 9781913029948.

70 N. Katherine Hayles, a foundational thinker in posthuman theory, argues that information cannot exist without a material substrate—a direct challenge to disembodied conceptions of data and cognition. In *How We Became Posthuman*, she critiques the separation of mind from body in cybernetics and proposes that embodiment and materiality are essential to understanding information, subjectivity, and intelligence. See: Hayles, *How We Became Posthuman*.

visible and measurable - transduced into data. The aesthetics of the digital twin begin in the material conditions and technical architectures that make technological sensing possible. This section explores how this sensing body operates, how it extends perception beyond human capacities, and how it constructs a new mode of spectral, computational planetary aisthesis.

Weizman and Fuller, and their investigative aesthetics, recognize two extreme modes of aesthetics: hyper-aesthetics and hyperaesthesia.⁷¹ Hyper-aesthetics refers to the magnification and expansion of aestheticisation. New sensing technologies are designed to sense in a way unimaginable for humans. The massive networks of sensors are attuned to fractions of milliseconds, as in CERN particle colliders, which sense the collisions of particles, and to electromagnetic signals from more than 50 million light-years away, such as the Event Horizon Telescope (EHT), that captured the black hole. With the EHT, the whole Earth has become a sensor.⁷² This heightened mode of sensing emerges even more in entire complex networks of monitoring, counting and measuring devices, from digital greenhouses through smart cities to the digital twin of Earth.

This complex hyper-aestheticized network of the digital twin of Earth includes satellites occupying orbits around Earth and measuring nearly every pixel of Earth in increasingly higher spatial and temporal resolutions. Satellite constellations are the most important actor in climate science. National (NASA, ESA) and private (SpaceX, Planet) companies lead Earth Observation programmes, releasing more and more satellites every year, with nearly 12000 active objects orbiting the Earth as of March 2025.⁷³

The process of launching satellites into space involves rocket ignition, staging, and orbital insertion, a precisely timed and planned choreography that presents this cultural event of the technological sublime. After leaving the Earth's atmosphere, the First Stage, which provides the initial force, detaches and falls back down to Earth. Once the rocket reaches space, the satellites are exposed, and the Second Stage performs the final push to place the satellite into orbit. The Second Stage disposes itself as debris in the "graveyard orbit", a retired rocket heaven.

Satellites are equipped with various sensors, each sensing different parts of the electromagnetic spectrum in various spatial and temporal resolutions. Passive hyperspectral sensors collect hundreds of narrow, contiguous spectral bands to identify objects and materials based on their "spectral signatures". It is a technique to see beyond the "visible light" (meaning "visible" to humans). In Earth Observation, it is used to detect ecological degradation by detecting the chlorophyll content of plants or the composition of the soil. Other optical sensors capture reflected sunlight in the visible and near-infrared bands or detect thermal radiation emitted by surfaces.

Active sensors on satellites emit energy and measure response, with the agency to

71 Eyal Weizman and Matthew Fuller propose *investigative aesthetics* as a method that combines artistic, technological, and scientific practices to expose systems of power and violence. Rather than seeking objectivity, it embraces situated, evidentiary practices that make the invisible visible. Their work is discussed in more detail later in the thesis. See: Fuller and Weizman, *Investigative Aesthetics*.

72 Halpern and Mitchell, *The Smartness Mandate*.

73 Orbiting Now. "Active Satellite Orbit Data" [online]. [cit. 2025-04-04]. Available from: <https://orbiting-now.com/>

function independently of sunlight or weather. They are used to map the terrain, ground deformation, ice movement, floods or for military surveillance. Radars and Lidars illuminate the Earth, seeing through the clouds and detecting at night, giving us information about the changing topography of the planet.

Satellite sensing operates through the interaction between electromagnetic energy and matter, detecting physical light's reflections, emissions, responses and traces. It uses specialised optical materials, such as germanium, silicon, and indium antimonide, that can detect particular wavelengths. Satellite imagery begins with radiation, reflected or emitted energy, that gets encoded as raw data representing signal intensity per pixel, per spectral band. As a stream of electrical signals, it gets structured and geo-tagged in the satellite and travels via radio frequencies to the ground stations and further data processing centres, where it gets decoded on different levels. Such a data stream does not make much sense for a human being - it is a language for machines.

2. 1. 2. Data lands

Orbiting high above the surface of the Earth, the vast satellite constellations have begun to form what could be described as the exoskeleton of the Earth. Almost biblically, the body of the digital twin of Earth materialises from the Earth's own soils, rocks, minerals and waters, extending the Earth's lithosphere into the technosphere. The rising accumulation of orbital machinery and debris creates whole landscapes of fractured antennas, broken solar panels, and fragments moving at hypersonic speeds. The weight of all the debris circling the Earth is calculated to be more than 9500 tonnes.⁷⁴

Another sensor infrastructure extends downward in the Earth's soils, beneath forests, deserts, and oceans, measuring seismic activity, groundwater levels, and soil compositions. Networks of smart agricultural systems and underground fibre optic cables all contribute to the sensory fields of digital twins.

This material body of planetary sensing and sense-making relies on the extractive geopolitical economies of lithium, cobalt, copper, and silicon. Rare earths are harvested through mining operations that scar Earth's landscapes, produce toxicities, and displace more-than-human communities. The sensing infrastructure matters materially.

The data that the digital twin of Earth produces must be stored and processed. The space where all this happens is often called the cloud. It is a curious name, as it implies immateriality and evanescence, as it is a higher space that does not take physical space. In the early years of the Internet, the tech industry explaining this mysterious networking infrastructure used the icon of a cloud in their technical diagrams, as it represented its distributed, borderless quality. Nowadays, it is a widely used term for servers accessed through the internet; however, it does not represent the reality of the Internet very well.

The very real architectures of hyperdata centres are storing huge amounts of data all over the world. The big buildings filled with sensors, cooling systems, and electricity generators consume enormous amounts of energy and water, producing heat, noise, light, and emissions. Aesthetically, they're interesting places: whole fields of visually banal block buildings, often painted in "neutral" greens and greys to blend with the surrounding

74 EUROPEAN SPACE AGENCY. "About Space Debris" [online]. [cit. 2025-04-04]. Available from: https://www.esa.int/Space_Safety/Space_Debris/About_space_debris

“nature”, with intense security lights and cameras, surrounded by high fences, and accompanied by rumbling low-frequency sound. Inside, there are sterile corridors stacked with perfectly lined servers, thousands of colourful blinking lights, and thousands of perfectly organised cables. Artists Niels Schrader and Roel Backaert document these data centre facilities in the Netherlands in their research project Acid Clouds, questioning “*the image of “the cloud” as clean, sterile and environmentally-friendly domain*”.⁷⁵

These data lands, in addition to producing material pollution, also embody the societal problem of digital pollution. How much data do we actually need? With the idea that cloud-based data storage can be unlimited, we started to datafy everything. The total amount of data in 2024 was 149 zettabytes, and information overload started to saturate not only servers and storage facilities but also human cognition.⁷⁶

2. 1. 3. Beautiful Anthropocene

Photographs of lands in destruction (mines, factories, burning forests) have become the iconography of the Anthropocene—a geological epoch of anthropogenic mass extinction named by Paul Crutzen in 2000 and discussed many times since.⁷⁷ Edward Burtynsky is one of the leading photographers of such sceneries - large-scale images of landscapes altered by industry are presented in projects like “The Anthropocene Project”, a cinematic and interactive visual work created together with filmmakers Jennifer Baichval and Nicholas de Pencier.⁷⁸ In their Gigapixel Essays, they present photographs of three locations - the forest of British Columbia, dense settlements in Lagos, Nigeria, and marble quarries in Italian Carrara - in high resolution, allowing the viewer to zoom in for details and locate special hidden content about terraforming, urbanisation and resource extraction.

Visually stunning, these compositions, together with other aesthetically pleasing representations of anthropogenic destruction, are being questioned by art historian T. J. Demos in *Against the Anthropocene* for the lack of political and ethical considerations.⁷⁹ Consumed as high-art commodities in galleries and museums, they introduce a paradox where images of destruction become luxury items, reinforcing the very structures responsible for environmental devastation.

75 SCHRADER, Niels; BACKAERT, Roel. “Acid Clouds” [online]. [cit. 2025-04-04]. Available from: <https://acidcloud.org/>

76 IDC; Statista; Various sources. “Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2023, with forecasts from 2024 to 2028 (in zettabytes)” [online]. May 31, 2024 [cit. 2025-04-04]. Available from: <https://www.statista.com/statistics/871513/worldwide-data-created/>

77 CRUTZEN, Paul J. “The Anthropocene.” *Global Change Newsletter* [online]. 2000, no. 41, pp. 17–18 [cit. 2025-04-04]. Available from: <https://www.igbp.net/download/18.316f18321323470177580001401/1376383088452/NL41.pdf>

78 BURTYSKY, Edward; BAICHVAL, Jennifer; DE PENCIER, Nicholas. “The Anthropocene Project” [online]. [cit. 2025-04-04]. Available from: <https://theanthropocene.org/>

79 DEMOS, T.J. *Against the Anthropocene: Visual Culture and Environment Today*. Berlin: Sternberg Press, 2017. ISBN 9783956792106.

2. 1. 4. Destination Earth's body

Destination Earth (DestinE), a leading project in the development of Earth's digital twin, was briefly introduced at the beginning of the thesis. Here, I follow more closely the material infrastructure it is based on. One of the core inputs comes from Copernicus, the EU's Earth Observation Programme. It operates a large family of missions called the Sentinels, constellations of different satellites, each designed to observe specific features of the planet. All sentinel satellites produce open-access data.

The data is downloaded to ground stations, processed in Copernicus hubs and stored in data lakes, eventually feeding into the computation of climate models. The DestinE Data Lake is managed by the European Centre for Medium-Range Weather Forecast (ECMWF). It stores a wide range of data types, including observational data such as the Copernicus Sentinel satellite data, in-situ measurements from ground-based sensors, ocean buoys and weather stations, and modelled data from climate reanalysis, simulations and forecasting. Some of the major supporting facilities include the ECMWF's Bologna data centre, one of the most powerful weather and climate computing hubs in Europe. The cloud architecture of the Data Lake follows the FAIR principle: findable, accessible, interoperable, and reusable - ensuring accessibility for researchers, public institutions and AI systems. Access to the data lake is provided by APIs and portals connected to the Core Service Platform, which acts as the user interface layer.

We are confronted with the aesthetics of the digital twin on two levels: first, as a material project that consumes land, energy, and labour, and second, as a sensing body that extends our perceptual reach beyond human limits. It sees what we cannot: chlorophyll from orbit, atmospheric methane from space, and soil moisture from buried cables. But what kind of vision is this? As the focus of this thesis shifts from the hardware of sense to the software of sense-making, we follow the data into its processing, visualisation, and interpretation.

2. 2. The Earth composed: computational rendering

2. 2. 1. Seeing the Earth through its twin

Making sense of what the hardware body has sensed is the act of computation. Computation structures knowledge by processing raw data, recognising patterns, simulating and modelling, and increasingly making decisions without human intervention. The first-level data, streams of numbers and signals, often still do not make sense to humans. To bridge this gap, we rely on visualization. This chapter focuses on the algorithmic aesthetics of the twin: the processes that render the Earth into images, graphs, maps, and models.

To see the Earth through its digital twin is to see an Earth translated, rendered and composed through processes of computation - it is not a photograph, or live feed, but a simulation, smoothly rotating, animated globe textured with data. The visualization is the result of many hidden layers of sensing, correction, calculation, and design. The globe is covered in colour gradients - shades of blue, purple, red, and green - indicating simulated heatwaves or precipitation. Other layers of coloured gradients can show wind speed, sea ice thickness, or carbon concentrations. It is a visual language of the vast Earth's condi-

tions shifting over decades.

Climate change is often described as “invisible.” Its causes are distributed, its effects are delayed, and its processes operate across scales and timeframes that are impossible to perceive. Yet, we live within it, experience its changes, and weather effects. Data visualisation becomes essential to make microscopic particles, atmospheric patterns, glacial movements, and ocean currents visible and actionable. The visual outputs, such as maps, heat maps, wind patterns, and satellite views, are the results of a technical chain of processing and translation.

2. 2. 2. Spectral aesthetics

The stream of electrical information produced by satellites, whose materiality we have been following in the previous chapter, becomes an image through data processing. First, the raw data must be cleaned, corrected, and structured into meaningful data. The first process is a radiometric correction to adjust for sensor noise and differences in light conditions. Next, the data needs to be aligned with map coordinates through geometric correction.

The scanning of the Earth has a spatial and temporal quality - as satellites moves in orbital patterns around the globe, they scans it in tiles, captured one by one, mosaicked and stitched together into a composite of (almost) the whole planet. Each pass of satellites captures only a narrow strip of Earth’s surface, and it takes multiple orbits, often over several days, to piece together a whole Earth. The same locations are scanned repeatedly over time, depending on the mission’s temporal resolution to allow for tracking changes across time.

An important part of processing is cloud masking, which identifies and removes cloud-covered areas. The masking is done using algorithmic detection and spectral analysis. Images from different days or weeks are layered, replacing cloud-covered areas with “clear” pixels from another time. The synthetic, cloud-free composite never actually existed in a single moment. Next to multi-temporal compositing, SWIR composites are used to identify clouds, and machine learning models classify them and remove them. But why do climate scientists delete clouds? Clouds are a natural part of Earth’s atmosphere, yet in remote sensing, they are seen as interference that prevents a “clear” and “useful” view of the ground. The paradox is that clouds are essential to climate science. They regulate temperature, precipitation, and atmospheric circulation. However, their instability and disorganisation make them difficult to study by science organised by stability, predictability and legibility, and therefore they’re removed.

Satellites capture Earth’s landscapes by sensing the individual bands of the electromagnetic spectrum. While humans see only the “visible light,” which contains a narrow range of red, green, and blue wavelengths, satellites capture multiplicities far beyond what we can perceive, including infrared, microwave, and ultraviolet. These additional bands allow us to see what is otherwise “invisible”, revealing information about vegetation health, soil moisture, atmospheric gases, and the chemical composition of the Earth’s surface. In satellite images, these spectral bands are combined based on the goal of the analysis. The same landscape can look dramatically different depending on the band combination used—revealing layers of reality that would otherwise be imperceptible. True Color Composite, the closest representation to human vision, combines visible red, green and blue

bands. It can be used for urban mapping, detecting water bodies, and general landscape observations. False Color Composite replaces blue with near-infrared (NIR) band, which causes vegetation to appear bright red, as healthy plants reflect large amounts of NIR light. Moisture levels are detected by Shortwave Infrared (SWIR) Composites, and heat radiation by Thermal Infrared (TIR) Imaging.

Hyperspectral imaging parses the Earth into hundreds of spectral bands, enabling machines to identify materials by their chemical signature. What emerges is not an image in the conventional sense but a spectral map, a matrix of signals where each pixel is a data point rather than a colour or contour. Much of what the digital twin “sees” is never meant for human vision.

Artist and theoretician Trevor Paglen writes about this reality of images produced by machines, for machines, outside of human perception or aesthetic experience. Such “invisible images” – arrays of numbers, spectral signatures, pixel grids, temporal indices – are not made to be looked at by people, but to perform a function within a machine system: identification, targeting, classification, prediction.⁸⁰ The digital twin of Earth relies heavily on this infrastructure of machine vision.

Most of the sensed spectral bands are outside the range of human vision. Infrared, shortwave infrared (SWIR), and thermal infrared (TIR) wavelengths cannot be seen by the human eye. To make this data usable in visual form, these non-visible wavelengths are shifted into the visible spectrum, assigned to red, green, or blue channels so they can be rendered as color composites. The digital twin relies on this process of spectral substitution, turning non-human sensing into visual language, further entangling machine vision with human comprehension.

2. 2. 3. Objective disguise

The aesthetic regime within which the digital twin operates is grounded in scientific abstraction and visual minimalism. Its visual language is both diagrammatic and generative, using graphics not only to depict data, but to produce a specific view. Colour is their most immediate communicative tool: precipitation gradients shift from deep blue to soft violet; sea ice thickness ranges from black to pale cyan; wind speeds ripple across the globe in bands of orange, pink, and yellow. There is a kind of semantic grammar at play: blue to red gradients are used to communicate heat and urgency, purples and cool blues signal calm or emptiness, and saturated neon tones indicate anomalies and edge conditions. Though each colour corresponds to a specific data value, they also carry affects, encoding emotional resonance into numerical precision.

This language draws from a longer visual tradition of scientific imaging, described by Peter Galison and Lorraine Daston in *Objectivity*.⁸¹ In the 19th century, with new scientific tools, the ideal of mechanical objectivity emerged in response to anxiety about subjective judgement. Scientists turned to photography and machine-produced images as more truthful alternatives to human-drawn illustrations. Over time, this was supplemented by what they call trained judgement, when we recognized that trained judgement

80 Paglen, “Invisible Images.”

81 DASTON, Lorraine; GALISON, Peter. *Objectivity*. New York: Zone Books, 2007. ISBN 9781890951788.

is still needed, especially when dealing with complex, layered or noisy data.

The digital twin exists at their convergence. It promises neutrality through automation—satellite feeds, model outputs, algorithmic corrections—yet it also depends on interpretive decisions about what to visualize, what to remove, and how to display it.

As visual theoretician Johanna Drucker argues in *Graphesis*, data does not have an inherent visual form. “*Most information visualizations*” she writes, “*are acts of interpretation masquerading as presentation. In other words, they are images that act as if they are just showing us what is, but in actuality, they are arguments made in graphical form.*”⁸² Information visualizations produce meaning through layout, shape, colour, rhythm, and clarity. Climate maps, heat gradients, and simulations on platforms like DestinE pretend to show reality, but actually perform a persuasive function.

Drucker continues: “*the primary effect of visual forms of knowledge production in any medium—the codex book, digital interface, information visualizations, virtual renderings, or screen displays—is to mask the very fact of their visibility, to render invisible the very means through which they function as argument.*”⁸³ In the digital twin this invisibility takes the form of seamless overlays, smooth transitions, or seemingly objective colour harmonies. The twin disguises itself as Earth, trying to hide what it actually is. The world is translated into numbers, and those numbers into graphics that appear to show what is happening, when in fact, they encode decisions about what matters (and what doesn’t): erasing clouds, flattening uncertainty, reinforcing borders, and what is measurable.

The result is a seemingly neutral image, which clarity, smoothness, and harmony carry a certain seductive aesthetic pleasure. The looping flows of simulated wind, the radiant colour scales of heat maps, the elegance of movement: they are tools of attraction. Never before have a disaster look so beautiful. Instead of the chaos of climate breakdown, and information overload we get lulled by balanced compositions of smooth, colourful gradient flows. Here, scientific visualization crosses into the realm of the sublime, not the natural sublime of mountains and storms, but a data sublime.

2. 2. 4. Data sublime

The visual pleasure is not incidental - it is often explicit part of how data is crafted and shared. Scientific visualizations require decisions about colour, contrast, composition and style. A striking example of how deeply traditional aesthetic judgement is embedded in these technical processes is the Sentinel Hub Custom Script Homage to Mondrian⁸⁴. In the Sentinel hub competition scientists are invited to process Sentinel satellite data and submit new algorithmic visualizations. Homage to Mondrian Sentinel-2 script mimics the style of Dutch modernist painter Piet Mondrian. In this script, the Earth’s surface is rendered in red, blue, and yellow squares. This view of Earth as a canvas is generated by the same algorithmic logic as scientific visualisations, by data processing scripts, combining spec-

82 DRUCKER, Johanna. *Graphesis: Visual Forms of Knowledge Production*. Cambridge, MA: Harvard University Press, 2014. ISBN 9780674724938.

83 Ibid.

84 PINTAR, Matevž. “Homage to Mondrian Script.” Sentinel Hub Custom Scripts [online]. 2018 [cit. 2025-05-01]. Available from: https://custom-scripts.sentinel-hub.com/custom-scripts/sentinel-2/homage_to_mondrian/

tral bands, applying filters, and using contrast-enhancement techniques.

The aesthetics of data visualisations, in the form of lines, gradients, geometric shapes, and particle simulations in the carefully curated colour palettes and compositions have become the new medium for experiencing the sublime, a feeling traditionally associated with the overwhelming natural phenomena that evoke awe and wonder. This “data sublime” can elicit feelings of astonishment and insignificance by revealing the vastness and intricacy of the information, leading to an appreciation of the magnitude of data.

Through the digital twin the viewer is placed in an elevated, almost omniscient position able to glide across the planet, observe its transformations, and toggle between timelines. This is a new kind of sublime: not one of being overwhelmed, but of being elevated above, above complexity, above the mess of lived experience, floating in a cloud of beautifully managed information.

Immense in scale and seductively beautiful, the data sublime also permeated the art world. Artists like Refik Anadol create generative works using massive datasets and machine-learning algorithms to produce immersive digital environments. As noted in e-flux’s critique of Unsupervised, Anadol’s work “*makes the viewer feel technologically awestruck without ever demanding critical engagement*.”⁸⁵ Data is turned into a spectacle—its algorithmic operations and political implications are obscured by visual effects.

Just as in Burtynsky’s “The Anthropocene Project,” these aesthetically pleasing data representations of environmental destruction may inadvertently desensitise viewers or commodify the depicted crises. The proliferation of such data-driven aesthetics shapes not only how we see the Earth, but also how we think about it, guiding our perceptions, shaping our decisions, and influencing political imaginaries. The same visual systems that render the climate crisis legible through elegant gradients, loops, and glowing overlays also set boundaries around what can be seen, and how.

The same structures that make the Earth appear smooth, continuous, and controllable also conceal its fractures, glitches, and blind spots. For every data stream and simulation, there is a shadow, an area of low resolution, a process too complex to code, a lived experience that resists being visualized. In the aesthetic regime of the digital twin, invisibility is not incidental but is designed through omission, erasure, simplification, or aesthetic smoothing. To understand what the twin reveals, we must also attend to what it refuses, distorts, or simply cannot show.

2.2.5. Invisibility

In the digital twin, as in most satellite-based systems, visibility is tied to resolution, a technical threshold that determines what can be seen, with what level of detail, and how often. Some areas of the planet are scanned at ultra-high resolution, with updates measured in days or even hours. Others remain blurry, infrequently updated, or missing altogether. The poles, vast oceanic regions, and much of the Global South exist in lower fidelity, not due to technological limits alone, but to geopolitical and economic priorities embedded in Earth observation infrastructures. Yet, in the Blue Marble image – the foun-

85 LOSSIN, R.H. “Refik Anadol’s “Unsupervised.”” *e-flux Criticism* [online]. March 14, 2023 [cit. 2025-04-04]. Available from: <https://www.e-flux.com/criticism/527236/refik-anadol-s-unsupervised>

dational image of Earth from space – the planet presented two continents to the U.S. crew: Africa and Antarctica. A visual moment, both prophetic and ironic.

Antarctic Resolution is an interdisciplinary project led by architect Giulia Foscari that advocates for rethinking the ways Antarctica is represented, understood, and governed.⁸⁶ Drawing from science, policy, and visual culture, the project confronts the paradox of a continent that is both central to global climate systems and largely absent from the high-resolution images and data infrastructures that shape planetary understanding and climate science. Antarctica appears in satellite visualisations, but often as a blank expanse, a margin. Its lack of permanent population, extractive industry or sovereign ownership places it outside the dominant logics that drive imaging technologies and territorial management.

Resolution, the project argues, is not just a matter of pixels, it is a measure of care and political attention. To be rendered in detail is to be mapped, monitored, and planned for. To remain low-res is to hover at the edge of comprehension. While densely populated cities, sites of strategic interest, or zones of extractive activity are continuously updated in high fidelity, other areas are rendered only partially, or not at all. What appears as a seamless planetary model is, in fact, stratified by visibility, governed by uneven attentions and intentions.

This uneven geography of vision is what other research-based artistic practices seek to confront and reorient. Forensic Architecture and Territorial Agency are two groups that repurpose the tools of satellite imaging, modelling and data visualisation to expose the blind spots of institutional power. Forensic Architecture, a practice of Eyal Weizman, uses satellite data, ground-level imagery, and 3d reconstructions to investigate state violence, environmental crimes, and human rights abuses—situations often rendered invisible by official accounts or deliberately obscured from public view.⁸⁷ Their work treats resolution not just as a technical affordance, but as a forensic threshold, where pixel-level analysis becomes a method of witnessing. Similarly, Territorial Agency employs Earth observation data to reveal the spatial consequences of climate change, particularly in maritime zones and coastal infrastructures.⁸⁸ Their maps are not smooth abstractions but dense, layered compositions that foreground complexity. In all three projects, the image is a site of resistance, used not to simplify the Earth into clean gradients but to surface unevenness, uncertainty, and injustice.

Yet some things simply exceed the frame. What cannot be visualised? Grief, displacement, cultural memory, spiritual ties to land, and indigenous ways of knowing are absent because they are not translatable into data. The twin's logic of visibility depends on metrics, thresholds, and abstractions. But cultural meaning, affect, and embodied knowledge do not scale. They are not pixel-based. As climate knowledge is increasingly mediated through visualisations, there is a risk that what cannot be seen, because it cannot be mea-

86 FOSCARI, Giulia, ed. *Antarctic Resolution*. Zurich: Lars Müller Publishers, 2021. ISBN 9783037786406.

87 FORENSIC ARCHITECTURE. "Forensic Architecture" [online]. [cit. 2025-05-01]. Available from: <https://forensic-architecture.org>

88 TERRITORIAL AGENCY. "Territorial Agency" [online]. [cit. 2025-05-01]. Available from: <https://territorialagency.com>

sured, will also cease to be known.

And yet, in this opacity, a kind of power can be claimed. Drawing from Legacy Russell's *Glitch Feminism*, we can think of the glitch as a refusal to perform legibility within normative systems—a break that reveals how the system operates, and how it might be otherwise.⁸⁹ In the context of the digital twin, glitch might appear as a missing data tile, an unreadable spectral band, or a corrupted rendering. These interruptions are moments when the seamless model falters, and its constructedness is exposed. To remain invisible within such a system can be a form of resistance to instrumentalisation. Invisibility, then, is not always a deficit. It may be a refusal to be flattened into pixels, to be extracted or planned for. It is a reminder that some aspects of the Earth, like some aspects of being, resist capture, and in that resistance, assert their own kind of presence.

As the numero-centric visual regime leaves little room for ambiguity, contradiction, or fuzziness, Drucker reminds us: knowledge is not always clean or stable.⁹⁰ To visualize the planet differently, to stay with uncertainty, to acknowledge invisibility, to trace fragility, requires a different kind of aesthetic altogether. One that does not rely on abstraction and simplification, but embraces complexity, opacity, and the limits of representation. To stay with the invisible is not to give up on knowing, but to imagine other ways of relating to data, to Earth, to each other.

Not everything must be visualised to be understood, nor made available to be valuable. It is where autographic design, a visual and material practice that considers this relationality in data visualisations, begin to emerge. This practice of Professor Dietmar Offenhuber suggests attending to the traces the world leaves of itself. Rather than aiming for abstraction or total visibility, autographic approaches consider how data might register materially, relationally, and affectively. For example, a glacier's retreat is inscribed directly onto the landscape: through bare rock, exposed sediment, and altered rivers.⁹¹

Autographic visualisations aim for material presence, the melt of ice, the stain of pollution, the cracks in concrete. These are visuals for care, witnessing, and staying with. As the visual regimes of climate knowledge continue to expand, so too must our capacity to attune to what exceeds them.

As we become attuned to what resists visualisation, we turn back to how visualizations increasingly function. More and more, climate data is embedded into interactive platforms: maps you can scroll through, simulations you can manipulate, dashboards through which decisions are made. Visualisations become an interface.

89 In *Glitch Feminism*, Legacy Russell frames the glitch not as an error to be corrected but as a site of potential where systems of normativity can be interrupted and subverted. Glitch becomes a feminist strategy of opacity and refusal, offering resistance against computational and social protocols that demand visibility, legibility, and conformity. See: RUSSELL, Legacy. *Glitch Feminism: A Manifesto*. London: Verso Books, 2020. ISBN 9781786632661.

90 Drucker, *Graphesis*.

91 OFFENHUBER, Dietmar. *Autographic Design: The Matter of Data in a Self-Inscribing World*. Cambridge, MA: MIT Press, 2023. ISBN 9780262545164.

2.3. The Earth as Interactive Interface

This chapter traces my encounter with the digital twin of Earth—both as a literal engagement with the Destination Earth platform and as a theoretical inquiry into its underlying interface logics. Oscillating between empirical observation and critical reflection, I document the experience of navigating the interface: rotating Earths, swirling heatwaves, clickable futures. At the same time, I unpack how such visual and interactive simulations are shaped by gamified epistemologies and interface-driven logics. This journey through the twin is both sensory and conceptual, revealing how a seemingly playful platform embodies deeper questions of power and perception in the age of planetary computation.

2.3.1. Meeting the twin

DestinE brings a new paradigm into climate science, developing a new informational system beyond modelling and simulating. Interactivity plays a big role in the conceptualisation of such an initiative. Its twins can be probed, adapted and extended, enabling tweaking inputs and watching what happens under various climate scenarios or policy interventions. Users can explore maps and interact with climate simulations via zoomable, scrollable, filterable GIS-based maps. They can change the input variables and choose SSP scenario pathways, time periods, and climate variables. Unlike traditional climate models, simulations in DestinE can be based on live satellite feeds or user-defined thresholds with immediate feedback. Visualization tools are embedded within the platform to generate charts, graphs, comparative maps or time sliders, as well as impactful stories. For advanced users, they offer application programming interfaces (APIs) and software development kits (SDKs) to integrate digital twins into their own tools and dashboards.

When I log in to the DestinE Platform, I can read that it is my “gateway to a sustainable future.” Curious, I can see the smooth visualization of the Earth’s digital twin rotate while the simulation of heat waves from shades of blue through green to elements of red whirls around the globe. I read that it is a visualization of the total precipitation rate in mm/hr. Deep blue means zero, and light purple means sixty-four. At some places over the oceans, it makes beautiful swirls.

Above is the timeline, explaining that it is one month of Destine Climate DT (2025), from January to February. The timeline automatically loops, so when you get really hypnotised by the swirls, the jump back to January interrupts your dreaming.

I have the option to revolve the sphere into a plane or a plane laid out in 3D space. Then, it does not rotate anymore, but you can move the map left and right unlimitedly, and the Earth unfolds into a limitless background. Expecting the ultra high resolution (2-4km)⁹², I feel a bit sad I cannot zoom in. But perhaps a full-screen? In the full-screen mode, the text overlaying the visualizations disappears.

I can choose from different simulations: the default total precipitation rate (mm/hr), time-mean sea ice thickness (m), and 10m wind speed (m/s). When switching between them, I notice the differences in colour palettes. Time-mean sea ice thickness introduces shades of blue from black to almost white, zero to two. It seems like there is not a lot of

92 Destination Earth. “Frequently Asked Questions” [online]. [cit. 2025-04-04]. Available from: <https://destination-earth.eu/frequently-asked-questions/>

ice on Earth. A bit later, I also notice that the timeline is different. Now, it's between January and December 2024.

Wind speed is again from January to February 2025. The gradients of the simulations are much smoother, going from deep blue through purple, pink, red, orange, and yellow. Also, you can always see the national border outlines. It is already so automatic for me that I did not even realise it in the first place. Here, they outline every country, not only the continents. I can go further in exploring the data from the two available digital twins.

"The DestinE Data Portfolio is tailored to user needs and composed of federated data, DestinE Digital Twins data and DestinE user-generated data with a specified and agreed lifecycle."⁹³ I can read that their digital twins "enable the assessment of the implications of climate change and the impacts of extreme events, from global to local"⁹⁴. Each twin focuses on a different domain: Climate Change Adaptation Digital Twin (Climate DT) simulates long-term climate scenarios and helps with climate mitigation and adaptation planning. Extreme Natural Disasters Digital Twin (Extremes DT) models short-term events like floods, wildfires, and earthquakes and is useful for early warning systems and disaster response. Other twins that are planned are for urban planning, oceans, biodiversity, et cetera.

Let's have a closer look at the Climate DT. It operationalises the production of global multi-decadal climate projections (until 2050) on a regular yearly basis. Its simulations are based on three models, ICON, IFS-NEMO and IFS-FESOM, which run at resolutions between five to ten kilometres. ICON is key for atmospheric dynamics in high resolution, which is made possible by the use of a non-hydrostatic icosahedral grid. That means that the Earth is divided into polyhedrons with 20 triangular faces that are recursively subdivided into smaller triangles. Non-hydrostatic means it also calculates vertical dimensions. IFS-NEMO combines the IFS atmospheric model for medium and long-range weather forecasts and the NEMO ocean circulation model for ocean forecasting to simulate ocean-atmosphere interaction as a critical feedback loop in climate. IFS-FESOM combines IFS with the FESOM ocean-sea ice model for highly detailed sea ice dynamics, ice thickness, drift, melt ponds and thermodynamic exchange and is used in simulations with a focus on polar feedback loops. These models run parallel in simulations.

To illustrate an example, we want to simulate a future heatwave in Europe. We know we cannot model only the atmosphere because oceanic changes and sea ice loss can amplify the event. In separate simulations, all the different models provide complementary perspectives. ICON handles atmospheric modelling to determine how the heatwave forms and persists through modelling pressure systems, winds, moisture, convection, and temperature fields. IFS-NEMO helps to understand the intensity and duration of heat waves based on ocean heat content and sea-air energy exchange. IFS-FESOM then models Arctic sea ice loss, which changes albedo (reflectivity), causing more warming in polar regions, which affects the temperature gradient - the difference between poles and equators, weakening the jet stream - fast high-altitude air current that normally circles the globe. A weaker jet stream can trap weather patterns in place and cause persistent heatwaves,

93 Destination Earth. "DestinE Data Portfolio" [online]. [cit. 2025-04-04]. Available from: <https://platform.destine.eu/destine-data-portfolio/>

94 Ibid.

prolonged droughts and stuck storms.

The models allow for simulations. Climate DT performs five types: historical simulations, future projections, storyline simulations, control simulation, and spinup strategy. Historical simulations start in 1990 until 2020. The future projection uses the Shared Socioeconomic Pathway (SSP) 3-7.0 scenario, which counts on the future continuous increase in CO₂ emissions with no strong mitigation efforts. The other SSP scenarios, the more hopeful and more disastrous, will be explored in further stages of DestinE. Storyline simulations are for what-if scenarios to explore past events in different climatic conditions. Control simulation provides context and control for the interpretation of historical and scenario simulations. The spinup strategy is used before the simulation itself to bring the model into a realistic, stable state before running the actual climate experiment.

I need to upgrade my access to get the data produced by the digital twins. Unfortunately, this is only available for projects that contribute to the development of Destination Earth. However, I can still learn more about them. Destination Earth has multiple services that provide access to the data at different processing levels.

The services are structured in three categories: Access and exploit data, Discover DestinE applications, and Access DestinE data on the edge. In addition, there are services in Beta testing and ones Coming soon. In total, in April 2025, DestinE offers 22 services. *As I understand it, all services are linked to the shared Data Lake data and independently process and offer them to users in various complexities.*

I am drawn to the services' subtitles: Insula—The hub between data and decision; Eden—DestinE data portfolio at your fingertips and beyond; Vision—Real-time Earth at your Fingertips; SesameEO—Access anything; Vizlab—Pixels from numbers / Stories from data. That gives me a sense of power.

I download the Vision service. After logging in, I can see a 3D model of Earth with true-colour texture. Exploring the parameters: I can make the graphics of the Earth more glossy, metallic, or transparent. I can also adjust the Digital Elevation Model (DEM), which creates structure and depth and raises mountains. It is fun to play around. Moreover, we can visualise the DestinE data through advanced 3D rendering technology. As I read through their introduction, Vision's aim is to make complex data accessible, understandable and engaging to a broad audience through a "real-time Earth at their fingertips".

DestinE Climate DT is being developed with several real-world applications across various sectors. In collaboration with Finnish forestry management projects, the Wildfire Risk Assessment use case aims to provide detailed information on the potential evolution of wildfires in Finland and the Northern Hemisphere to support decision-makers in developing effective adaptation policies. The Wind Energy Resource Evaluation focuses on informing investment strategies in the wind power sector by assessing future wind energy potential and turbine vulnerability, facilitating better design and site selection. Other application targets the challenges posed by urban heat islands.

2.3.2. The world as a playable interface

DestinE conceptually and technically overlaps game engines, sandbox games, and computational gaming logic. It shares many similarities with how games simulate, visualise, and allow user interaction with complex systems. It is conceptualised as a us-

er-friendly entry point that allows everyone to “play” with the digital representation of Earth’s system.

Game engines, such as Unreal Engine or Unity, simulate a virtual world with physics, time, objects and behaviours, allowing user interaction with that world in real-time and rendering visuals dynamically based on the input and model states. DestinE is doing something very similar, but for the actual planet: It simulates real-world physical systems, allows for real-time interaction via parameters, scenarios and visualizations and provides dynamic, evolving outputs based on the inputs. *“Think of a Game Engine type framework but for Earth Systems...”*⁹⁵ In the presentation by Irina Sandu from ECMWF, we can see that DestinE is fundamentally conceptualised as a game engine.

Sandbox games, such as Minecraft or SimCity, allow for free exploration and testing of their own “what-if” scenarios. As a great example, we can mention The Powder Toy, an open-source falling-sand game released in 2008 that *“simulates air pressure and velocity, heat, gravity and a countless number of interactions between different substances”* and *“provides you with various building materials liquids, gases and electronic components which can be used to construct complex machines, guns, bombs, realistic terrains and almost anything else.”*⁹⁶ DestinE’s storyline simulations and use cases mirror this playable, open-ended logic of sandbox games.

This gamified epistemology refers to a mode of understanding where knowledge is acquired through interaction, simulation and experimentation rather than passive observation. Complex systems are learned through playful manipulation and what-if scenarios. DestinE treats the Earth like a programmable, interactive system that enables the conceptualisation of Earth as a simulation that we can model, steer, and test. Through testing and iteration, the policy becomes gameplay, and science goes beyond studying the world to engaging with it and experiencing it through its digital twin.

Gamification has become a broader practice in our lives - from education through fitness, workplace and marketing - to drive motivation, engagement or productivity. In the world organised through surveillance capitalism, it is a strategy for soft governance, nudging users, capturing attention, modifying behaviour and monetising it. We can see this type of practice being applied in metaverses, or smart cities, not yet so much in the digital twin of Earth. However, there is a risk of flattening the complexity of Earth systems and climate change into shallow interactivity with adjustable parameters - turning a planetary emergency into a playable interface and policy into a kind of strategic “minigame.”

Moreover, as Orit Halpern’s analysis of the smart city Songdo shows, we came to envision the world as an interface, *“an entire sensory environment where human actions and reactions can be traced, tracked, and responded to in the name of consumer satisfaction and efficiency.”* Gamification and this interface logic are two sides of the same coin: they both organise experience around responsiveness, input-output loops, and systems thinking, whether in the name of learning, governance and control, or consumption and mon-

95 EUROPEAN COMMISSION. “Destination Earth Webinar: Participation and Upcoming Collaboration Opportunities” [online]. July 2023 [cit. 2025-05-01]. Available from: https://destina-tion-earth.eu/wp-content/uploads/2023/07/DestinE_webinar_0723.pdf

96 THE POWDER TOY. “The Powder Toy” [online]. [cit. 2025-05-01]. Available from: <https://powder-toy.co.uk/>

etisation. In the context of DestinE, this fusion means that planetary-scale processes are increasingly visualised, clickable, and interacted with as if they were part of a software platform. It opens new, powerful ways to engage with climate change and risks abstracting and instrumentalising it, obscuring the deeper social, ecological, and political dimensions.

Digital twin's logic builds on a unique epistemological infrastructure: through immediacy, it offers real-time data access, interactivity enables testing, modularity allows for simulations to be compartmentalised and recombined, programmability facilitates adaptive control, and containerisation organises environmental phenomena into bounded, manageable units. These principles (immediacy, interactivity, modularity, programmability, containerisation) align the twin with the broader logics of computational governance through which they penetrate much deeper into our lives.

The problem with such projects is that they aim to bring top-down solutions, for us to be able to keep our lives and society as they are, with all their inequalities, top-down governance, and consumerism, without ever questioning them. They bring techno-fix after techno-fix, leading to a simulation that does not have much to do with reality. Coming back to the Planetary Mattering, we can analyse that scientific projects such as DestinE organise the world mostly through matters of fact and matters of risk, which position scientific facts and predictions (considered as facts) on climate change and extreme weather risks in the centre.

When we start seeing the world through the matters of justice, care, and hope, we start to understand that the current societal organisation, which scientific projects often fail to question, is no longer thinkable. A more radical twin would attend to these matters and create a tool which is less for optimisation, and more about coexistence and attunement. We come back to such imaginations towards the end of the thesis.

2. 4. Perceiving computationally

This chapter explores how the digital twin of Earth operates as a visual and aesthetic machine that sees, senses, processes, and represents the Earth and fully constructs our perception of climate change. Tracing the aesthetic logics of the system, this chapter interrogates how Earth becomes visible and governable through technologies of perception. It engages the intersection of scientific visualization, data aesthetics, machine sensing, and artistic critique to analyze what is seen, how it is seen, and what remains unseen.

What is the Earth as seen through its digital twin? Coming back to one of the central questions of this thesis, we can ask further: What is our perception of Earth that we are twinning? What do we actually see when looking at the digital twin? How does our perception of Earth change when seen through its digital twin? What Earth is the twin designed for? What and how does the twin sense? What does it visualise? What does it make visible, and what does it obscure? What matters do we design the twin with?

2. 4. 1. Imagining the twin otherwise

Through the methodology of comparative planetology, we can learn how different aesthetic qualities transform planetary imaginations. With its central question: “*For what Earth do we design?*” the framework is rooted in visual culture, exploring the visual and philosophical imaginations of the planet—“*the way we envisage our planet through concepts, theories, maps, paintings, photographs, videos, buildings and architectural drawings, computer models, graphs, books, and other cultural artifacts*”⁹⁷—and its implications for geopolitical arrangements. Each figure of Likavčan’s analysis - Globe, Terrestrial, Planetary - arises from different work with concepts and visualisations. Bruno Latour famously states: “*We don’t seem to live on the same planet*”⁹⁸, and the reason for this is the different epistemologies formed at least partly through the materials we think-with and from how these materials matter to us.

Seeing Earth as a Globe, Terrestrial, and Planetary creates different aesthetic imaginations. The “perfectly smooth sphere,” the top-down view from space, zoomed-out, and seeing the Earth as a totality to be known, measured, and managed are aesthetics of the planet understood as a Globe. Likavčan illustrates this with the architectural utopias of Buckminster Fuller’s geodesic domes and the Spaceship Earth metaphor⁹⁹. Such imaginations imply the harmonious unity of humankind as crew members on “our” small, fragile, enclosed planet that we need to operate and carefully control. This figure is deeply tied to globalisation, technocratic governance, and universalism.

The digital twin of Earth is a natural culmination of the technocratic dream of a fully knowable, controllable, optimised Earth, the Earth as a Globe. Run by international organizations and tech giants, this logic is evident in projects such as Destination Earth, which are analysed throughout this thesis.

The Terrestrial is on the ground, muddy, textured, and embodied. It turns our gaze from the smooth abstractions to the material, lived realities of the Earth, a web to be entangled with. It is tied with eco-feminist, posthumanist, Indigenous, and decolonial perspectives that emphasise relationality, care, and situated knowledge. As a framework that is deeply suspicious of the totalising ambitions of the Globe’s digital twin of Earth, we can think more of projects of community-based DIY sensor networks, Indigenous mapping, and decentralised citizen science.

The Planetary evokes a sense of massiveness, unknowability, and strangeness. Earth is seen as a cosmic body subject to deep time, entropy, emergence, and multiple temporalities. It forces us to confront an Earth that exceeds human frameworks. Not fully graspable, it spans beyond humans, beyond national borders, and beyond cultural identities and

97 Likavčan, *Introduction to Comparative Planetology*, p. 9.

98 LATOUR, Bruno. “We Don’t Seem to Live on the Same Planet – A Fictional Planetarium.” In: *Designs for Different Futures*. Edited by Kathryn B. Hiesinger and Michelle Millar Fisher. Philadelphia: Philadelphia Museum of Art, 2019, pp. 193–199. ISBN 9780876332955.

99 Buckminster Fuller was an American architect, designer, and systems theorist known for his visionary proposals integrating technology, ecology, and global responsibility. Likavčan draws on his metaphors to illustrate the aesthetic and political logic of the “Globe” as one planetary figure. See: FULLER, R. Buckminster. *Operating Manual for Spaceship Earth*. New York: E.P. Dutton, 1969. ISBN 9780525564006.
Likavčan, *Introduction to Comparative Planetology*.

challenges the very idea of the digital twin of Earth. Earth is too vast, too strange, too entangled in different temporalities (deep time, microbial time) to be twinned. The Planetary is the most challenging figure of Earth, ontologically humiliating, philosophically speculative, and nonhuman, turning the project of the digital twin of Earth meaningless.

The Globe, the Terrestrial and the Planetary are operative imaginaries that shape how we understand, design and govern Earth. By asking how a digital twin would look through each of these planetary figures, this thesis actively interrogates the epistemological foundations and political assumptions embedded in the twinning. As the digital twin of Earth becomes thinkable through the figure of Globe and often goes unchallenged in policy discourses presenting itself as inevitable progress, bringing in the Terrestrial and Planetary frameworks can help to de-naturalize these assumptions, showing that other imaginaries are not only possible but necessary.

2. 4. 2. From vision to visualization

So, how is this conceptualization of Earth transformed in the age of its digital twin? What happens to our imagination when we “square” the Earth in a uniform grid, translate its ecosystems into quantifiable units of data, visualize it in heat maps, vector fields, and topographies, look down on it from an aerial perspective, with the possibility to pick only some of its “layers” and project them in simulated futures?

To understand how the perception of Earth is transformed and how this affects environmental politics in the context of climate change it is necessary to explore this phenomenon within the broader societal context of smart technologies, planetary-scale computation, programmable environments, visual cultures, datafication, and twinning.

The interplay of cultural, scientific, historical, and technological factors shapes the different ways we imagine and conceptualize Earth. Each figure arises from different epistemologies, ontologies, and ideologies that inform our interaction with the world. What came to become the main tool of the 20th century was “vision”, quietly rising to shape how we think.¹⁰⁰

Vision has become the dominant mode of knowledge, Orit Halpern writes as she traces the reformulation of vision and reason since 1945 in her book “Beautiful Data”¹⁰¹. It has become the most important sense for humans. Halpern explores vision in its multiple forms: vision as the physiological and philosophical capacity to see; visualization as the technical and computational process of rendering data into perceptible form; visibility as the cultural and social politics of how we see and what is made visible; and visibilités, drawing on Foucault¹⁰², as the regimes of power that determine the conditions under which something becomes visible at all. Through this distinction we understand that “seeing”

100 HALPERN, Orit. *Beautiful Data: A History of Vision and Reason since 1945*. Durham: Duke University Press, 2015. ISBN 9780822357445.

101 Ibid.

102 Michel Foucault’s notion of visibilités refers to the historically and politically constructed conditions that govern what can be seen, said, and known. Rather than treating visibility as neutral, Foucault shows how regimes of power produce particular forms of seeing—structuring what becomes legible, surveillable, or knowable. This concept appears notably in his analysis of disciplinary institutions and panopticism. See: FOUCAULT, Michel. *Discipline and Punish: The Birth of the Prison*. Translated by Alan Sheridan. New York: Vintage Books, 1995. ISBN 9780679752554.

goes beyond optical and neutral, being shaped by historical and political forces.

In the digital twin, visualisation is integral to the logic of simulation itself, a core computational function. Visualisation shapes how we see and how we think about the planet and its changing climates. It has evolved from “*the formation of mental images not actually present in sight*” through “*any action or processes of making visible*” to rendering visible through machines and scientific instruments.¹⁰³ Halpern traces a genealogy of vision that departs from classical optical theories to focus on infrastructures, devices, and epistemologies that make contemporary forms of seeing possible. Through this evolution, visualization, the derivative of vision, is no longer the product of perception - it is an infrastructure of perception in itself.

This reformulation of vision transforms knowledge into something that must be visual, manageable, and actionable. In her words, data visualisations become part of a “smart” rationality, a mode of governing life through feedback, prediction, and simulation, which is a topic explored in other parts of this thesis. They promise clarity but often obscure the underlying complexity. Vision becomes a tool of governance as much as of understanding.

A pivotal transformation in the imagination of Earth occurred with the iconic Blue Marble photograph in 1972. This photograph of Earth, taken by the astronauts of Apollo 17, offers a view of the planet Earth as a one-unified space and gives space for planetary consciousness that sparked environmental movements and ecological awareness. A subsequent transformation is illustrated by the new version of Blue Marble from 2012, which was composed and processed from grids of satellite images.¹⁰⁴ Today, most of the visualizations of the world - such as satellite images - are automatically generated through algorithms, yet the assumption that such practices are objective and “true” is misleading.

Nicholas Mirzoeff, in “How to See the World,”¹⁰⁵ emphasizes the crucial role of visual culture, particularly in war. Visualization became necessary to manage the complexity of modern warfare, with tools like maps enabling the coordination of large-scale operations. Computation enabled and caused the demand for new tools and better ways to process and visualize information with the need for better visual overviews. In this context, data visualization became essential to manipulating and navigating the “global city.” We “*learn not to see*” the city but to see its representation in maps, graphs, and city plans¹⁰⁶ - artefacts of visualization designed and processed by machines. In the dominance of this observation mode, the direct sensory experience of the daily micro-events that make living “*beautiful*”¹⁰⁷ lost prominence. We found this beauty elsewhere: in visualizing “beautiful data.”¹⁰⁸

Cybernetics, statistics, informatics, and computation both enabled and forced us to

103 Halpern, *Beautiful Data*.

104 MIRZOEFF, Nicholas. *Jak vidět svět*. Překlad Andrea Průchová Hrůzová a Jan J. Škrob. Praha: ArtMap, 2018. ISBN 9788090659957.

105 Ibid.

106 Ibid, p. 200

107 Timothy Morton, in *All Art is Ecological*, critiques conventional notions of beauty tied to aesthetic distance and harmony, proposing instead an ecological sense of beauty that embraces entanglement, strangeness, and the everyday. See: MORTON, Timothy. *All Art is Ecological*. London: Penguin Books, 2021. ISBN 9780141997001.

108 Halpern, *Beautiful data*.

“scale out” vision outward to see global, large-scale, vast information. Rather than observing the world closely, we began zooming out, seeking patterns in data. As a result, we no longer directly look at the world; we look at visualizations of it. Orit Halpern documents the emergence of this “algorithmic optic” through the projects, philosophies, and lectures of designers and pedagogues Gyorgy Kepes, Charles Eames, and Kevin Lynch, as well as through innovative projects of smart cities.¹⁰⁹ Through these shifts, seeing and thinking merged through data processing into a new form of recognition: identifying patterns across scales. This redefined what it means to “observe”: to scan, see connections, and process vast amounts of information quickly.

As Halpern traces, vision and cognition merged and transformed how we perceive space and the environment. As environments became increasingly mapped, categorised, and visualised through technological tools, a new spatial understanding arose, and spaces became abstract, governable entities. The planetary optics were formed while zooming out with our technologies in the context of infrastructural globalism¹¹⁰.

2. 4. 3. Zooming-out, seeing through

In the age of Earth’s digital twin, the Earth became just an interface. We are learning to see through it, across it, and beyond it, across nonhuman scales of spacetime. As Benjamin Bratton writes, “As we quickly learn more precise and higher-resolution processes, it becomes correspondingly harder to see the whole at once”¹¹¹. The further we got from Earth (physically and metaphysically), the closer we zoomed (technically). High-performance computing, synthetic aperture radar, and hyperspectral sensors enable increasingly higher (spatial and temporal) resolutions, aiming to see the Earth on a meter scale. Hyperspectral sensors carried by satellites travelling hundreds of kilometres far from the surface of Earth let us see the presence of chlorophyll, or atmospheric methane, both on the molecular scale. This paradoxical spatiality, where space is both smooth and ruptured, highly detailed and abstracted, local and planetary, transforms our perception of space. The more precise our focus becomes, the harder it is to see the entirety of the system at once. This cognitive dissonance forces us to confront the limits of human cognition in the face of vast computational systems. The simultaneous zoom-ins and zoom-outs through ever-higher resolutions flatten the local and global into a new type of space.

The new planetary vision of Earth, first offered in photographs, like the Blue Marble, followed by satellite imagery, and lately also simulations, completely transformed our environmental perception. The planetary evolved from science’s need for globality, and as its holism sparked environmental movements, it zoomed out way too far. As we no longer see the Earth, we need its digital twin.

109 Halpern traces the development of an “algorithmic optic” through mid-20th-century design and planning experiments such as Gyorgy Kepes’s work on visual education and civic design at MIT, Charles and Ray Eames’s data-driven films and exhibitions (like *Powers of Ten*), and Kevin Lynch’s cognitive mapping of urban form in *The Image of the City*. These projects linked perception, computation, and governance, laying groundwork for contemporary smart city imaginaries. See: Halpern, *Beautiful data*.

110 Infrastructural globalism is a term coined by Paul Edwards and is further discussed in Part 1: Twinning of this thesis. Edwards, *A Vast Machine*.

111 Bratton, *The Stack*, p. xviii.

2. 4. 4. Seeing the world update

This hyper-aestheticization of Earth is also introduced through fundamentally new regimes of temporality, in which time becomes modelled, compressed and operationalized. Through layers of data, simulations, and predictive algorithms, the digital twin of Earth produce multiplicities of time scales.

Just as the spatial resolution spans from megameters to micrometres, temporal resolution can move from centuries to milliseconds. Temporal resolution is an important parameter in remote sensing, referring to the frequency of capturing images of the same area. Environmental sensors and models operate on different time scales, some capturing the near-instantaneous - particle collisions, seismic vibrations, and electrical pulses, and others measuring gradual shifts over hours or days (atmospheric pressure, soil moisture). Climate models then simulate dynamics across centuries or millennia. A digital twin of Earth integrates these multi-scalar times into an interface-able structure where users can scroll between epochs as easily as days, collapsing deep pasts and speculative futures into a seamless now.

As an aesthetic and operational framework, this synthetic temporality of the digital twin of Earth simulates, compresses and optimises time. Seamless images of Earth, the satellite composites, may appear as single snapshots but are, in fact, stitched together from a sequence of pictures taken across minutes or hours. In this way, even the stillness of the image is engineered, producing the illusion of temporal coherence from fragmented moments.

Perhaps the most profound shift introduced by digital twins is the dominance of predictive temporalities. Weather patterns, migration flows, carbon emissions, infrastructure stress, and human behaviours are modelled as projected trends. The future, once perceived as open and unknowable, is reconfigured as a variable to be managed. Governance then follows a logic of preemption. Actions are taken not in response to reality but in response to predicted futures.¹¹² Within the twin, the future precedes the present: it is a driver of decisions, investments and interventions.

Orit Halpern, in her book *Smartness Mandate*, writes about the temporal logic of smart infrastructures inherited from software development - projects that are never finished, always testing and updating. These systems operate in a perpetual beta state, always “demo-ing” the next version. She considers the ethical implications - smart systems never being complete enough to be held responsible, never stable enough to be evaluated. The demo becomes a form of temporal management, where the present is a placeholder for an improved future that never fully arrives. Such a world is governed by logistics, focusing “on how to move things from point A to point B rather than questions of where they should

112 Brian Massumi introduces *preemption* as a key mode of power in late modernity, where governance operates through affective responses to potential threats before they materialize. This anticipatory logic does not wait for evidence but acts on the intensity of threat itself—turning uncertainty into a condition for intervention. His work helps frame how predictive technologies restructure temporality and political action. See: MASSUMI, Brian. *The Future Birth of the Affective Fact: The Political Ontology of Threat*. In: *The Affect Theory Reader*. Edited by Melissa Gregg and Gregory J. Seigworth. Durham: Duke University Press, 2010, pp. 52–70. ISBN 9780822347743.

end up.”¹¹³

In this logic, time is looped and recursive, organised toward future responsiveness rather than historical reflection. It outsources memory to the machines - Halpern cites the archival condition of contemporary data infrastructures as one in which “we record to produce the capacity to forget”¹¹⁴ At the same time, the digital twin incorporates vast temporal datasets drawn from paleoclimatic records embedded in deep time: ice cores, geological records, climate proxy, sedimentation rates, carbon histories. As all these durations convert into scrollable and zoomable data layers, the epistemological consequence is the detachment from historical consciousness.

In this world, real-time is the only time, and we navigate through it. The planetary-scale smart infrastructures reconfigure our perception of time, leaving us lingering in the meta-temporal state—detached from embodied rhythms, seasonal cycles, and cultural histories.

2. 4. 5. Planetary disorientation

How does this new spatiotemporal condition alter our cognition? The continuous shifting between micrometres and megameters, seconds and eons, produces a strange, disorienting state. The digital twin of Earth promises a new ability to see, model and act upon Earth at unprecedented resolutions. Yet, what emerges as we scroll across millennia, simulate futures, and zoom between Earth and space is a confrontation with the limits of our frameworks. In the age of Earth’s digital twin, our perception requires special temporal and spatial attunement to perceive “the planetary.”

This is the paradox of the digital twin of Earth: it is born out of the Globe—the modernist vision of Earth as a unified, knowable system with the epistemological assumptions of universal legibility, seamless integration, and technocratic control. The Globe’s aesthetics remain intact: top-down, gridded, smooth, while the phenomena it renders—climate tipping points, deep time, atmospheric patterns—do not belong to the Globe. They belong to the Planetary.

In recent theoretical discourse, the term “planetary” has emerged not simply in relation to “world-scale” but as a distinct way of reconfiguring thought, perception, and aesthetics in response to the environmental crisis, computation and deep entanglements of human and nonhuman life. If the planetary, as Chakrabarty and Likavčan suggest¹¹⁵, is about confronting the limits of human frameworks, then the temporality of the digital twin

113 Halpern and Mitchell, *The Smartness Mandate*, p. 27.

114 Halpern, *Beautiful Data*, p. 76.

115 The term *planetary* has emerged in contemporary theory as a way to move beyond anthropocentric, globalist frameworks and to grapple with the entanglement of human and nonhuman histories, deep time, and ecological limits. Dipesh Chakrabarty distinguishes the planetary from the global, suggesting that the planetary introduces a sense of scale and agency that destabilizes conventional human-centered narratives. It foregrounds the limits of political and cognitive systems in addressing crises like climate change, urging new forms of historical and ethical thought. This planetary condition challenges us to think across inhuman timescales and geophysical processes that resist representation and mastery. See: CHAKRABARTY, Dipesh. *The Climate of History in a Planetary Age*. Chicago: University of Chicago Press, 2021. ISBN 9780226732862.

brings us face-to-face with those limits. We are asked to think and act across timescales we cannot inhabit: from the microbial to the geological. And yet, we lack institutional, political, and cognitive models that can operate at these temporal thresholds. The digital twin of Earth becomes a kind of epistemic glitch - an interface that reveals how broken our relationship with time and space has become.

The digital twin of Earth aims to visualise the planetary, but it necessarily fails by not being able to contain it. It overlays a logic of control onto a condition that demands humility and new forms of imagination. Here, I examined how the aesthetic regime of the digital twin transforms our perception. What comes into focus now, at the threshold of the next chapter, is the question of what affective consequences this transformation of perception in the planetary world oriented towards predicting disasters have.

3. AFFECTS

Throughout this thesis, the digital twin of Earth has been investigated as a complex figure that crosses science, politics, and aesthetics and lives within broader phenomena of datafication, doubling, smartness, and algorithmic governance. Conceived as a project to face our crises and tackle problems, it emerges at a moment marked by widespread feelings of worry, sadness, anger, discomfort, and uncertainty. The digital twin is responding to times when it seems like the traditional frameworks for organising our individual and collective lives appear increasingly broken. Yet, paradoxically, the imaginations and aspirations that bring the twin into its existence (yet still incomplete) still largely reflect our old understandings and feelings about the world.

Furthermore, the rapid and automatic integration of planetary-scale computation into our daily lives often occurs without critical reflection on how such technologies reshape our perception, emotional states, and political realities. We find ourselves confronted by extremes: extreme weather, mass extinctions, information overload, deepening political divisions, wars, and the rapid evolution of artificial intelligence - all of those complex networks amplify feelings of anxiety and instability. The digital twin of Earth thus both reflects and influences our emotional landscape, embodying the complexities, contradictions, and urgent questions of our contemporary moment.

Having examined the digital twin technologically, philosophically, and aesthetically, the thesis shifts focus towards the emotional and societal dimensions - the affective responses provoked by these technologically mediated representations of Earth's changing climate. What feelings, anxieties, hopes, and resistances do these simulated realities invoke? In the era of the digital twin of Earth designed to feel climate, how do we feel about climate?¹¹⁶ The final chapter explores these questions, analysing the affective currents beneath the surface of digital twinning and how collective feelings and perceptions shape responses to the urgent realities of climate change.

Through feelings of uncanny strangeness, overwhelm, melancholic sadness, anxiety, and comfort this chapter builds an emotional map of life under climate crisis and its technological mediation. These affects, encountered throughout my research, accumulate, collide and mutate. This is an affective journey from discomfort and alienation towards an ethics of staying-with, sensing-with, and feeling-with the planet.

¹¹⁶ This section is inspired by the powerful opening line from *Sad Planets*: "To feel climate, to feel about climate." The phrase captures the emotional and affective dimensions of planetary crisis, pointing toward the need not only to understand climate scientifically, but to engage with it experientially, ethically, and affectively. See: PETTMAN, Dominic; THACKER, Eugene. *Sad Planets*. Cambridge: Polity Press, 2024. ISBN 9781509562350, p. 10.

3.1. Uncanny doubles

When confronted with instability, we find ourselves looking into a mirror—searching for clarity, reassurance, or perhaps an escape. Doubles emerge in these moments: utopian cities during industrial turmoil, simulated wars in Cold War command centres, and now, planetary-scale digital twins in the face of ecological breakdown.¹¹⁷ They are cultural constructs shaped by fear, hope, and the need to simplify complexity. Facing these doubles feels both intimately familiar and disturbingly foreign.

In *Doppelgänger*, feminist author Naomi Klein delves into our “doppelgänger culture,” shaped by our obsession with replication. While confronted and confused by her own real-world double, Klein explores the distortions of identities, realities, and truth caused by modern technology, like social media platforms and their algorithm systems, data mining and surveillance tools, and digital twins and simulation technologies.¹¹⁸

She describes the uncanny experience of seeing one’s double—“*everything so familiar, and yet more than a little off*” - and a resulting sense of disorientation and confusion.¹¹⁹ This sensation goes beyond being psychological to a deeper disturbance in how we relate to the world through its digital counterpart. The digital twin promises a precise and knowable Earth, yet what it reflects is a filtered, optimised, and strangely flattened version of it. Familiarity without intimacy, presence without connection. This feeling, hovering between comfort and alienation, becomes a key affective register of our relationship to simulated planetary futures.

In searching for and creating our “twins” and “doubles,” we tend to project our idealised qualities outward onto external personas to perform the best version of ourselves while simultaneously displacing our flaws onto others - mirroring a cultural tendency to avoid confronting the more uncomfortable aspects of our own identities (or realities). Klein considers twins and “*all of its mirroring, synthetic selves, and manufactured realities*”¹²⁰ as a *way of not seeing*, making us feel uncanny in this moment of history.¹²¹ Klein’s notion of selective seeing in doppelgänger culture reveals how we curate external representations to avoid confronting inconvenient truths.

What does it mean in the context of the digital twin of Earth being constructed *to see* the invisible, the hyperobject of climate, the yet-to-come?¹²² In the digital twin of Earth,

117 One example is the Cold War-era RAND Corporation simulations, where military strategists used war games and abstract models to simulate nuclear conflict scenarios. These simulated doubles of the world were used to test strategies for managing an unthinkable future.

118 In *Doppelgänger*, Naomi Klein reflects on being mistaken for another public figure whose politics oppose her own, using this confusion as a lens to examine the broader cultural and technological forces that distort identity and reality. She unpacks how algorithmic platforms, surveillance systems, and simulation technologies amplify fragmentation and confusion, creating “mirror worlds” where doubles proliferate and truth becomes unstable. The doppelgänger becomes a metaphor for the psychological and political disorientation of living in an era of replication, simulation, and deepfakes. See: Klein, *Doppelgänger*.

119 Ibid, p. 322

120 Ibid.

121 Ibid.

122 MORTON, Timothy. 2013. *Hyperobjects: Philosophy and Ecology after the End of the World*. Minneapolis: University of Minnesota Press.

we project our desires for control, mastery and predictability in response to the chaotic realities of climate change.

Twinning ourselves into individual doubles and twinning in the sense of planetary-scale simulation requires different attunements. However, what Klein's Doppelgänger offers for our thesis is the cultural and psychological dimension that deepens the critique of digital twins. It helps explore how the digital twin embodies a distorted reflection of Earth, selectively amplifying aspects that align with human control and mastery while ignoring messier, less manageable realities. Doubles reveal less about the one they replicate than about the desires and anxieties of the one who creates them. Based on this assumption, the digital twin of Earth is not only a representation of Earth's processes but also humanity's unresolved contradictions. It reflects our need for resolution in the face of ecological crisis, yet it ultimately deepens our estrangement.

This affective dissonance resonates with what philosopher Mark Fisher calls *the weird and the eerie*, concepts that offer a language for the discomfort provoked by technologies that disturb our perception of the real.¹²³ The weird, according to Fisher, names the arrival of something that should not belong, a strange presence that unsettles the everyday. The digital twin of Earth, a full-scale simulation promising omniscience, becomes weird in this sense: it exists in a register where the familiar is refracted through an unfamiliar logic of endless computation and abstraction. It is an updateable version of Earth.

The eerie, on the other hand, arises from the strange disjunctions created by digital twins and the infrastructures around them, particularly in how they distort our perception of time, agency, and space. Mark Fisher identifies the eerie with the sense of agency gone awry: we feel it when systems act without clear authorship or when something expected is absent. In this light, the eerie surfaces in the logic of automated governance enabled by digital twins – in the uncanny autonomy of satellites, sensors, AI and simulations.

Earth begins to feel like a ghost, and the systems around the twin (planetary computation, predictive modelling, and algorithmic governance) form a machinic logic that mimics agency while bypassing responsibility. This, Fisher would argue, is the eeriness of our time: the sensation that things are moving, that decisions are being made, but that no one is truly there.

This uncanniness is cosmic. As Dominic Pettman and Eugene Thacker write in *Sad Planets*, “seeing beyond the horizon of the familiar is an uncanny feeling: a cosmic feeling, to realise not only mentally but viscerally that we are but fleeting creatures clinging to a rock that is somehow both spinning and hurtling through the endless inky darkness of space”¹²⁴. The digital twin of Earth emerges within this planetary vertigo—between the affective smallness of human life and the vast computational architectures that claim to map it. We try to model Earth precisely at the moment when we most profoundly feel its elusiveness. Pettman and Thacker call this the condition of a neo-millennarian age: no longer guided by preachers predicting fire and brimstone, but by scientists presenting “cataclysmic events” with graphs and charts from Senate floors and UN assemblies.¹²⁵ “Human

123 FISHER, Mark. *The Weird and the Eerie*. London: Repeater Books, 2016. ISBN 9781910924383.

124 Pettman and Thacker. *Sad Planets*. p. 10.

125 Ibid, p. 12.

race can suddenly see an unexpected finishing line looming ahead of us, and yet it cannot slow down the pace in a bid to keep the marathon going.”¹²⁶

In our attempt to grapple with planetary-scale crises, we build digital twins to render the invisible visible—to simulate complexity, to map the unthinkable. These doubles promise orientation in a disoriented world, offering the illusion of clarity in the face of chaos. Yet the very scale and logic that define the digital twin threaten to replicate the problem it aims to solve. Instead of taming the vastness of climate change, the twin multiplies it—producing an ever-expanding accumulation of data, simulations, and predictive models that themselves take on the characteristics of what Timothy Morton calls *hyperobjects*: entities so massive in temporal and spatial scale that they exceed human comprehension.¹²⁷ In trying to grasp the hyperobject of climate, we have created another—technical, abstract, and emotionally elusive - haunted, perhaps, by the weird and the eerie logics they were meant to overcome.

3. 2. Overwhelming hyperobjects

Climate change is not a singular event. It is not a storm, a wildfire, or a melting glacier. It is something far larger, stranger, and more temporally diffuse. It unfolds over centuries, seeps into atmospheres and oceans, and manifests differently across the globe. It is, in Timothy Morton’s terms, a *hyperobject*—an entity so vast in time and space that it resists our ordinary ways of thinking, seeing, and feeling. Climate change is everywhere and nowhere: too abstract to grasp, too intimate to ignore.¹²⁸

Hyperobjects are viscous: they stick to everything, impossible to escape. They are nonlocal: their causes and effects are dispersed and asynchronous. They phase in and out of perception, never fully revealing themselves. They operate on geological time but affect every moment of our daily lives.¹²⁹

Perceiving this scale mismatch is exhausting. As Morton writes, they induce temporal vertigo: a collapse between deep time and real time, where the future seeps into the present and overwhelms our capacity to act or respond. Weizman and Morton call this state hyper-aesthesia, which occurs when sensation stops making sense. This happens due to information overload or overabundance of a system. It is a state on the edge of collapse. This condition mirrors the existential fatigue described by Pettman and Thacker: “*It is an act of self-preservation to avoid grasping this knowledge fully.*”¹³⁰ As they put it: “*Never before have we known so much about the planet; never before have we felt so estranged from that same planet – to say nothing of the wider cosmos.*”¹³¹ Perhaps, “*We need not*

126 Ibid, p. 12.

127 Morton, *Hyperobjects*.

128 Pettman and Thacker, *Sad Planets*, “*Climate seems at once distant or remote and at the same time the most intimate and immediate,*” p. 3.

129 Morton, *Hyperobjects*.

130 Pettman and Thacker, *Sad Planets*, p.16.

131 Ibid, preface.

*always make sense.*¹³²

In response to this ungraspable scale, we turn to measurement. The digital twin of Earth is one of the most technologically sophisticated attempts to capture, simulate, and forecast the hyperobject of climate. However, the data, too, become a burden—ecologically, economically, and epistemologically.

The infrastructures of the digital twin of Earth, by continuously sensing, updating, and archiving, risk producing a world of endless signal without pause. A reality where everything is recorded but little is reflected upon. The question is no longer just what we can measure, but what we choose to care about, and whether this care can survive within a system that privileges accumulation over understanding.

The digital twin promises insight, but delivers information overload. We may contemplate: How can a machine far away in space see inside a plant more clearly than I sitting in the grass next to it? This disjuncture that disrupts knowledge about scales and times also disrupts trust in our own perception. As we get disoriented, trapped between the close and the distant, the quantified and the lived, climate change intrudes “our” world, and we struggle to assimilate. The limited space-times of human meaning facing the vast, impersonal scales of the potentially uninhabitable Earth are haunting. “*How should we relate to something as devastatingly impersonal as hurricane, a wildfire, a flood... How should we relate to something as diffuse and ambient as the weather, as climate?*”¹³³

In a medially saturated world, we are expected to feel informed, stay aware, take action, remain hopeful, be critical, be resilient, all at once, in rapid succession. “*The modern individual has so many masks to wear, codes to master, and expectations to navigate that we find it increasingly difficult to separate the performance from the performer.*”¹³⁴ Surrounded by a constant feed of climate models, catastrophic footage, and emergency alerts, we live in a state of emotional overexposure. Feeling numb, we become estranged not only from the planet but also from any stable sense of who we are within it.

Hyper-aesthesia is a crash. Caught between overwhelming input and diminishing comprehension, a point where “*sensation does not add information but erases and distorts it*” can be found as trauma. It is a trauma of inhabiting abstraction. At this threshold, anxiety emerges as the dominant affect of climate mediation: a recursive tension between knowing too much and feeling unable to act.

3.3. Recursive Anxiety

The affective crash produced by hyper-aesthesia is not only traumatic in its over-registration of sensation, but also anxious in its recursive, anticipatory structure. Trauma flattens perception, while anxiety loops it and traps us in a constant cycle of awareness without resolution. In the age of planetary-scale computation, where digital twins predict and simulate what may come, we inhabit a world governed by anticipation.

Climate anxiety has been described as heightened emotional, mental, or physical dis-

132 Fuller and Weizman, *Investigative Aesthetics*, p. 89.

133 Pettman and Thacker, *Sad Planets*, p. 5.

134 Ibid, p. 24.

stress in response to climate change. It is not defined as a clinical disorder, but a rational emotional response to environmental crisis, ecological degradation, and the perceived failure of institutions to act. Though experienced by people of all ages, young people are disproportionately affected by climate anxiety, expressing apocalyptic and pessimistic views about the future. Other related terms are eco-anxiety, ecological grief, solastalgia, eco-angst and environmental distress.¹³⁵

As a structurally produced, collective affect shaped by global systems of ecological degradation, data saturation, and delayed response, climate anxiety is not an irrational state. It is a sign of emotional intelligence and moral engagement, an awareness that something is deeply wrong. Yet this heightened sensitivity does not always translate into clarity or empowerment. For some time now, it has been abundantly obvious what must be done: we need to dramatically reduce carbon emissions. And here, we encounter the familiar paradox, that the individual action feels insufficient, while collective action remains elusive. The behavioural change of one person does not change much, and the change of many could change everything. We are dealing with a systemic issue, that is too vast for one person to solve. We depend on one another, yet find ourselves governed by top-down systems that are increasingly polarised, slow to respond, or entirely unresponsive. This transforms into frustration, helplessness, and recursive anxiety. We feel that everything matters, and nothing feels like it is enough.

So, we get offered the digital twin of Earth. Designed to forecast and pre-empt environmental catastrophe, it projects crises before they arrive, turns unknowns into predictive probabilities, and generates governance systems that act in response to what may happen. But in doing so, it amplifies anxiety. Climate anxiety is fed by this constant exposure to the uncertain not-yet, to imagined disasters and scenarios just over the horizon. It is the affective product of a system that is always looking ahead, in continuous update, never landing anywhere.

Timothy Morton, in *Being Ecological*, writes about this looped temporality. The future keeps arriving, and the crisis is both always already happening and never quite fully here. In this suspended time, we anticipate, forever deferring action, because the disaster remains speculative, out of reach. Anxiety has a specific relationship to time, and it thrives on delayed, suspended waiting, in tension with the simultaneous feeling of imminence.

Through forecasts, scenarios, and simulations, the digital twin of Earth displaces the present. As simulations become more granular, our sense of immediacy erodes and we begin to live in the world's projections. The more we know, the further we feel from what is actually happening. Timothy Morton describes this as a fundamental gap between data and things. There is a structural disjunction in which data multiplies and meaning evaporates. He writes, "we are stuck in the opening stages of trauma", unable to move forward, endlessly refreshing the feed.

This loop between anxiety and abstraction, knowledge and helplessness, becomes the dominant mood of our time. It is a feeling of being shaped by systems designed to predict and manage the future, yet unable to resolve the present. Here, anxiety appears as a

135 Working Group on Learning for Sustainability. "Eco-anxiety and Wellbeing: The Policy Challenges" [online]. European Commission, 2023 [cit. 2025-04-04]. Available from: https://wikis.ec.europa.eu/download/attachments/44165726/SEPT%2023%20Input_paper_ecoanxiety.pdf

collective atmosphere. But no system can sustain this affect indefinitely. Where anxiety persists without release, it either collapses into sadness and melancholy, or seeks coping strategies in illusions of control. Next, we explore the fragile comforts of techno-optimism.

3. 4. Comfort in techno-optimism

Climate change confronts us with uncomfortable truths about systemic environmental and social crises. The overwhelming complexity of these issues generates all sorts of negative affects, some of them described here: anxiety, melancholy, feelings of strangeness or overwhelm. However, as Klein explains, digital twins seem to offer solutions, serving as protection strategies in these existential crises. We do not want to participate in mass extinction. “*Humans did not need to trash the planet.*”¹³⁶

A digital twin of Earth offers a way to externalise and simplify the overwhelming complexity of the climate crisis, transforming it into something seemingly manageable and actionable. Simulating Earth’s systems provides a sense of control and predictability, aligning with humanity’s desire to project solutions onto technological constructs rather than confronting the systemic roots of these crises. As Klein’s doppelgänger culture suggests, the twin reflects an idealised version of the planet, one that prioritises optimisation and control while deflecting attention from the messier realities of inequality, extractivism, and historical injustices. In this way, the digital twin acts as both a promise of hope and a mechanism for avoidance, allowing us to navigate the existential anxiety of climate change without fully engaging with its underlying causes.

When all starts to fall apart, we hand the wheel to the twin, as someone (something), who cannot be held accountable, but claims to be in control. As artist Tega Brain reminds in her essay *The Environment is not a system*, “*we use data to study problems that would be more effectively addressed through simple political action.*”¹³⁷ Technological solutions are, perhaps intentionally, increasingly acting to maintain the status quo. The digital twin allows us to return again and again to the fantasy that the climate crisis can be solved with more precision, more data, more modelling, rather than systemic change.

Cultural theorist Lauren Berlant calls such affect a cruel optimism, described as the attachment to an object that sustains us while also obstructing the transformation we long for. The digital twin is optimistic because it enables us to stay in proximity to a scene of imagined resolution. As Berlant writes, optimism is cruel “*when the object/scene that ignites a sense of possibility actually makes it impossible to attain the expansive transformation for which a person or people risks striving.*”¹³⁸ It allows us to expect that the nearness to the simulation, to the dashboard, to the platform, will make a difference. It is cruel, precisely because it allows for the material conditions that drive the collapse to remain unchanged. Technology as both a remedy and a poison, as Bernard Stiegler de-

136 Pettman and Thacker, *Sad Planets*, p. 36

137 Brain, “The Environment Is Not a System.”

138 BERLANT, Lauren. *Cruel Optimism*. Durham: Duke University Press, 2011. ISBN 9780822351115, p. 2.

scribes and terms pharmakon. The same systems that soothe our fears also poison our actions. The same infrastructures that claim to sense the Earth more fully, closely, and better, are the ones that buffer us from its material and emotional reality.

The Earth we see through its digital twin is the idealised version, a truth we can bear. “*The fear of anticipation is less intense than the fear you experience in the middle of an entirely unexpected trauma.*”¹³⁹ The digital twin of Earth is not burdened with cruel colonial histories and extractive violence. It is a nicely clean, structured, high-resolution composition, made comprehensible, made playable, made comforting. It absorbs the anxieties, fears, guilt and shame that would otherwise be activated by the direct encounter with climate devastation. As an affective infrastructure, it dangerously manages our emotions.

The tech bros’ Neo-promethean desire to master nature through elaborate technologies, geoengineering, and smartification here can be understood as a coping mechanism with emotions too difficult to deal with. “*Techno-optimism is the metallic silver frosting on the deep-baked cake of sadness on which we chew like a cud in a doomed bid to ignore the loudly howling void.*”¹⁴⁰ We should see techno-optimism for what it is – “*the symptomatic flip-side of a profound sadness, or even an ‘infinite resignation,’ regarding the future of not only the human race but the grim trajectory of the entire planet.*”¹⁴¹

3.5. Melancholy

Sadness is “*what remains when the energy or passion ... burn away.*”¹⁴² Pettman and Thacker focus on the affect of sadness, as an underlying condition of anxiety, angst, and anger. Sadness is not eruptive like anger, or pungent like fear. It stays and lingers as the residual affect following crisis, slowly, quietly and heavily. Unlike anxiety, sadness does not look forward, and unlike rage, sadness does not demand change. It is a simple recognition of loss.

In a time “*that asks us to sacrifice everything but our optimism and hope,*” sadness is culturally unspeakable. We believe we must act, be resilient and remain hopeful. And sadness creeps in as a refusal to forget, holding us on the ache of disappearance. It is, perhaps, the most honest response to the slow violence of climate collapse.

This is sadness for the world that is slipping away, not only physically, but in its very intelligibility. The grief arises when the frameworks and narratives we used to understand our place in the world begin to break down. Our cultural narratives of progress, growth, and human supremacy are no longer adequate, but nothing coherent has replaced them. Sadness emerges not only for what is getting lost, but as a feeling that we no longer know how to live within what remains.

As Pettman and Thacker write, we have lost the world. The world, which was once rather abstract and full of symbolic resonance, has translated into an objective, knowable

139 MORTON, Timothy. *Ekobyť*. Přeložil Ondřej Trhoň. Praha: ArtMap, 2023. ISBN 9788088268442, s. 24.

140 Pettman and Thacker, *Sad Planets*, p. 35.

141 Ibid, p. 35.

142 Ibid, p. 8.

factual object. Heidegger called modernity in 1938 “the age of the world picture”, when the world is turned through science and technologies into an object for observation and manipulation. “*Making the world visible*”, the usual argument of science, is in the end distancing us further from the world. In the age of the world picture, we are losing worldhood with all its rich, lived and shared experience of the world as something we are in, not only looking at.¹⁴³ It is somberly ironic, “*the moment we see the world as a unified visual, cognitively graspable object, we lose the capacity to really think about the world ... Assuredly, the scientific gaze tells us as much about the world as the male gaze tells us about women.*”¹⁴⁴

The digital twin of Earth, as it should be obvious now, crystallises from this condition of the picture of the world. To make visible the planetary processes of climate change does not make them any more palpable. Melancholy emerges only in the absence of such systems, when the simulation ends, and the full emotional reality of loss is allowed to surface. In that sense, the digital twin functions as an affective filter that, by modelling the Earth, suppresses the grief we might feel for it.

In the face of planetary loss, the most radical thing one can do may be to mourn the world properly. Not to reduce loss to data, or defer grief through simulation, but to stay with the sorrow of what is vanishing. It is about grieving beyond specific events towards entire epochs, cosmologies, and modes of being. As the planet warms and old narratives collapse, melancholy becomes the mood of a species losing its story.

“*Pre-modern cultures invented all sorts of rituals, stories, and creative mechanisms for feeling at home in this world. Indeed, they invented worlds, in collaboration with the Earth, which made living more meaningful, more sensory.*”¹⁴⁵ These worldviews, however, were dismissed as “backward” or “savage” by the very same systems that now seek to manage and control the planet through abstract representations in the name of progress.

In such a time, mourning becomes a slow political practice, not calling us to immediate action, but asking us to stay-with, resist the pressure to move on, to heal quickly, or to be optimistic. Staying-with creates potential to quietly refuse the world that enabled its loss in the first place. Perhaps melancholy can lead toward another way of relating to the Earth, one that is grounded in what truly matters - listening, humility, and enduring attention - toward something like attunement.

143 HEIDEGGER, Martin. *The Age of the World Picture. In: The Question Concerning Technology and Other Essays*. Translated and edited by William Lovitt. New York: Harper & Row, 1977. ISBN 9780061319693, pp. 115–154.

144 Pettman and Thacker, *Sad Planets*, p. 13.

145 Pettman and Thacker, *Sad Planets*, p. 33.

IV. Attunement

Anxiety, sadness, overwhelm, anger, hopelessness, rage, all these negative affects bleed into each other, coexist, and build an atmosphere for living. They shape individual emotional landscapes but also collective moods, saturating the everyday with disorientation and pressure. It is important to recognise that the focus here is not on pathologising emotional experience, but rather on tracing how these negative affects emerge as sane, understandable responses to broader systemic conditions: ecological collapse, political failure, technological acceleration.

Here, the question shifts from what is the Earth as seen through its digital twin and how it makes us feel, to how to live with and within the conditions revealed by these machinic infrastructures.

What follows is not a conclusive proposal, but a personal and conceptual orientation. It is a way of gathering some of the threads this thesis has traced and asking: what kinds of responses, sensibilities, and infrastructures might support livable futures under conditions of planetary crisis? These reflections come from within my own entangled position as an artist navigating technological infrastructures, as a subject shaped by anxiety, burnout, and beauty, and as someone trying to make sense of a world that often feels too fast, too complex, too broken to hold.

IV. I. Atmospheric Pressure

When I first encountered the idea of the digital twin of Earth, a world that could be simulated, seen, and perhaps even understood, I was fascinated. As an artist working with satellite imagery, environmental sensors, and weather APIs, I was fascinated by the ways data could make invisible processes visible. It felt powerful to be able to map, measure, and visualise the unseen phenomena of Earth.

The deeper I went into this world of sensors, simulations, and technical systems, the more I felt lost. The complexity of the infrastructures, the endless streams of new information, the constant remodelling of futures, it all became overwhelming. Instead of feeling closer to the Earth, I felt strangely detached from it.

I often find myself paralyzed between contradictory pressures. The fascination with technological power to see and model alongside an unsettling sense of distance; moments of excitement blurred into feelings of sadness; hope for technological solutions clashed with the growing awareness that the problems are deeper. The imperative to “keep up,” to “grow,” to optimize myself into resilience, comes hand-in-hand with the creeping knowledge that these demands are symptoms of the very systems making life increasingly

unliveable.

Climate collapse saturates my daily life as a background pressure woven into everyday work, future planning, and even attention itself. I live between futures modelled in simulations and pasts archived in data, often losing the felt presence of the now. Perhaps anxiety, sadness, anger, exhaustion are not failures of individual coping, but the only embodied way to sense planetary crisis. Affects become the medium through which planetary instability is lived before it is fully understood.

Living through planetary crisis, one often inhabits a state of affective layering where sadness and anger, fear and numbness, grief and helplessness accumulate. Not a personal failure, nor simply an individual psychological burden, it is an atmosphere produced by structures far larger. The tensions produced by political systems that demand resilience while offering no security, economic logics that accelerate extraction and collapse while prescribing individual self-care as the solution, and technological infrastructures that promise control while deepening alienation are all forces contributing to this condition.

During the research for this thesis, I found myself close to burnout. It was a condition so many of us inhabit: a constant state of motion, moving from studies to work to side projects and internships, rarely pausing. Trying to understand the labyrinthine architectures behind the digital twin, its satellites, sensors, climate models, predictive interfaces, it became too much. The scale of climate change and its technological infrastructures often exceeds what the mind and body can hold. It was the complexity of the systems I was researching, and the tempo of the world around them, and around me.

It was also a moment of inner tension for me, moving from critical analysis of Earth data infrastructure, to professionally working as a creative coder who uses those very datasets to communicate climate change. The air pollution sensors I worked with gave neat numbers, thresholds of good and bad, but breathing the air outside felt harder to frame.

In this disorientation, the only way forward was to slow down and shift focus from trying to control or fully understand the whole, toward paying close attention to the small, the nearby, the specific. To notice the warmth of the ground, the heaviness of humid air, the smell of rain-soaked dust. This change in attention also reshaped my artistic practice. I moved from working mainly with abstract data visualisations to creating multisensory installations and experiences that invite breathing, touching, listening, feeling. Planetary knowledge must be embodied, felt, relational.

Therapy and reflection also helped. And I see this all around me, among friends, peers, other young and passionate people trying to make sense of their place in the world. It's almost become a quiet part of how we live now, something many of us turn to just to keep going. Not the kind of therapy that urges relentless positivity or promises quick productivity, but approaches that allow grief, anger, sadness to be present. Accepting these feelings instead of fighting them made it possible to stay open and to remain attuned to the complexity.

Through this process, I realised that feelings like anxiety and sadness are not problems to be fixed, but ways of sensing the world's instability before it can be fully named or understood. They emerge as sane, understandable responses to broader systemic conditions: ecological collapse, political failure, technological acceleration. They are forms of connection to a world in crisis.

Attunement, then, is not calm acceptance. It is learning to stay with uncertainty, to

remain connected even when things do not make sense, to care even when solutions are not clear. And sometimes, it simply means allowing space to feel what is happening and to mourn, to rage, to grieve, and still to find small, stubborn ways to care for the world we are part of.

IV. II. Responding

From this personal terrain of affective experience, the thesis now moves toward conceptualising what it proposes as a response: attunement. To attune, in the context of planetary crisis, is a way of acknowledging the impossibility of fully mastering or resolving the scales of crisis we inhabit, while remaining committed to care, relation, and situated presence. I position attunement within broader critical traditions, grounding it against feminist, ecological, and posthumanist thought. Here, attunement operates as an open, ongoing orientation toward complexity.

Drawing from feminist, ecological, and posthumanist traditions, attunement refers to a situated, relational practice of sensing-with and thinking-with the world. It insists that knowledge is never abstract, disembodied, or outside its conditions of emergence. As Donna Haraway reminds, to “stay with the trouble” is to remain within the messy entanglements of life on a damaged Earth, resisting the fantasies of transcendence that so often accompany technological and scientific imaginaries.¹⁴⁶ Anna Tsing, in *The Mushroom at the End of the World*, similarly proposes the arts of noticing.¹⁴⁷ She teaches that in the worlds of precarity and ruin, survival depends on sensitivity to contingent relations. She also teaches to attune to the form in motion and to notice carefully other ways than language, that species express themselves.

Both Haraway and Tsing foreground an ethic of situatedness and response-ability: the capacity to respond, to stay-with, to be changed by encounters. Attunement, in this lineage, is not passive observation. It is a call to attentively listen where modernity taught us to command. It requires us to slow down and learn from entanglement, rather than seek to untangle or resolve it. In a world structured by abstraction and disconnection, attunement becomes a form of resistance: a method for making meaning in complexity without erasing it.

Attunement is not easy. It does not eliminate anxiety, melancholy, or rage. It does not “solve” planetary crisis. Nor does it offer a single path forward. In many ways, it increases sensitivity—to grief, to uncertainty, to fragility. But it also opens spaces for collective care, for solidarity, for remaining with the complexity without being paralyzed by it.

To attune, then, is also to participate in processes of planetary mattering: to stay responsive to how worlds are co-constituted through technologies, imaginaries, affects, and politics. Attunement, in this sense, is a refusal to take these computational renderings at face value. It asks: whose Earth is being twinned? What is being excluded in the name of

146 Haraway, *Staying with the trouble*.

147 Tsing, *Mushroom at the End of the World*.

precision? What alternative forms of sensing, knowing, and caring are sidelined by the drive toward simulation? To attune is to approach this modelling with a heightened awareness of its partiality, its politics, and its emotional charge. It is a way of staying accountable to the Earth we inhabit, not just the one we simulate.

If Haraway and Tsing help us develop the ethics of attention, care, and response-ability, this sensibility must now meet its most difficult test: the scale, abstraction, and infrastructure of planetary computation. How do we attune not only to mushrooms and moss, but to orbital satellites, predictive dashboards, and climate simulations? This is where attunement must stretch—not abandoning the terrestrial, but holding space within the planetary.

IV. III. Between Scales

The planetary infrastructures that shape today's reality—satellite constellations, climate models, algorithmic forecasts—have scaled far beyond the immediate sensory world. They operate at spatio-temporalities we cannot inhabit: geological, computational, future-predictive. As Benjamin Bratton argues, we now live inside systems that are planetary not by metaphor, but by infrastructure. These are the architectures within which perception, decision, and governance increasingly operate.

While planetary infrastructures extend into temporalities and scales that far exceed our everyday experience, our ability to respond begins in much smaller registers: in perception, relation, and attention. Attunement emerges here as a practice rooted in this gap. It works through situated, embodied encounters that resonate with the wider structures we inhabit.

Comparative Planetology works with three figures: Globe, Planetary, Terrestrial. In light of Lukáš Likavčan's cosmology, the thesis positions itself primarily as a critique of the Globe, the dominant imaginary of Earth as a calculable, optimisable whole. The digital twin of Earth exemplifies this worldview as a smooth, high-resolution representation aimed at simulation, control, and prediction. Most of this thesis has traced how this figure emerges, what political and epistemic assumptions it carries, and what it leaves out.

From this critique, another orientation emerges. Likavčan offers the Planetary and the Terrestrial as conceptual departures from the Globe. The Planetary foregrounds abstract infrastructures and machinic systems, drawing attention to the entangled, computational, and post-anthropocentric scales at which contemporary crises are. It is a call to develop conceptual tools capable of thinking-with vast, systemic, nonlocal realities.

The Terrestrial, by contrast, insists on proximity, partiality, and care. It seeks to recover grounded, lived forms of knowing, emphasising vulnerability, attachment, and the ethical dimensions of shared existence. Likavčan treats the Terrestrial as a necessary counterweight to abstract planetary reasoning, but he leans toward the Planetary, not as an endorsement of abstraction for its own sake, but as a call to develop conceptual tools that can engage with systems already shaping life at global scales—tools that must, nonetheless, remain aware of their epistemic limits. He cautions against romanticising locality, warning that without systemic thinking, the Terrestrial risks becoming politically ineffective or nostalgically inward-looking. Still, he acknowledges that any viable politics must remain sensitive to the lived and the embodied.

Attunement, as developed here, moves between these two figures. It draws on the conceptual depth and scale of the Planetary while staying rooted in the ethical force of

the Terrestrial. It aims to inhabit the tension between them. Attunement becomes a way of navigating planetary-scale complexity without surrendering the capacities to care, to grieve, to remain present.

Where Comparative Planetology maps how Earth is imagined and organised at scale, the framework of Planetary Mattering, developed within the More-than-Planet project at Waag Futurelab, asks what becomes meaningful within those imaginaries.¹⁴⁸ It shifts the question from what the Earth is to what matters, and for whom. It insists that not all data, models, or futures are equal and recognises that value, care, and justice must be made explicit within infrastructures of knowledge.

Mattering, as developed from feminist, STS, and posthumanist traditions, rejects the dichotomy of fact and value. Instead, it foregrounds the entanglement of epistemology and ethics. As Karen Barad, Isabelle Stengers, and Donna Haraway argue, facts are not neutral; they are formed within relations of power, desire, and care. Mattering asks us to consider what gets represented, what gets left out, and what consequences follow.

Within this framework, the digital twin of Earth is analysed not only as a matter of fact as a grid of measurable data but as a socio-technical assemblage shaped by matters of risk, control, concern, justice, care, and hope. While it promises predictive insight, it often reproduces the same logics that produced the climate crisis: abstraction, optimisation, and exclusion.

Planetary Mattering complements Comparative Planetology by asking us to shift attention. Where the latter describes figures of the Earth, the former interrogates what is made to matter within those figures. Together, they support an inquiry that is both conceptual and ethical, both systemic and situated. Attunement, then, emerges from the combined reading of both.

As Likavčan provocatively asks, citing Jan Zalasiewicz, “*Was this project, in which the Earth formulated from itself a biochemical intensity (aka humans) capable of knowing how old it is, worth the cost?*”¹⁴⁹ The image is striking: Earth producing the human as an instrument to measure and understand itself—a planetary-scale reflexivity. But this is not a question that simulation or optimisation can answer. It is a question that belongs to attunement and to mattering. It asks not only what the Earth is, but what it means to know it at such cost. It echoes Likavčan’s Earth-without-us, a figure that “*has always been here, we just failed to notice.*”¹⁵⁰ Attunement, then, becomes a way of noticing: a way of staying with this strange and irreversible unfolding, and asking what matters, to whom, and at what price.

It’s not a question of opposing local knowledge to global systems, but of insisting that the relational, the lived, and the historical be part of how we build planetary tools. The Netherlands sophisticated water management infrastructure is often held up as a global model combining predictive simulations, hydraulic engineering, and real-time environmental sensing. It mirrors the ethos of digital twin, anticipating, controlling, stabilising.

148 It is important to note that the concept of Planetary Mattering builds upon Likavčan’s research, with Likavčan himself being closely involved from the outset—leading workshops and contributing to the development of the Planetary Public Stack.

149 Likavčan, *Introduction to Comparative Planetology*, p. 88.

150 Ibid, p. 92.

Attunement here asks differently.

In my earlier research situated in the Netherlands, I studied diatoms, microscopic algae, whose lives are altered by the opening and closing of dykes. These tiny organisms register infrastructural decisions in embodied ways through changes in water flow, light, and nutrients. They are witnesses of planetary management. Attuning to diatoms makes us ask what the systems overlook. This is not about romanticising the microscopic, but about asking whether planetary tools can be designed to respond to the multispecies ecologies they impact, even, or especially, when those relations do not fit cleanly into models.

In this example, through *The Planetary* we can grasp the infrastructural and computational logics at work in water governance, while *Planetary Mattering* shifts attention toward the ethical and affective dimensions of the consequences for human and nonhuman life, the epistemic exclusions, the histories of control. What if attunement informed the design of planetary systems, not as a soft addition, but as a fundamental principle of responsiveness, of situated accountability? Rather than simply simulating Earth's dynamics, infrastructures could begin to care with them.

To attune is not to retreat from abstraction, but to insist that abstraction must remain in relation to feeling, to ethics, to life. It is to think-with the Planetary, while remaining accountable to the Terrestrial. It is to refuse the fantasy of seamless knowing and instead cultivate politics that can hold contradiction, remain with complexity, and ask not only what is, but what ought to be.

This is the kind of planetary consciousness the thesis moves toward—not one simulated by a twin, but one lived-with, from within. A consciousness that listens, that lingers, that stays—even when nothing makes sense. Even when the answers don't come. Even when all we can do is notice, breathe, and begin again.

After tracing these systems, it becomes clear that part of attunement is also knowing when to pause. What happens when we refuse the pace, the pressure, the imperative to fix? What if doing less is not apathy, but a form of care? From the planetary stack, we now return to the ground—to sitting, resting, refusing, in a personal, honest reflection.

IV. IV. Troubling pace

Technological innovations like the digital twin of Earth are, undeniably, remarkable achievements. Their complexity, precision, and scale are impressive. We can appreciate their meticulousness, their innovative potential. It is clear they serve as an ego-boost for many politicians, scientists, people who work so hard to deliver such a product, believing in its promise to tackle the climate crisis, or at the very least just pay their rent.

Even though this thesis gave these projects a hard time, I want to express appreciation for the great work of all the individual beings involved often with genuine hope and belief in doing something good for humanity. It is a beautiful thing to believe in your work. It is not such a beautiful thing if the tools, done with care, get absorbed by the larger logics of control.

And we need a critical mind. It is my work, as an aspiring artist (that I sometimes believe in), as a thinker, and as someone implicated in these systems, to question, to stay critical, and to propose counter-acts.

What I want to propose here is simple. And it even makes me cringe a little, because

I wrote so many pages to come to this point. I believe we should just not try so hard. I believe that tackling climate crisis might be an embarrassingly simple endeavour – not in scale or stakes, but in the kind of attention it requires: not more control, but more care. Here, I do not mean it in the sense of being easy, but in the sense of requiring less effortful control, and more intentional attention. It is something more universal, than working with laborious things.

All these try-hard solutions, expensive, energy-consuming (electrical and emotional), born in stress, deadlines, over-hours pressure, negotiations and competitive proofs-of-concept are not going to make it. And paradoxically, I really tried hard to arrive at this point.

We often say, “this is not enough,” or that “we need more action,” we push pressure on ourselves and on others to recycle properly, to do more, to optimise, to be productive “for the planet”. And these are important impulses. They’re caring acts. It means we care, we have empathy, we are worried and we are trying. These are beautiful, generous, thoughtful things in this world. Much of what we do comes from a place of curiosity, love, or necessity. And I know many of us take genuine pleasure in our work, or at least in parts of it. That matters.

What I’m pointing to is something more subtle: the way even good things get pulled into a logic of optimisation. The way joy becomes tied to performance, and care gets instrumentalised. The way serious worries about climate collapse are routed through tools designed for risk assessment and prediction. A project like the digital twin of Earth may emerge from institutional ambitions, but it is also shaped by the scientists, engineers, designers who make it, many of whom are genuinely concerned, deeply fascinated, or simply passionate about the complexity of the Earth and the elegance of modelling it. These motivations are real and important. But even they are not immune to being swept into broader systems that reward productivity, mastery, and quantifiable results.

Much of this has to do with how science is funded. Research priorities are not being shaped by curiosity or need, but by the agendas of funding bodies and policy frameworks. Proposals must align with key calls, pass through bureaucratic approval processes, and promise clear deliverables. Often, projects that claim to tackle climate change are shaped more by what can be measured, modelled, or managed than by what is most urgent or ethically pressing. It is definitely not the fault of individual researchers, but of a system that makes it difficult to imagine other ways of doing, thinking, or caring.

As Timothy Morton reminds us, it’s not about choosing sides, but learning to live in the in-between.¹⁵¹ To notice when things tilt too far. To make space for the parts that don’t fit the metrics. We need ways of holding contradiction, of living in systems we critique, loving things we also question, believing in small gestures even when larger ones feel compromised.

And so, maybe we just need to chill down a little. Slow down. Not in a way that is apathetic, but in a way that restores the possibility to live thoughtfully, sensorially, collectively. The trouble is, we live in a system that has made this “chill” way unthinkable. Through all those try-hards, innovations, progress applications, updating CVs, negotiating, arguing, trying to make a point, we lost it. We have been trained to believe that if we are not producing, optimising, growing, we are failing.

151 Morton, *All Art is Ecological*.

The world is a mess right now, and not by accident. It is the outcome of centuries of decisions, beliefs, ambitions, and frameworks that most of us alive today did not invent, but live within. It is not useful to assign blame to individuals, but equally we cannot pretend it just randomly happened. The mindset of mastery, growths, control and extraction, carried forward through empires and industries, has shaped the systems we inhabit, that are failing and exhausting us. But trying to entangle them carelessly often makes things worse. Like a messy tangled line, when we are impatient, pulling too fast, too hard, we tighten the knots. It ends up in disaster. Leaving those systems will not be an act of escape, but of careful deliberate unwinding. That requires more than critique.

And I want to sit on the grass, under the tree, and read, perhaps write – not to change the world, not because I’m paid to do it, not to reach my GoodReads goals, but because I enjoy it. I want to walk, sunbathe, get sunburnt, have meaningful conversations and lots of laughs, cry from overwhelming love or broken heart, feel the warmth of sun and the cold of rain, taste and smell all the flavours, cook nice food and perhaps burn it sometimes or over-salt it, struggle to move against the wind, swim in cold waters, watch the stars. These should not be read like overly romantic luxurious well-being programme. But of course, who has time for all that, except in the one week off from work.

That is the troubling thing. We have arrived at a moment where building digital twin of Earth feels more feasible than making time to lie in the grass. Is it just me? That is where I see the real absurdity. That rest, attention, collective slowness are now rarer than planetary-scale computation. So yeah. I think chill is the most useful thing we can do in a world in crisis. Not as an escape, or self-care, but as orientation towards vulnerability, slowness, thoughtful presence. Doing less can be a powerful political gesture in a system that only values doing more.

And attunement is a fancy little word for this. I suppose it makes it sound more serious, or digestible. But maybe that’s what it’s for—to give shape to something that is both deeply ordinary and politically urgent. In a way, it is the same idea as attunement to the planetary systems and infrastructural complexity, just zoomed in, as an experience of small, embodied refusals, on an ordinary Tuesday, under a tree. Because in the end, it’s not just about rest, but about a reorientation of values and systems. So how do we think of attunement as something more than a vibe or a personal coping mechanism?

This question carries forward into the next final chapter on Attunement. If attunement can hold both the planetary and the personal, then how might it begin to inform how we design, analyse, and inhabit the infrastructures around us? What kinds of artistic, technical, collective practices can support this orientation? What follows is a shift toward these more situated practices: experiments, examples, and invitations that treat attunement not as an escape, but as a way to stay with the mess, the data, and the world.

IV. V. Patchy Practices

Attunement, in its most concrete sense, is not just a concept but a practice. It is how we begin to build forms of noticing and care into the infrastructures we inherit and imagine. Across this thesis, attunement has emerged as both a conceptual orientation and a practical gesture: personal and collective, sensory and systemic, grounded in embodied attention yet inseparable from broader imaginaries and infrastructures.

If attunement is about noticing what matters within systems too vast to fully grasp, then how we attune depends not only on our individual dispositions, but on the tools, relationships, and institutional structures that shape perception itself. No project or methodology is perfect—indeed, perfection is often a trap of optimisation—but some attempts gesture toward what it might mean to attune at scale: politically, ecologically, and creatively.

This chapter turns to two clusters of such practice: LTER-LIFE and Open-Weather Collective, and Feral Atlas and Vertical Atlas. These projects vary in scope and structure—from ecological monitoring to speculative mapping, from institutional science to grassroots experimentation—but each in its own way sustains forms of attention that challenge extractive logics. They offer partial, situated responses to the question: what kinds of infrastructures might support not just data collection, but deepened capacities for noticing, care, and shared responsibility?

What if attunement were built into the very systems we live and work within? What if research projects were funded for attention, not outcomes? If climate visualisations invited discomfort instead of clarity? If institutions made time for collective grieving? If learning to “do less” were recognised as a form of climate adaptation? These are not rhetorical questions—they are invitations to imagine how attunement might begin to take root, not as a solution, but as an ongoing and infrastructural practice.

IV. V. I. Observing Otherwise: LTER-LIFE, Open-Weather Collective

The following two projects, LTER-LIFE and Open-Weather collective, come from very different institutional and methodological contexts—one grounded in ecological science, the other in feminist, open-source experimentation. Neither offers a fully realised model of attuned infrastructure, but both open important possibilities. They suggest that even within very different constraints, it is possible to reimagine what sensing can do for knowing and relating to the world differently. Placing them side by side is not to compare them, but to trace a field of potential asking what forms of collective attention and situated responsibility might be made possible through their practices.

LTER-LIFE and Open-Weather collective both cultivate attunement through long-term observation and environmental sensing, both building systems for long-term observation, often with nonhuman and citizen actors. Both projects are anchored in care for the environmental conditions that make life possible, and both offer ways of attuning that are gradual, patient, and open-ended.

LTER-LIFE research program in the Netherlands, which I encountered during fieldwork at Royal Netherlands Institute for Sea Research (NIOZ) on Texel island, is developing digital twins of ecosystems like the Wadden Sea and the Veluwe. While technically situated within the world of digital twins and data infrastructure, its approach differs from more grandiose planetary-scale efforts. These are not twins of the whole Earth, but highly specific, modular systems intended to support ecological research.¹⁵² As Dr. Qing Zhan explained during our conversation, these digital twins begin not with a dataset, but with a question.

152 LTER-LIFE. “LTER-LIFE: Digital Twins of Ecosystems.”

At NIOZ, ecologist Prof. Dr. Katja Philippart focuses on the role of diatoms in the Wadden Sea, a dynamic intertidal zone where human-made dikes and locks govern the flow of water. Diatoms rely on the vertical mixing of water to access light, making them sensitive indicators of how infrastructural decisions made at the human scale ripple across nonhuman ecologies. By combining satellite data and in-situ monitoring, LTER-LIFE enables researchers to simulate and study these dynamics and potentially inform environmental policy.

Unlike Destination Earth, which tends to work from the scale of the planet downward, LTER-LIFE works from specific ecologies outward. It does not attempt to simulate everything at once. Its infrastructure is built to support partial, situated, and question-driven modelling. However, its commitment to reproducibility, interoperability, and predictive modelling still locates it within the paradigm of scientific control. The platform's tools—containerised workflows, FAIR data pipelines, cloud-based virtual labs—enable collaboration, but they also consolidate particular assumptions about what knowledge matters and how it should be produced. Infrastructural openness does not necessarily guarantee epistemic plurality.

LTER-LIFE holds potential for more collaborative and accountable science, but it is not immune to the pressures of scale, funding, and techno-optimism. The question, then, is how to maintain space for ecological and ethical attunement within these infrastructures—how to listen not just to the data, but to what escapes or resists being modelled.

If LTER-LIFE approaches attunement through institutional science and infrastructural design, the Open-Weather collective takes a different path: one grounded in citizen science, creative practice, and feminist approaches to sensing.

A feminist and citizen-led meteorological collective, Open-Weather offers another type of attunement: a decentralised, participatory way of sensing and narrating weather. They connect people across the globe using open-source tools, satellite data, and radio receivers to collaboratively construct weather reports that are as much about emotion, politics, and presence as they are about temperature or humidity. By collectively capturing NOAA satellite signals and sharing their own local weather observations, participants reclaim a piece of the sensing apparatus typically dominated by states and corporations.¹⁵³

Rather than building centralised models, Open-Weather cultivates distributed, embodied, and participatory forms of sensing. Their Public Archive is an open, collaborative attempt to build a patchy, DIY archive of weather from below. Participants contribute readings using homemade ground stations or borrowed tools, describing the atmosphere not just through numbers, but through sensation and language: the air is scrambled, polluted, enveloping, thick, heavy. These are not anomalies or noise in the dataset—they are the data. Open-Weather invites a rethinking of what counts as climate knowledge. It asks: *“What would it mean to collectively image, and in doing so, reimagine the planet? To see its details and patterns from many situated positions? If we could each take a photo of our home from space, could we build a patchwork, an impossible view, another whole*

153 OPEN-WEATHER. “Open Weather Collective.” [online]. [cit. 2025-05-01]. Available from: <https://open-weather.community>

*Earth?*¹⁵⁴

The collective offers no singular output, no master model or central platform. Instead, it generates a “patchy record,” a fragmented, overlapping sensorium of climate as lived and felt. Over the course of their Impossible Weather Station project, contributors are invited not just to measure but to read the weather—collectively inventing new forms of storytelling and climate witnessing. This is attunement not as extraction, but as relation; not as solutionism, but as sensing-in-common. It’s a practice that refuses the closure of the forecast and instead opens space for shared witnessing.

While LTER-LIFE develops long-term ecological research infrastructures within institutional science, Open-Weather explores participatory sensing through DIY methods and speculative design. One is shaped by ecological modelling and policy relevance; the other by collective, situated experiences of weather. These projects differ in origin, scale, and structure—but both gesture toward attunement as a shared practice.

Attunement here is not a fixed technique, but a way of building environmental infrastructures that support noticing, slowness, and relational awareness. Rather than seeking seamless knowledge or control, both projects remain with complexity: through data and diatoms, through static interference and open skies.

By holding these projects in dialogue, we begin to see what attentional infrastructures might look like—whether supported by institutions or grassroots efforts. They remind us that how we structure the tools of sensing shapes what becomes visible, valued, and possible to care for.

IV. V. II. Rewriting the map: Feral Atlas, Vertical Atlas

Where the first case operates through infrastructure and situated sensing, Feral Atlas and Vertical Atlas intervene at the level of cartography and imagination. They do not measure so much as reorient. Both challenge how we visualise and narrate the planetary, refusing the smooth abstractions of global models or universal maps.

Feral Atlas, edited by Anna Tsing and collaborators is a digital cartography that collects over 70 field-based reports on more-than-human histories. These are disruptions not necessarily intended by humans but set in motion by infrastructural systems—like the spread of toxic algae due to shipping routes, or the movements of sandstorms linked to desertification from global agriculture. Rather than aiming for seamless integration or predictive clarity, the Atlas fragments the map, offering dozens of situated reports, each a portal into a different entangled zone of the Anthropocene.¹⁵⁵

These accounts make space for the messy, the historically situated, the ecologically strange. They invite a form of reading, and of worlding, that listens before it explains, that attends before it abstracts. It invites readers to shift their attention from mastery into muddy, difficult cohabitation with toxic residues, infrastructural violence, and wild non-human actors.

154 Open-Weather, “When I Image the Earth, I Imagine Another.” [online]. [cit. 2025-05-01]. Available from: <https://open-weather.community>

155 TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene* [online]. Stanford, CA: Stanford University Press, 2021 [cit. 2025-05-01]. Available from: <https://feralatlas.org>

The Atlas offers not a single map, but many entrances through narratives, drawings, and visual fragments. One such case, “The Victims of Carbon Dioxide Are Starting to Appear,” documents carbon dioxide not as a number or graph but as a feral actor—let loose from the regulatory rhythms of Earth’s systems. It traces its planetary invasion: bleaching coral reefs in Australia, fuelling wildfires in the Arctic, and collapsing ancient Antarctic ice shelves. Rather than a system variable, CO² becomes an agent of cascading transformations, whose scale and timelines stretch far beyond immediate human perception. The entry does not offer closure. It asks us to stay with the victims—to witness the slow violence carbon dioxide enacts on more-than-human life.¹⁵⁶

Another entry, “Coffee Rust Spreads Together with Coffee Plantations,” offers an intricate ecological history of how colonial infrastructures, global trade, and monocultural agricultural policies intensified a fungal disease that decimated coffee plants. The outbreak is not framed as a natural disaster, but as a feral effect of technification—of systems that replaced shade-grown, diverse agroecosystems with sun-exposed, pesticide-reliant monocultures.¹⁵⁷

A third case, “As Lichens Absorb Air Pollution, They Show Us the Limits of Livability,” centres on lichens and mosses as vegetal sensors of atmospheric change. Through centuries, they have quietly recorded environmental histories—pollution levels, industrial footprints, even radioactive fallout. Their presence, absence, and form tell stories of air quality and transformation. They are slow, partial, collective indicators, reminding us that environmental sensing need not be fast or high-tech to be meaningful. These organisms absorb the world’s changes through their very tissues, embodying the kind of lived, entangled attention that attunement calls for.¹⁵⁸

Feral Atlas, then, does not model the Earth. It fragments it. It multiplies entry points and epistemologies. It resists a single narrative and invites readers to wander through localities, processes, and witnesses. This is a cartography not of control, but of implication. It resonates deeply with the practice of attunement: not only asking what matters, but noticing how those matters appear—in fragments, in multispecies lives, in feral effects that escape prediction.

In a similar way, Vertical Atlas refuses the flattening effects of maps. Developed by Het Nieuwe Instituut and the Hives Digital Earth fellowship, it similarly rethinks cartography for the computational era. Rather than offering a singular, seamless image of the

156 MILON, Anne-Sophie; ZALASIEWICZ, Jan. “The Victims of Carbon Dioxide Are Starting to Appear” [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/the-victims-of-carbon-dioxide-are-starting-to-appear>

157 PERFECTO, Ivette. “Coffee Rust Spreads Together with Coffee Plantations” [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/coffee-rust-spreads-together-with-coffee-plantations>

158 GABRYS, Jennifer. “As Lichens Absorb Air Pollution, They Show Us the Limits of Livability” [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/as-lichens-absorb-air-pollution-they-show-us-the-limits-of-livability>

Earth, the project fragments and reorients our understanding of digital infrastructure by highlighting the verticality of power, data, and governance. The atlas is not a map in the conventional sense; it is a polyphonic, multi-perspectival tool that foregrounds friction and difference. It challenges the reader to understand where they stand—not just geographically, but within computational systems, media ecologies, and global infrastructures. Vertical Atlas doesn't offer orientation in the traditional sense. It multiplies perspectives, insisting that planetary life is built through overlapping, incommensurable frameworks.¹⁵⁹

One of the strands of this project is “world.orbit,” which focuses on critically engaging with satellite data. Through a series of workshops, participants explored the artistic, theoretical, and philosophical possibilities for a non-exploitative use of remote-sensing software to witness Earth in all its complexity. The workshops highlighted how satellite data, often perceived as neutral, are in fact shaped by specific goals and assumptions, influencing how we perceive and interact with our environment.¹⁶⁰ Cristina Cochior's essay, “Witnessing with Earth Observation Technologies,” expands on these workshops by examining how remote sensing participates in imaginaries that describe and mobilize the world in particular ways. Cochior emphasizes the need to repurpose remote-sensing technologies to relate to the world in more affirmative and generative ways, acknowledging the frictions and biases inherent in data generation and interpretation.¹⁶¹

These contributions underscore the importance of attunement—being sensitive to the complex, layered, and often conflicting realities that constitute our digital and physical environments. By embracing multivocal and multifocal perspectives, Vertical Atlas encourages a more nuanced engagement with technologies and understanding of their frictions and fault lines that define our contemporary condition.

Both Atlases present exercises in attunement to orient ourselves within a world that cannot be fully seen from above, or fixed through interfaces. They slow us down and call us into responsibility through situated noticing. They ask us not just to map the world, but to question how we are implicated in it. While not offering ready-made solutions, both projects perform an attunement of their own: they make complexity perceptible without reducing it to a singular image. Whether through algae, satellites, publications, or speculative software, they raise an essential question: what kinds of knowledge infrastructures could be designed not to master the world, but to stay with it?

Attunement, then, is also a practice of storytelling. Not just feeling differently, but narrating otherwise. It means noticing the stories we inherit—the ones about growth, control, mastery, inevitability—and to tune into those running underneath or alongside them: stories of maintenance, decay, collaboration, survival, improvisation. Stories told quietly, across generations, across species, in the background hum of infrastructures and the silences they produce.

159 DELLANOCE, Leonardo; KHALAF, Amal; KUITENBROUWER, Klaas; NYABOLA, Nanjala; ROUKENS, Renée; STEINER, Arthur; YOU, Mi, eds. *Vertical Atlas*. Arnhem: ArtEZ Press, 2022. ISBN 9789491444692.

160 NIEUWE INSTITUUT. “Vertical Atlas – World.Orbit” [online]. Rotterdam: Het Nieuwe Instituut, 2022 [cit. 2025-05-01]. Available from: <https://nieuweinstituut.nl/en/projects/vertical-atlas/worldorbit>

161 COCHIOR, Cristina. “Cristina Cochior – Vertical Atlas” [online]. Vertical Atlas, 2022 [cit. 2025-05-01]. Available from: <https://verticalatlas.net/#cristina-cochior>

IV. VI. This is not an ending

Attunement is not a framework or a fix. It does not promise resolution. Instead, it invites a shift in the terms of attention: from the scalable to the situated, from control to relation. It asks us to stay with partial truths, with remainders, with things that don't compute. It asks us to feel time differently—not in terms of efficiency, but endurance.

This might mean listening for the histories buried in soil and server farms: of extraction, resistance, kinship, refusal. It may mean reading the traces of empire in the supply chain, or noticing how care has always existed outside the models. It might mean learning from those whose cosmologies and knowledges were never encoded into Earth simulations but have long practiced forms of ecological stewardship and responsibility.

As Donna Haraway reminds us: *it matters what matters we use to think other matters with*.¹⁶² Attunement is not a passive reception of information, but an active choice to tune our frequencies to stories that complicate, resist, and deepen, thicken perception, and cultivate response-ability.

To attune, then, is to practice an ethics of noticing. To slow down not only how we perceive, but what we expect. It is to practice listening without assuming command, to remain with complexity, even when it unsettles. Planetary-scale computation cannot replace the need to live well with each other—on the ground, in bodies, through histories.

If there is a final gesture this thesis makes, it is not toward resolution but toward redirection: from modelling to mattering, from system to situation, from knowing to caring. In the end, attunement is not what fixes the world. But it might be what makes it possible to stay in it, to stay with it, and to stay with each other.

162 Haraway, *Staying with the trouble*.

Conclusion

This thesis has traced a trajectory across infrastructures, aesthetics, and affects, following the emergence of the digital twin of Earth as a contemporary figure visualising the planetary. The thesis layered analysis of technical architectures, visual regimes, and affective landscapes, with the aim to understand how planetary-scale sensing, simulation, and governance infrastructures reshape human perceptions of Earth, and how they generate new forms of subjectivity, knowledge, and emotion in the context of planetary crisis.

This thesis responds to the question of how the digital twin of Earth mediates our perception, governance, and emotional experience of planetary crisis by tracing the figure of the twin across its technical, aesthetic, and affective dimensions. It shows how the digital twin actively shapes how Earth is known, sensed, and governed. Through its reliance on planetary-scale computation and predictive modelling, the twin transforms the climate crisis into a calculable, manageable object, producing a new mode of planetary visibility that privileges abstraction and constant optimisation. Across chapters, the thesis layered technical research, conceptual frameworks, and artistic interventions to hold together the material, visual, and affective dimensions of Earth's doubling.

A central methodological strength of the work lies in its deliberate combination of empirical observation and theoretical reflection. The close study of digital twin platforms, such as *Destination Earth*, was grounded in detailed technical research and situated experience, while being woven together with conceptual frameworks drawn from media theory, critical infrastructure studies, aesthetics, and affect theory. This approach allowed the thesis to remain attentive to both material infrastructures and their cultural logics without reducing one to the other.

Rather than freezing its object of study into a fixed definition, the thesis stayed with the evolving, speculative, and unfinished nature of the digital twin. This processual approach allowed for a dynamic critique that respected the unfinished, sometimes contradictory realities of contemporary technological projects.

The thesis engaged with Likavčan's *Comparative Planetology* as a methodology to actively work with, by testing and applying the figures of the Globe, Terrestrial and Planetary to examine how the digital twin of Earth aligns with certain political and aesthetic imaginaries while foreclosing others. *Comparative Planetology* provided a valuable scaffold for tracing how the digital twin extends the technocratic vision of the Globe: smooth, manageable, and optimisable. It also offered a conceptual language for describing the challenges posed by the Planetary: an Earth that exceeds mastery, coherence, and human-centered narratives.

To complement and extend this diagnosis, the thesis turned to the framework of Plan-

etary Mattering. Emerging from feminist and posthumanist thought, Planetary Mattering foregrounds not only what is seen and conceptualised, but also what is felt, cared for, and made to matter. It shifts from understanding the structures that render Earth thinkable, to cultivating situated, affective, and ethical modes of relating to the more-than-human world.

By combining these two frameworks, with their distinct affordances, the thesis moves from critique to proposition. Comparative Planetology enables an analysis of how the digital twin of Earth frames planetary knowledge and governance. Planetary Mattering allows an attunement to what is excluded, flattened, or rendered invisible in those frames. Together, they support an inquiry that is attentive to the aesthetics of planetary representation, the affects they produce, and the possible reorientations they invite. It is through understanding how planetary visions are constructed that we can begin to reimagine how to inhabit the planetary otherwise.

The thesis builds on Baudrillard's theory of simulacrum, capturing how digital twins, rather than simply representing reality, increasingly constitute a new kind of reality that appears more actionable, more manageable, and also more detached from lived planetary complexity. It moves beyond this foundation through weaving concepts of Bratton, Halpern, Likavčan, Hui, and others, to describe a more nuanced planetary condition. It shows how planetary-scale computation has materialized simulations into operational infrastructures that govern real environmental, social, and political processes.

Along this path, it has become clear that the twin is more than just technical artifact, condensing broader desires for representation, control, mastery, and prediction, carrying the unresolved contradictions of the modern human project. The problem then, its not the digital twin of Earth itself, but the infrastructures of thought, affect and governance that demand it. The epistemological tendencies, the logics that seek to master what is vast, model what is emergent, and manage what is too complex, are rooted in colonialism, capitalism, and techno-optimism.

A notable achievement of the thesis is its capacity to connect thinkers who are not always associated together, such as Benjamin Bratton and Orit Halpern, Naomi Klein and Yuk Hui, in ways that make conceptual sense. It staged meaningful dialogues between discourses of computation, visibility, planetary aesthetics, and affect without flattening their differences. By bringing Klein's analysis of doubled realities and uncanny mirroring into conversation with the digital twin, the thesis added a novel cultural dimension to the reading of planetary-scale simulations, opening up affective and political critiques of how these technologies reflect and distort our collective desires and fears.

The turn towards affects significantly extends the thesis's contribution by introducing a layered emotional analysis of the climate crisis mediated by the digital twin of Earth. Building on Klein's cultural reading of mirroring and distortion, the chapter advances the argument by showing that planetary-scale simulations are not only epistemological and political constructs, but also affective infrastructures. Drawing on a diverse theoretical repertoire—Naomi Klein, Mark Fisher, Timothy Morton, Lauren Berlant, and others—the chapter weaves a compelling map of emotional states shaped by climate technologies, from the uncanny eeriness of automated sensing to the recursive temporality of climate anxiety and the lingering grief of planetary loss.

Importantly, the chapter does not treat these affects as merely individual responses

but frames them as structurally produced. It identifies the ways in which infrastructural systems generate specific moods and modes of feeling—urging optimisation, managing hope, and suppressing grief. In doing so, the analysis extends the conceptual reach of the thesis by showing how simulations of the Earth not only shape what we know, but also how we are expected to feel.

This affective focus deepens the earlier critique of digital twin logics by bringing in a phenomenological and emotional perspective. Drawing on existing work in critical infrastructure studies, planetary aesthetics, and affect theory, the chapter situates emotional responses—such as anxiety, melancholia, and eerie disorientation—not as incidental, but as integral to how planetary-scale computation is experienced and made meaningful. Rather than treating these affects as personal or marginal, the analysis shows how they are shaped by, and in turn shape, the logics and limits of climate mediation. In doing so, it contributes to a growing conversation about how planetary crisis is not only a matter of governance, scale, and representation, but also of relation, perception, and emotional inhabitation.

The thesis concludes by turning toward attunement as a mode of engaging with planetary complexity that resists the abstractions and compulsions of control. Building on feminist, posthumanist, and infrastructural thought, attunement is developed here as a practice of situated noticing, ethical responsiveness, and relational awareness. It draws attention to histories, bodies, affects, and ecologies that exceed measurement and simulation and do not fit cleanly into planetary-scale computation.

The thesis situates attunement as a fragile, ongoing practice enacted through tools, stories, collaborations, and refusals. Through readings of artistic, scientific, and speculative projects, it explores how attunement might be built into infrastructural and epistemic systems in ways that foreground care, multiplicity, and partial knowledge. In doing so, the thesis gestures toward another way of relating to Earth—not through mastery, but through shared vulnerability, endurance, and attention.

Zooming out, zooming in, how does climate appear?

Image 1, 2: Satellite images showing the Prague region and surrounding areas. The top image (Sentinel-3) displays surface moisture levels, with red indicating low moisture and blue indicating higher levels. The bottom image (Sentinel-2) presents the same area in natural color, showing fields, forests, settlements, and cloud cover. Both are generated from Copernicus Earth observation satellites.

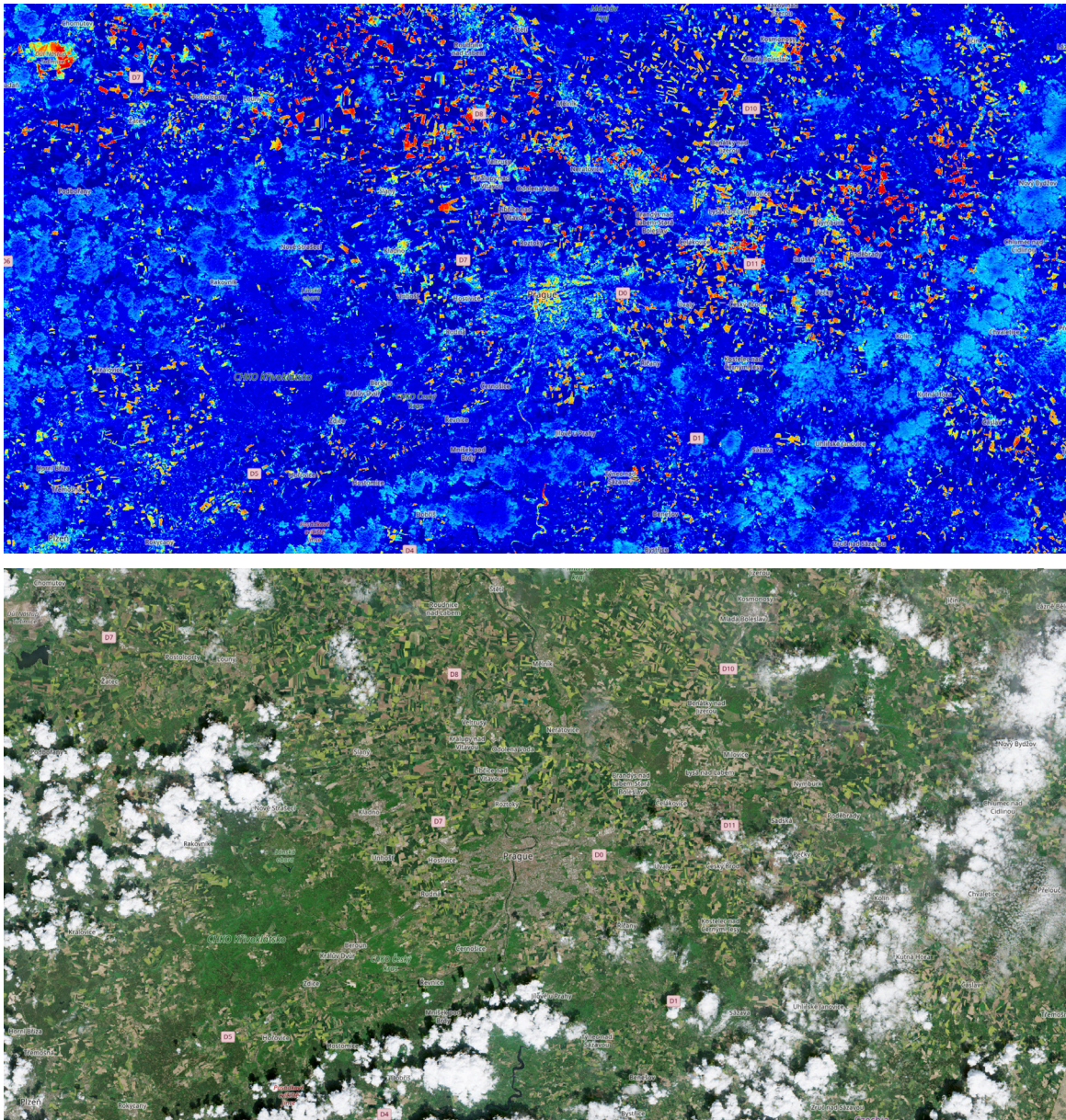
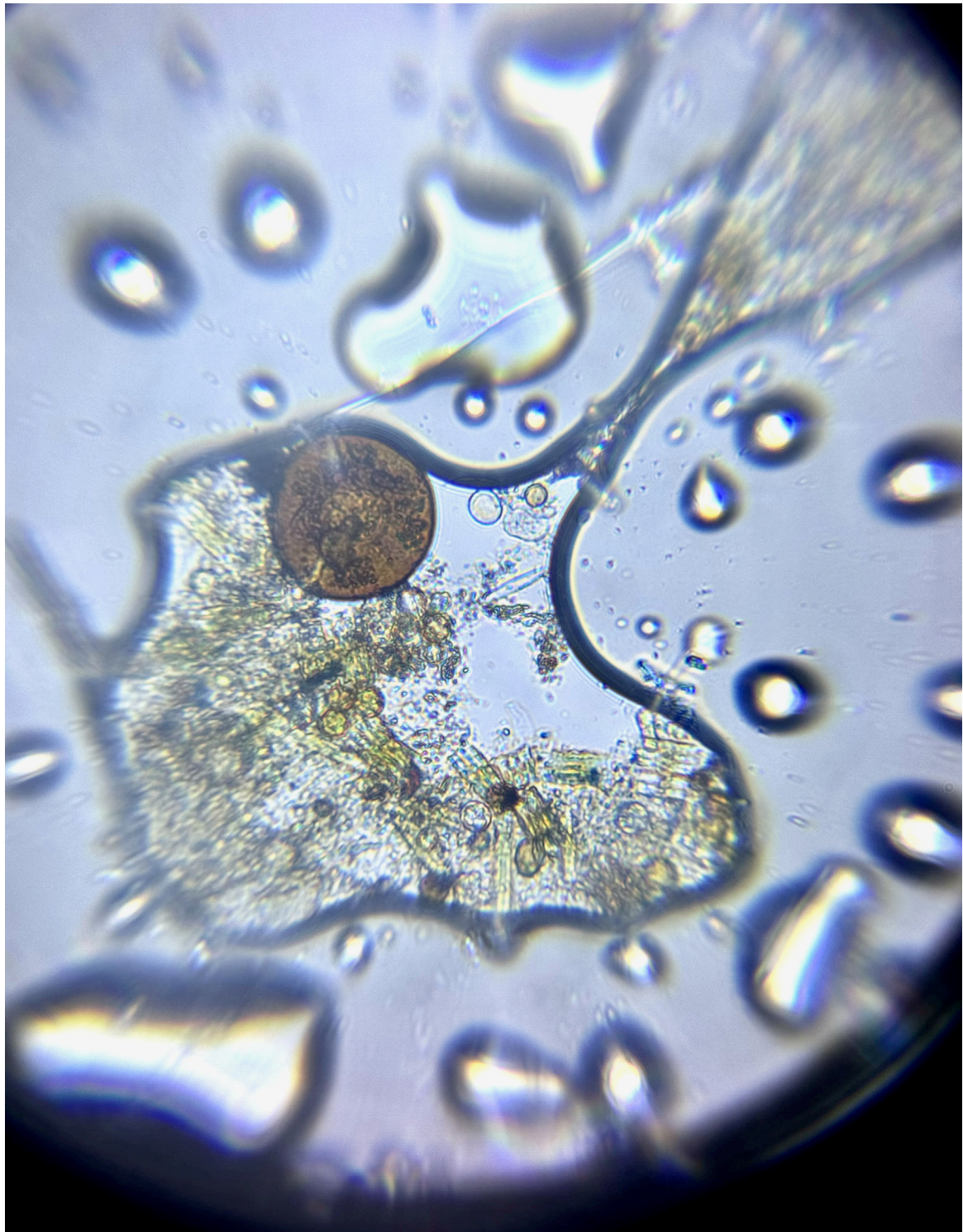


Image 3: Microscope image of diatoms suspended in water. Silicate shells are visible as circular and elongated structures alongside organic debris and air bubbles. The magnification reveals structural detail at the scale of tens of micrometers. The diatoms shown here are part of a broader investigation into microscopic algae as indicators of environmental conditions. The image was captured using transmitted light microscopy during laboratory work with freshwater samples.



A sky counted, encountered

Image 4, 5: Two images generated from live satellite-tracking platforms visualizing the orbital shell surrounding Earth. Each dot or symbol represents a satellite or piece of debris currently orbiting the Earth. Earth's atmosphere as a space of coordination and collision risk, made visible through data.

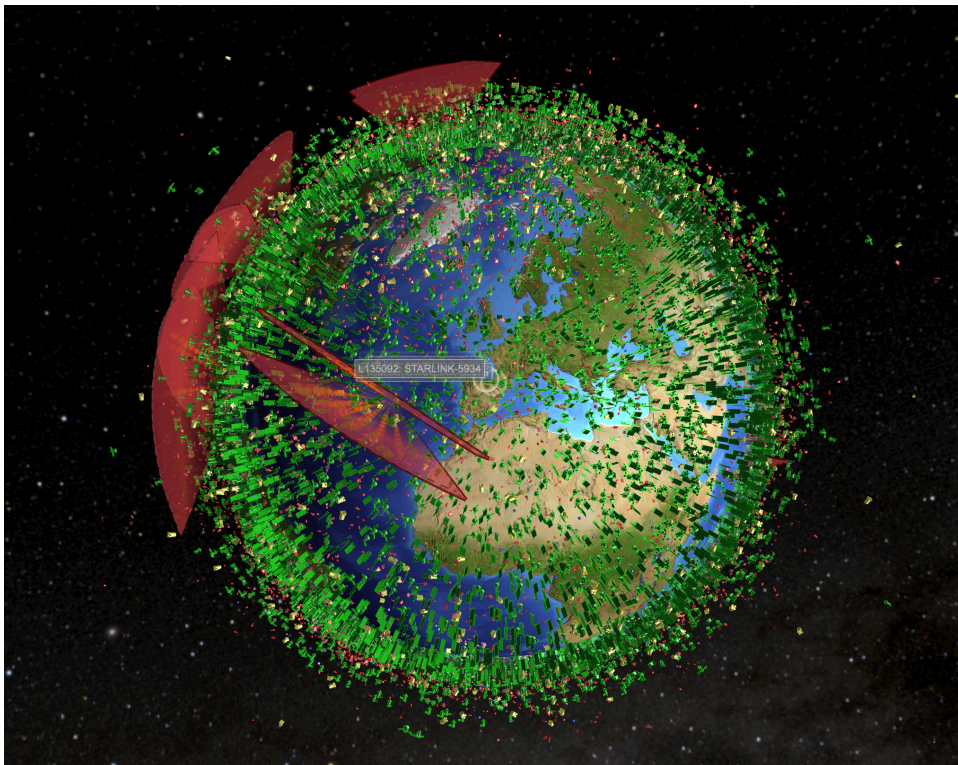
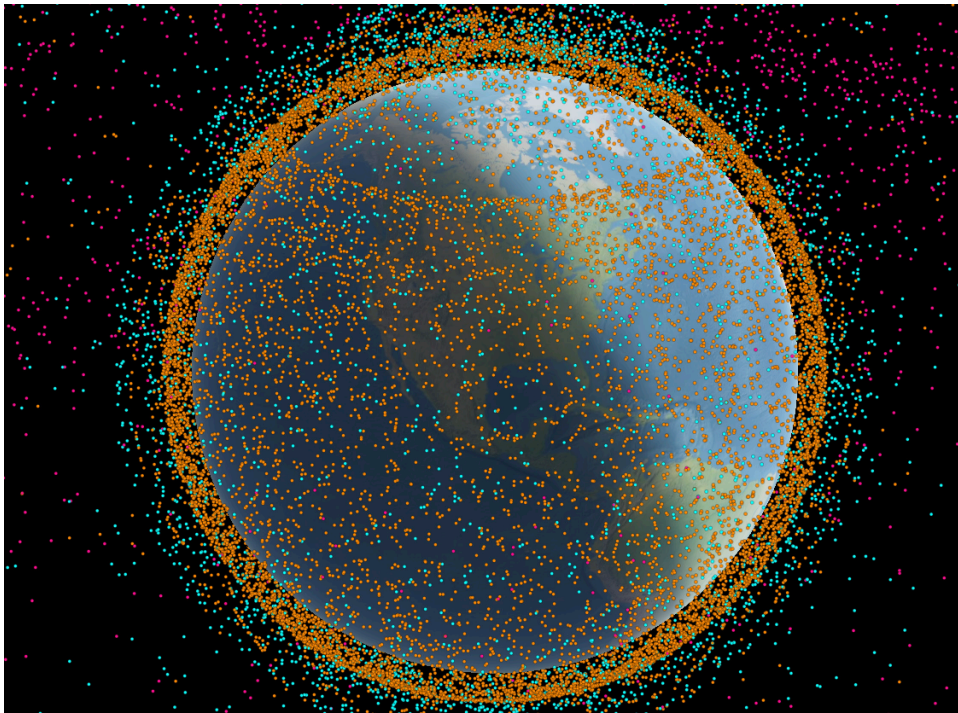


Image 6, 7: Two photographs taken from below and within the atmosphere. In the first, a bird glides over open sea, beneath an unbroken sky. In the second, a soft cloud mass fills the frame.



Projected curves and patterned grounds

Image 8, 9: Two digital visualizations of global and regional climate. The first image shows a 3D volume rendering of global surface air temperature anomalies, based on Copernicus data, processed within the Destination Earth platform. The second displays historical and projected temperature changes for Czechia from 1950 to 2100, including multiple Shared Socioeconomic Pathways (SSPs). Color and height are used to express deviation and probability, situating local data within planetary infrastructure.

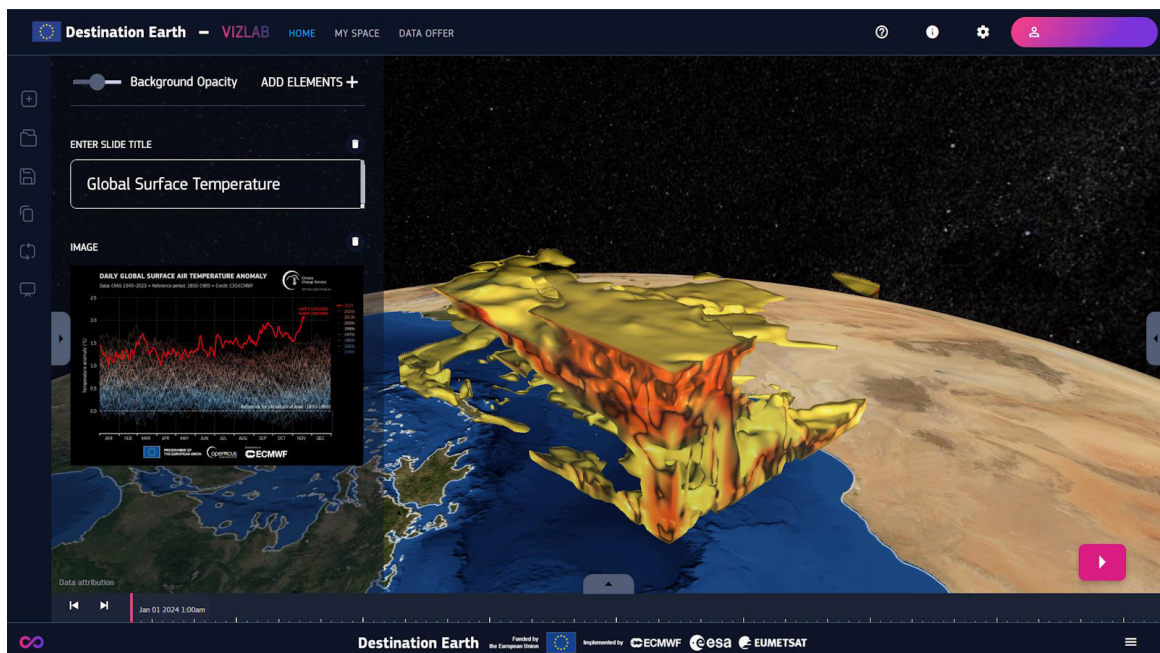
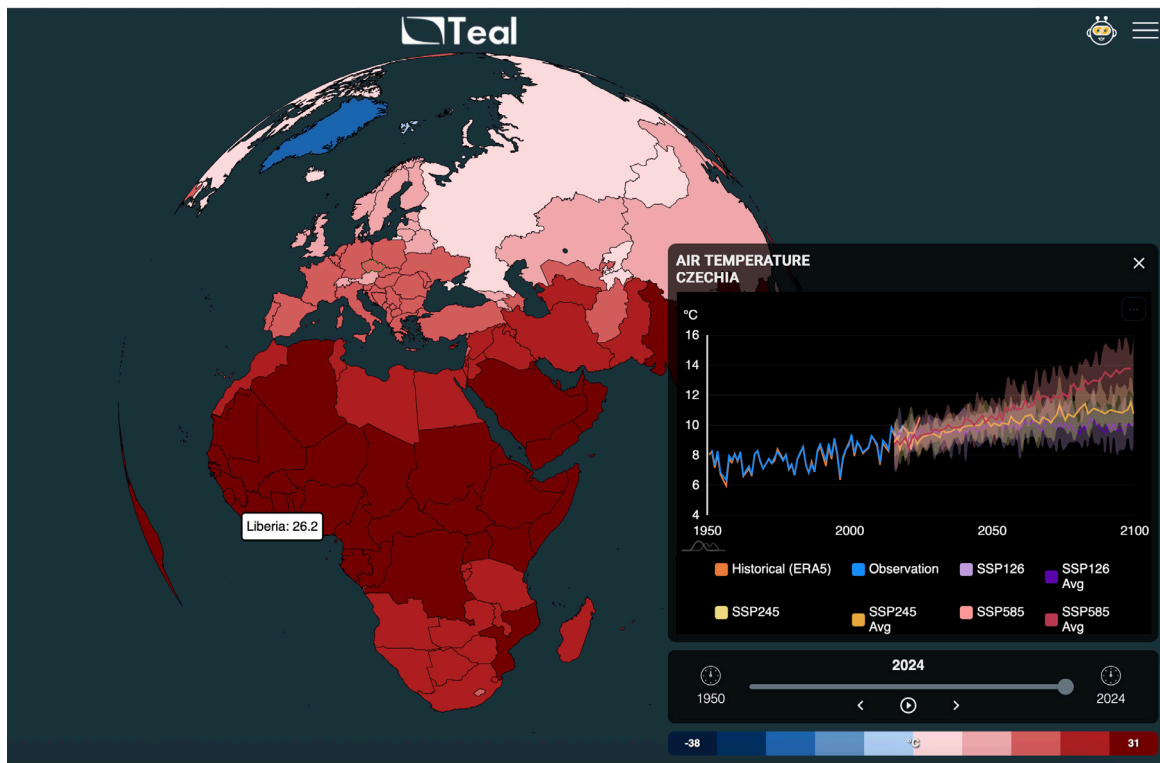


Image 10: A close-up of cracked and drying ground at a raised peat bog in Krušné Hory, Czechia. The image shows mineral discoloration, embedded organic material, and surface fissures formed by prolonged exposure to heat and dryness. Formerly water-saturated, the bog's surface now appears hardened and fragmented. The photograph captures local, visible effects of environmental conditions over time.



Near contact

Image 11: Satellite visualization showing current close approaches of objects in Earth's orbit. Each red dot marks a potential near-collision or high-risk trajectory. Orbital paths and collision probabilities are calculated in real time, with proximity and velocity rendered in visual layers. Earth appears partially visible beneath the cloud of data points. The system continuously predicts conjunctions between satellites and debris.

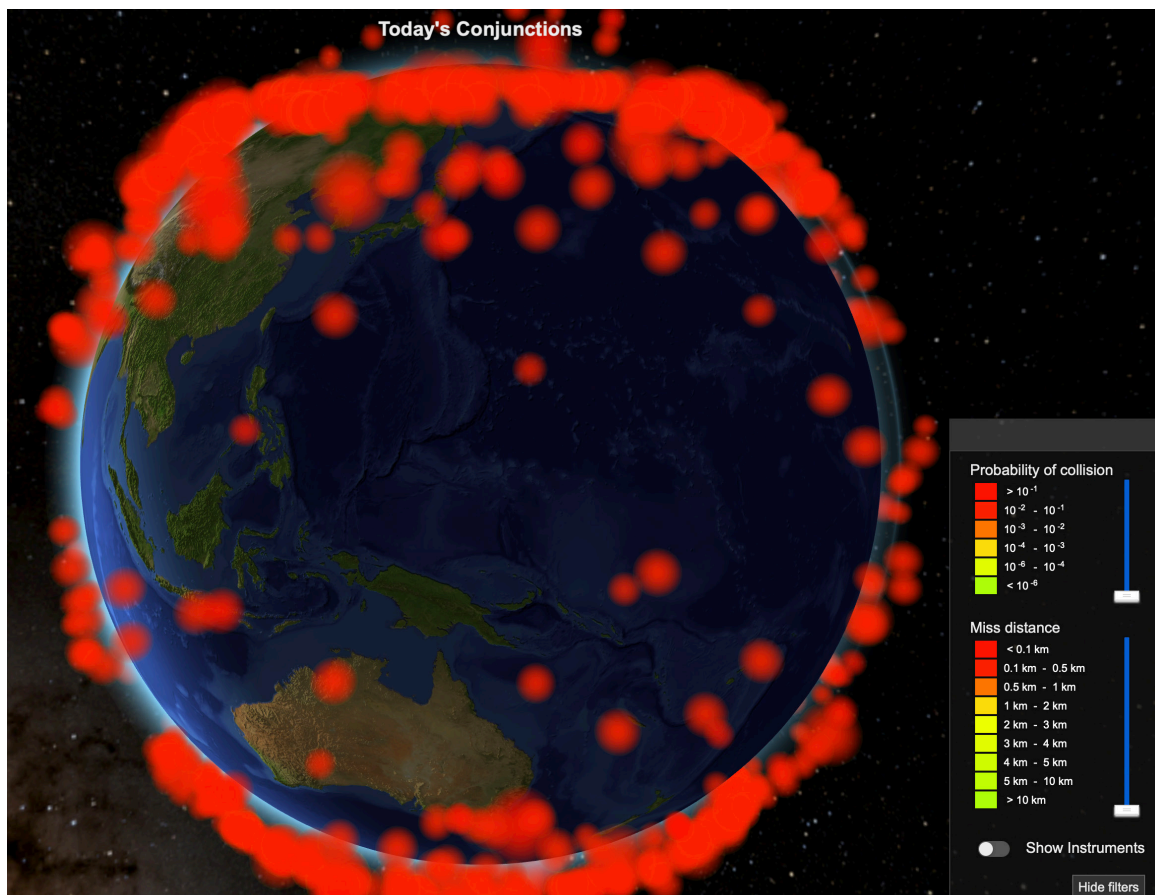


Image 12, 13: Two photographs taken during fieldwork while collecting water and sediment for the study of diatoms as climate indicators. Records of conjunctions of the body and environment. In one image, suspended organic material and algae are visible beneath the surface of shallow water, with reflection of myself. The other is a sample tube—water, sediment, microbial growth for later observations under microscope.



Can you feel the heaviness?

Image 14, 15, 16: Three digital renderings of global wind speed and atmospheric humidity. Color-coded vectors and volume fields represent air movement and moisture distribution across different altitudes and regions. Data is processed and visualized using simulation engines designed to track and predict weather systems at planetary scale. Flow patterns, temperature gradients, and pressure levels are rendered as animated fields of motion.

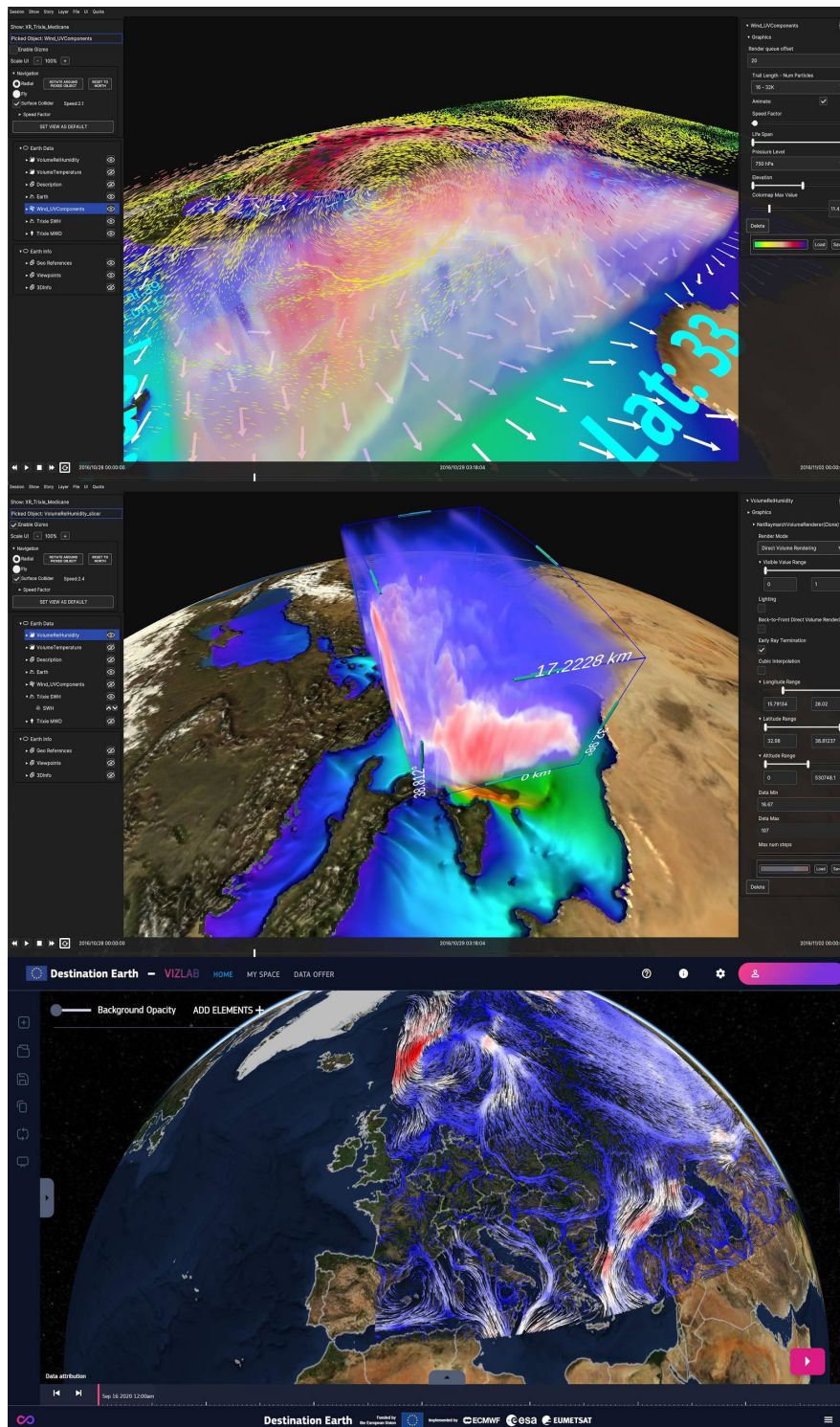


Image 17: A photo taken on a cold, humid day in early winter. Snow falls across a partially frozen lake, with ice sheets forming at the shoreline. A line of trees fades into dense air, visibility reduced by cloud and weather. The atmosphere appears heavy, quiet, and still in motion. It was 21. December 2023.



Moving with the winds

Image 18, 19: Digital renderings of global wind speed and direction. Color gradients indicate velocity in meters per second; swirling vector fields show air movement patterns at various altitudes. The Earth is presented as a continuously updating model of atmospheric motion, built from meteorological data and animated across time.

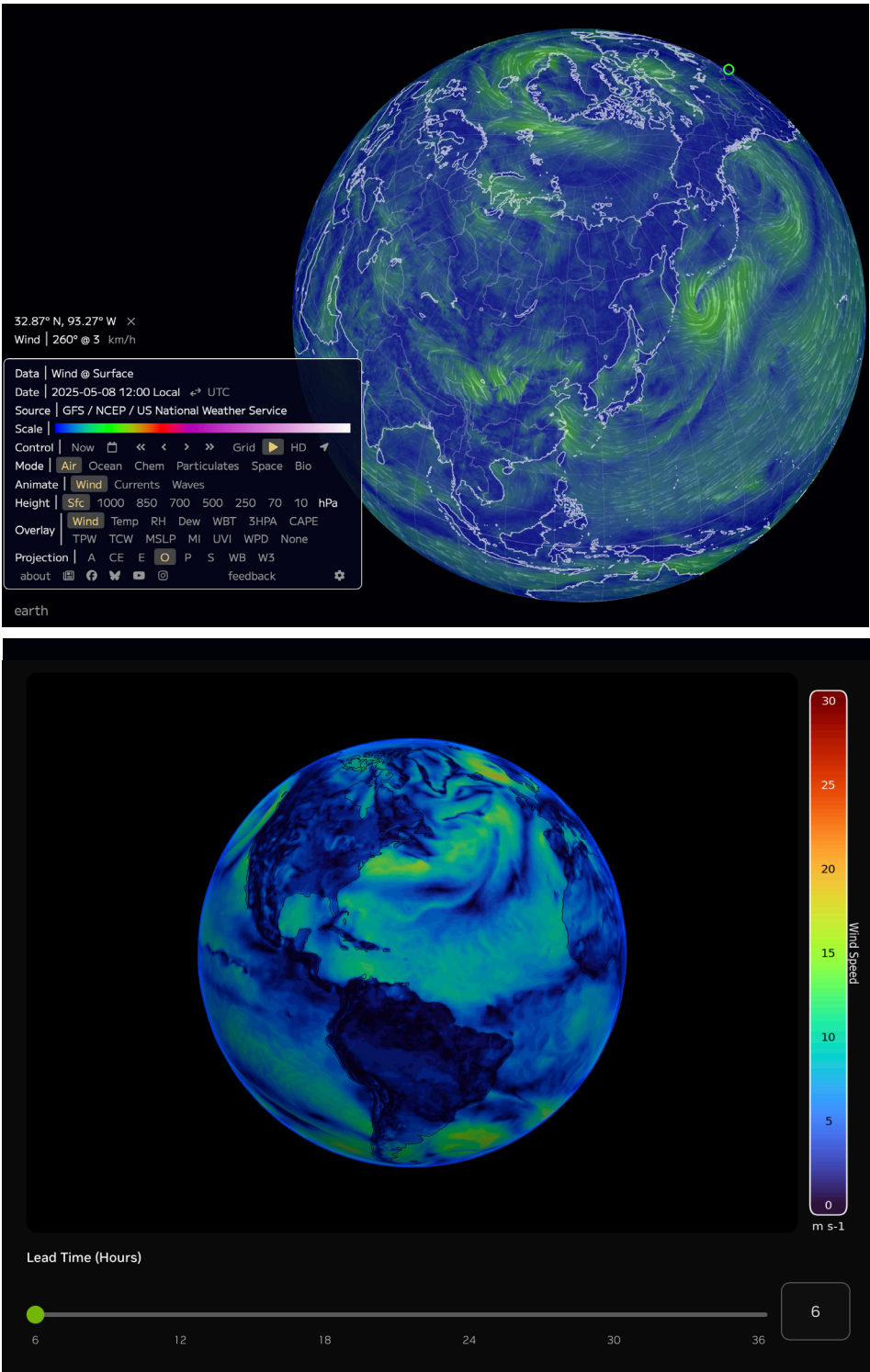


Image 20, 21: Two photographs taken on a very windy day at the beach. In one, waves break under low, fast-moving clouds while a kite arcs over the water. In the other, wind sculpts the sand into streams and ridges, blurring the surface and sweeping across the shoreline. The wind was strong enough to carry us.



Bibliography / Seznam literatury

- ANTIKYTHERA. “Research Overview” [online]. [cit. 2025-04-02]. Available from: <https://research.antikythera.org/>
- ANTIKYTHERA. “Recursive Simulations” [online]. [cit. 2025-04-02]. Available from: <https://research.antikythera.org/#recursive-simulations>.
- ANNONI, Alessandro; NATIVI, Stefano; ÇÖLTEKIN, Arzu; DESHA, Cheryl; EREMCHENKO, Eugene; GEVAERT, Caroline M.; GIULIANI, Gregory; CHEN, Min; PEREZ-MORA, Luis; STROBL, Josef; TUMAMPOS, Stephanie. Digital Earth: Yesterday, Today, and Tomorrow. *International Journal of Digital Earth* [online]. 2023, vol. 16, no. 1, pp. 1022–1072 [cit. 2025-05-01]. Available from: <https://doi.org/10.1080/17538947.2023.2187467>
- BARAD, Karen. Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning. Durham: Duke University Press, 2007. ISBN 9780822339175.
- BARROS, Ana P. Digital Twin Earth: The next-Generation Earth Information System. *Frontiers in Science* [online]. 2024, 2. [cit. 2025-04-04]. Available from: <https://doi.org/10.3389/fsci.2024.1383659>.
- BAUDRILLARD, Jean. Simulacra and Simulation. Translated by Sheila Faria Glaser. Ann Arbor: University of Michigan Press, 1994. ISBN 9780472065219.
- BAUER, Peter; STEVENS, Bjorn; HAZELEGER, Wilco. A Digital Twin of Earth for the Green Transition. *Nature Climate Change*. 2021, 11(2), 80–83. [cit. 2025-04-04] <https://doi.org/10.1038/s41558-021-00986-y>.
- BERLANT, Lauren. Cruel Optimism. Durham: Duke University Press, 2011. ISBN 9780822351115.
- BRATTON, Benjamin H. The Stack: On Software and Sovereignty. Cambridge, MA: MIT Press, 2016. ISBN 9780262029574.
- BRATTON, Benjamin. “Simulations and Doubling.” YouTube [online], 20 February 2022 [cit. 2025-04-02]. Available from: https://www.youtube.com/watch?v=Z0-Ij_ACL0U
- BRAIN, Tega. “The Environment Is Not a System.” *A Peer-Reviewed Journal About*. 2018, 7(1), 152–65. <https://doi.org/10.7146/aprja.v7i1.116062>.
- BURTYNSKY, Edward; BAICHWAL, Jennifer; DE PENCIER, Nicholas. “The Anthropocene Project” [online]. [cit. 2025-04-04]. Available from: <https://theanthropocene.org/>
- COCHIOR, Cristina. “Cristina Cochior – Vertical Atlas” [online]. Vertical Atlas, 2022 [cit. 2025-05-01]. Available from: <https://verticalatlas.net/#cristina-cochior>
- Craglia, Max et al. Digital Earth 2020: Towards the Vision for the Next Decade. *International Journal of Digital Earth*. 2012, 5(1), 4–21. [cit. 2025-04-04]. <https://doi.org/10.1080/17538947.2011.638500>.
- CRUTZEN, Paul J. “The Anthropocene.” *Global Change Newsletter* [online]. 2000, no. 41, pp. 17–18 [cit. 2025-04-04]. Available from: <https://www.igbp.net/download/18.316f18321323470177580001401/1376383088452/NL41.pdf>
- DASTON, Lorraine; GALISON, Peter. Objectivity. New York: Zone Books, 2007. ISBN 9781890951788.

- DELLANOCE, Leonardo; KHALAF, Amal; KUITENBROUWER, Klaas; NYABOLA, Nanjala; ROUKENS, Renée; STEINER, Arthur; YOU, Mi, eds. *Vertical Atlas*. Arnhem: ArtEZ Press, 2022. ISBN 9789491444692.
- DEMOS, T. J. *Against the Anthropocene: Visual Culture and Environment Today*. Berlin: Sternberg Press, 2017. ISBN 9783956792106.
- DESTINATION EARTH. “DestinE Data Portfolio” [online]. [cit. 2025-04-04]. Available from: <https://platform.destine.eu/destine-data-portfolio/>
- DESTINATION EARTH. “Frequently Asked Questions” [online]. [cit. 2025-04-04]. Available from: <https://destination-earth.eu/frequently-asked-questions/>
- DIETACHMAIR, Philipp; GIELEN, Pascal; NICOLAU, Georgia, eds. *Sensing Earth: Cultural Quests Across a Heated Globe*. Amsterdam: Valiz, 2023. ISBN 9789493246249.
- DIGITAL TWIN ENGINE. *Digital Twin Engine Documentation* [online]. 2022. [cit. 2025-04-04] Available from: <https://digital-twin-engine.readthedocs.io/en/latest/>
- DRUCKER, Johanna. *Graphesis: Visual Forms of Knowledge Production*. Cambridge, MA: Harvard University Press, 2014. ISBN 9780674724938.
- EASTERLING, Keller. *Extrastatecraft: The Power of Infrastructure Space*. London: Verso Books, 2014. ISBN 9781781685877.
- EDWARDS, Paul N. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming*. Cambridge, MA: MIT Press, 2010. ISBN 9780262013924.
- EUROPEAN COMMISSION. *Destination Earth* [online]. 2022. [cit. 2025-04-04] Available from: <https://destination-earth.eu/>
- EUROPEAN COMMISSION. “Destination Earth Webinar: Participation and Upcoming Collaboration Opportunities” [online]. July 2023 [cit. 2025-05-01]. Available from: https://destination-earth.eu/wp-content/uploads/2023/07/DestinE_webinar_0723.pdf
- EUROPEAN COMMISSION. “Smart Cities” [online]. [cit. 2025-04-02]. Available from: https://commission.europa.eu/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en
- EUROPEAN SPACE AGENCY. “About Space Debris” [online]. [cit. 2025-04-04]. Available from: https://www.esa.int/Space_Safety/Space_Debris/About_space_debris
- FERGUSON, Stephen. “Apollo 13: The first digital twin.” *Siemens Blog* [online], 14 April 2020 [cit. 2025-04-02]. Available from: <https://blogs.sw.siemens.com/simcenter/apollo-13-the-first-digital-twin/>
- FISHER, Mark. *Capitalist Realism: Is There No Alternative?* Winchester: Zero Books, 2009. ISBN 9781846943171.
- FISHER, Mark. *The Weird and the Eerie*. London: Repeater Books, 2016. ISBN 9781910924383.
- FOUCAULT, Michel. *Discipline and Punish: The Birth of the Prison*. Translated by Alan Sheridan. New York: Vintage Books, 1995. ISBN 9780679752554.

- FORENSIC ARCHITECTURE. “Forensic Architecture” [online]. [cit. 2025-05-01]. Available from: <https://forensic-architecture.org>
- FOSCARI, Giulia, ed. Antarctic Resolution. Zurich: Lars Müller Publishers, 2021. ISBN 9783037786406.
- FOWKES, Maja; FOWKES, Reuben. Art and Climate Change. London: Thames & Hudson, 2022. ISBN 9780500204757.
- FURUHATA, Yuriko. Climatic Media: Transpacific Experiments in Atmospheric Control. Durham: Duke University Press, 2022. ISBN 9781478017806.
- GABRYS, Jennifer. Program Earth: Environmental Sensing Technology and the Making of a Computational Planet. Minneapolis: University of Minnesota Press, 2016. ISBN 9780816693122.
- GABRYS, Jennifer. “As Lichens Absorb Air Pollution, They Show Us the Limits of Livability” [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/as-lichens-absorb-air-pollution-they-show-us-the-limits-of-livability>
- GELERTNER, David. Mirror Worlds: Or the Day Software Puts the Universe in a Shoebox... How It Will Happen and What It Will Mean. Oxford: Oxford University Press, 1991. ISBN 9780195079067.
- GORE, Al. The Digital Earth: Understanding Our Planet in the 21st Century. Speech at the California Science Center. 1998. [online] [cit. 2025-04-04].
- GRÜNBERGER, Christoph, ed. The Age of Data: Embracing Algorithms in Art & Design. Zurich: Niggli Verlag, 2022. ISBN 9783721210156.
- HALPERN, Orit. Beautiful Data: A History of Vision and Reason since 1945. Durham: Duke University Press, 2015. ISBN 9780822357445.
- HALPERN, Orit; MITCHELL, Robert. The Smartness Mandate. Cambridge, MA: MIT Press, 2023. ISBN 9780262047899.
- HARAWAY, Donna J. Staying with the Trouble: Making Kin in the Chthulucene. Durham: Duke University Press, 2016. ISBN 9780822362142.
- HAZELEGER, Wilco; AERTS, J. P. M.; BAUER, Peter; BIERKENS, M. F. P.; CAMPS-VALLS, Gustau; DEKKER, M. M.; DOBLAS-REYES, Francisco J.; et al. Digital Twins of the Earth with and for Humans. *Communications Earth & Environment* [online]. 27 August 2024, vol. 5, no. 1, article 463 [cit. 2025-05-01]. Available from: <https://doi.org/10.1038/s43247-024-01626-x>
- HEIDEGGER, Martin. The Age of the World Picture. In: The Question Concerning Technology and Other Essays. Translated and edited by William Lovitt. New York: Harper & Row, 1977. ISBN 9780061319693, pp. 115–154.
- HEIDEGGER, Martin. The Question Concerning Technology and Other Essays. Translated by William Lovitt. New York: Harper & Row, 1977. ISBN 0061319694.

- HOUSER, Heather. The Aesthetics of Environmental Visualizations: More Than Information Ecstasy? *Public Culture* [online]. 2014, vol. 26, no. 2, pp. 319–337 [cit. 2025-05-01]. Available from: <https://doi.org/10.1215/08992363-2392084>
- HUI, Yuk. *Machine and Sovereignty: For a Planetary Thinking*. Minneapolis: University of Minnesota Press, 2024. ISBN 9781517917418.
- CHAKRABARTY, Dipesh. *The Climate of History in a Planetary Age*. Chicago: University of Chicago Press, 2021. ISBN 9780226732862.
- IBM. IBM builds a smarter planet [online]. 2024. Available from: <https://www.ibm.com/smarter-planet/us/en/> [cit. 2025-04-04].
- IBM. “What is a digital twin?” [online]. 5 August 2021 [cit. 2025-04-02]. Available from: <https://www.ibm.com/think/topics/what-is-a-digital-twin>
- IDC; Statista; Various sources. “Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2023, with forecasts from 2024 to 2028 (in zettabytes)” [online]. May 31, 2024 [cit. 2025-04-04]. Available from: <https://www.statista.com/statistics/871513/worldwide-data-created/>
- JASANOFF, Sheila. *The Science and Technology Studies Reader*. London: Routledge, 2008. ISBN 9780415403290.
- JAVAID, Mohd; HALEEM, Abid; SUMAN, Rajiv. Digital Twin Applications toward Industry 4.0: A Review. *Cognitive Robotics* [online]. 2023, vol. 3, pp. 71–92 [cit. 2025-05-01]. Available from: <https://doi.org/10.1016/j.cogr.2023.04.003>
- KIM, Heejin. “Songdo, South Korea’s Smartest City, Is Lonely.” Bloomberg [online]. 22 June 2018 [cit. 2025-04-02]. Available from: <https://www.bloomberg.com/news/articles/2018-06-22/songdo-south-korea-s-smartest-city-is-lonely>
- KLEIN, Naomi. *Doppelgänger: A Trip into the Mirror World*. London: Penguin Random House UK, 2023. ISBN 9780374279290.
- LATOUR, Bruno. *Down to Earth: Politics in the New Climatic Regime*. Cambridge: Polity Press, 2018. ISBN 9781509530564.
- LATOUR, Bruno. *Facing Gaia: Eight Lectures on the New Climatic Regime*. Cambridge: Polity Press, 2017. ISBN 9781509519743.
- LATOUR, Bruno. “We Don’t Seem to Live on the Same Planet – A Fictional Planetarium.” In: *Designs for Different Futures*. Edited by Kathryn B. Hiesinger and Michelle Millar Fisher. Philadelphia: Philadelphia Museum of Art, 2019, pp. 193–199. ISBN 9780876332955.
- LATOUR, Bruno; WOOLGAR, Steve. *Laboratory Life: The Construction of Scientific Facts*. Princeton: Princeton University Press, 1986. ISBN 9780691028323.
- LATOUR, Bruno. “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern.” *Critical Inquiry*. 2004, vol. 30, no. 2, pp. 225–248. ISSN 0093-1896. DOI: <https://doi.org/10.1086/421123>.
- LAWTON, George. “Grieves and Vickers - the history of digital twins.” *Diginomica* [online]. 13 September 2023 [cit. 2025-04-02]. Available from: <https://diginomica.com/grieves-and-vickers-history-digital-twins>

- LE GUIN, Ursula K. *The Carrier Bag Theory of Fiction*. San Francisco: Women's Press Collective, 1986.
- LIKAVČAN, Lukáš. "Another Earth: An Astronomical Concept of the Planet for the Environmental Humanities." *Distinktion: Journal of Social Theory* [online]. 2024, vol. 25, no. 1, pp. 17–36 [cit. 2025-04-04]. DOI: 10.1080/1600910X.2024.2326448. Available from: <https://doi.org/10.1080/1600910X.2024.2326448>
- LIKAVČAN, Lukáš. *Introduction to Comparative Planetology*. Moscow: Strelka Press, 2019. ISBN 9785907163034.
- LTER-LIFE. "LTER-LIFE: Towards Building Digital Twins of Ecosystems" [online]. [cit. 2025-04-02]. Available from: <https://lter-life.nl/en/>
- LOSSIN, R.H. "Refik Anadol's "Unsupervised"." *e-flux Criticism* [online]. March 14, 2023 [cit. 2025-04-04]. Available from: <https://www.e-flux.com/criticism/527236/refik-anadol-s-unsupervised>
- MASSUMI, Brian. *The Future Birth of the Affective Fact: The Political Ontology of Threat*. In: *The Affect Theory Reader*. Edited by Melissa Gregg and Gregory J. Seigworth. Durham: Duke University Press, 2010, pp. 52–70. ISBN 9780822347743.
- McLUHAN, Marshall. *Understanding Media: The Extensions of Man*. New York: McGraw-Hill, 1964. ISBN 9780262631593.
- MILON, Anne-Sophie; ZALASIEWICZ, Jan. "The Victims of Carbon Dioxide Are Starting to Appear" [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/the-victims-of-carbon-dioxide-are-starting-to-appear>
- MIRZOEFF, Nicholas. *Jak vidět svět*. Přeložili Andrea Průchová Hrůzová a Jan J. Škrob. Praha: ArtMap, 2018. ISBN 9788090659957.
- MORE-THAN-PLANET. *More-than-Planet* [online]. 2022. Available from: <https://www.more-than-planet.eu/> [cit. 2025-04-04].
- MORTON, Timothy. *Hyperobjects: Philosophy and Ecology after the End of the World*. Minneapolis: University of Minnesota Press, 2013. ISBN 9780816689231.
- MORTON, Timothy. *All Art is Ecological*. London: Penguin Books, 2021. ISBN 9780141997001.
- MORTON, Timothy. *Ekobytí*. Přeložil Ondřej Trhoň. Praha: ArtMap, 2023. ISBN 9788088268442, s. 24.
- MURPHY, Douglas. *Last Futures: Nature, Technology and the End of Architecture*. London: Verso Books, 2016. ISBN 9781781689752.
- NATIVI, Stefano; MAZZETTI, Paolo; CRAGLIA, Massimo. *Digital Ecosystems for Developing Digital Twins of the Earth: The Destination Earth Case*. *Remote Sensing*. 2021, 13(11), 2119. <https://doi.org/10.3390/rs13112119>.
- NIEUWE INSTITUUT. "Vertical Atlas – World.Orbit" [online]. Rotterdam: Het Nieuwe Instituut, 2022 [cit. 2025-05-01]. Available from: <https://nieuweinstituut.nl/en/projects/vertical-atlas/worldorbit>

- NVIDIA. “Earth-2 Platform for Climate Change Modeling” [online]. [cit. 2025-04-02]. Available from: <https://www.nvidia.com/en-us/high-performance-computing/earth-2/>
- OFFENHUBER, Dietmar. *Autographic Design: The Matter of Data in a Self-Inscribing World*. Cambridge, MA: MIT Press, 2023. ISBN 9780262545164.
- OPEN-WEATHER. “Open Weather Collective.” [online]. [cit. 2025-05-01]. Available from: <https://open-weather.community>
- Open Weather, “When I Image the Earth, I Imagine Another.” [online]. [cit. 2025-05-01]. Available from: <https://open-weather.community>
- PAGLEN, Trevor. “Invisible Images: Your Pictures Are Looking at You.” *The New Inquiry* [online]. 8 December 2016 [cit. 2025-05-01]. Available from: <https://thenewinquiry.com/invisible-images-your-pictures-are-looking-at-you/>
- PERFECTO, Ivette. “Coffee Rust Spreads Together with Coffee Plantations” [online]. In: TSING, Anna L.; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene*. Stanford University Press, 2020 [cit. 2025-05-01]. Available from: <https://feralatlas.supdigital.org/poster/coffee-rust-spreads-together-with-coffee-plantations>
- PETTMAN, Dominic; THACKER, Eugene. *Sad Planets*. Cambridge: Polity Press, 2024. ISBN 9781509562350
- PINTAR, Matevž. “Homage to Mondrian Script.” Sentinel Hub Custom Scripts [online]. 2018 [cit. 2025-05-01]. Available from: https://custom-scripts.sentinel-hub.com/custom-scripts/sentinel-2/homage_to_mondrian/
- PUIG DE LA BELLACASA, María. *Matters of Care: Speculative Ethics in More Than Human Worlds*. Minneapolis: University of Minnesota Press, 2017. ISBN 9781517900632.
- REINECKE, Robert; PIANOSI, Francesca; WAGENER, Thorsten. “How to use the impossible map – Considerations for a rigorous exploration of Digital Twins of the Earth.” *Socio-Environmental Systems Modelling* [online]. 2024, vol. 6, 18786 [cit. 2025-04-02]. ISSN 2397-7140. Available from: <https://doi.org/10.18174/sesmo.18786>
- RUBEIS, Giovanni. “Hyperreal Patients. Digital Twins as Simulacra and their impact on clinical heuristics.” In: LOH, Janina; GROTE, Thomas, eds. *Medizin – Technik – Ethik*. Berlin; Heidelberg: Springer, 2023, pp. 193–207. ISBN 9783662658680. Available from: https://doi.org/10.1007/978-3-662-65868-0_10
- RUSSELL, Legacy. *Glitch Feminism: A Manifesto*. London: Verso Books, 2020. ISBN 9781786632661
- SALTELLI, Andrea; GIGERENZER, Gerd; HULME, Mike; KATSIKOPOULOS, Konstantinos V.; MELSEN, Lieke A.; PETERS, Glen P.; PIELKE, Roger; ROBERTSON, Simon; STIRLING, Andy; TAVONI, Massimo; PUY, Arnald. “Bring Digital Twins Back to Earth.” *Wiley Interdisciplinary Reviews: Climate Change* [online]. 26 August 2024 [cit. 2025-04-04]. Vol. 15, no. 6, e915. Available from: <https://doi.org/10.1002/wcc.915>
- SANZ-MORÈRE, Inés; HINTZE, Kathrin. *DestinE Core Service Platform Framework. Copernicus Meetings* [online]. 22 February 2023 [cit. 2025-05-01]. Available from: <https://doi.org/10.5194/egusphere-egu23-1370>

- SCHNEIDER, Birgit. Climate Model Simulation Visualization from a Visual Studies Perspective. *WIREs Climate Change* [online]. 2012, vol. 3, no. 2, pp. 185–193 [cit. 2025-05-01]. Available from: <https://doi.org/10.1002/wcc.162>
- SCHRADER, Niels; BACKAERT, Roel. “Acid Clouds” [online]. [cit. 2025-04-04]. Available from: <https://acidcloud.org/>
- STENGERS, Isabelle. In Catastrophic Times: Resisting the Coming Barbarism. London: Open Humanities Press, 2015. ISBN 9781607853070.
- STEYERL, Hito. Duty Free Art: Art in the Age of Planetary Civil War. London: Verso, 2017. ISBN 9781786632449.
- STIEGLER, Bernard. Automatic Society, Volume 1: The Future of Work. Translated by Daniel Ross. Cambridge: Polity Press, 2016. ISBN 9781509506309.
- STIEGLER, Bernard. Technics and Time, 1: The Fault of Epimetheus. Stanford, CA: Stanford University Press, 1998. ISBN 9780804730419.
- The Increasing Potential and Challenges of Digital Twins. *Nature Computational Science* [online]. 2024, vol. 4, no. 3, pp. 145–146 [cit. 2025-05-01]. Available from: <https://doi.org/10.1038/s43588-024-00617-4>
- THE POWDER TOY. “The Powder Toy” [online]. [cit. 2025-05-01]. Available from: <https://powdertoy.co.uk/>
- TERRITORIAL AGENCY. “Territorial Agency” [online]. [cit. 2025-05-01]. Available from: <https://territorialagency.com>
- TRIPALDI, Laura. Parallel Minds: Discovering the Intelligence of Materials. Translated by Heather McRae. London: Urbanomic, 2022. ISBN 9781913029948.
- TSING, Anna Lowenhaupt. The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins. Princeton: Princeton University Press, 2015. ISBN 9780691178325.
- TSING, Anna Lowenhaupt; DEGER, Jennifer; KELEMAN SAXENA, Alder; ZHOU, Feifei, eds. *Feral Atlas: The More-Than-Human Anthropocene* [online]. Stanford, CA: Stanford University Press, 2021 [cit. 2025-05-01]. Available from: <https://feralatlas.org>
- TSING, Anna Lowenhaupt; SWANSON, Heather Anne; GAN, Elaine; BUBANDT, Nils, eds. Arts of Living on a Damaged Planet: Ghosts and Monsters of the Anthropocene. Minneapolis: University of Minnesota Press, 2017. ISBN 9781517902377.
- TURŠIČ, Miha; WAAG FUTURELAB. Planetary Public Stack [online]. 2023 [cit. 2025-04-04]. Available from: <https://ars.electronica.art/who-owns-the-truth/en/events/planetary-public-stack/>
- WAGG, David; BURR, Christopher; SHEPHERD, Jason; XUEREB CONTI, Zack; ENZER, Mark; NIEDERER, Steven. The Philosophical Foundations of Digital Twinning [online]. 29 January 2024 [cit. 2025-05-01]. Available from: <https://doi.org/10.31224/3500>
- WEIZMAN, Eyal; FULLER, Matthew. Investigative Aesthetics: Conflicts and Commons in the Politics of Truth. London: Verso Books, 2021. ISBN 9781788739085.

- WESTERLAKEN, Michelle. Digital Twins and the Digital Logics of Biodiversity. *Social Studies of Science* [online]. 2024, vol. 54, no. 4, pp. 575–597 [cit. 2025-05-01]. Available from: <https://doi.org/10.1177/03063127241236809>
- WIENER, Norbert. *Cybernetics: Or Control and Communication in the Animal and the Machine*. Cambridge, MA: MIT Press, 1948. ISBN 9780262537840.
- Working Group on Learning for Sustainability. “Eco-anxiety and Wellbeing: The Policy Challenges” [online]. *European Commission*, 2023 [cit. 2025-04-04]. Available from: https://wikis.ec.europa.eu/download/attachments/44165726/SEPT%2023%20Input_paper_ecoanxiety.pdf
- Orbiting Now. Active Satellite Orbit Data [online]. [cit. 2025-04-04]. Available from: <https://orbiting-now.com/>
- ZUBOFF, Shoshana. *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power*. New York: PublicAffairs, 2019. ISBN 9781610395694.

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