# AI, CULTURAL HERITAGE, ART AND SCIENCE

Workshop Proceedings
February 21 - 2025

Edited by
Antonella Guidazzoli
Maria Chiara Liguori

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Cineca

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# SUMMARY

# FOREWORD

Antonella Guidazzoli, Maria Chiara Liguori – VisitLab, Cineca

When it comes to Artificial Intelligence, there is still some uncertainty about its upper limits. Now, in its fifth edition of our workshop dedicated to the multiple interactions between Artificial Intelligence tools and fields such as Cultural Heritage and Art, it is not surprising to see how the possibilities for application continue to multiply.

At the same time, there is now a full awareness of how essential it is to have customized environments capable of adapting AI tools to different research and work needs. Besides, the strength of these tools lies precisely in their flexibility and adaptability. Starting from a predefined, general-purpose solution—whether it is an LLM or a GANN—it is possible, through fine-tuning or customization processes, to obtain "tailor-made" tools and customized models.

In addition to a thematic session dedicated to the relationship between AI and 'nature', considered from different perspectives, we have chosen to dedicate part of the workshop to the AI Factory and some of its potential users, precisely because of the growing awareness about the importance of customization. The aim is to provide an overview of how different needs can find effective and targeted solutions.

The AI Factory — represented in Italy by the IT4LIA project — is an important opportunity available to both the world of research, in a wide range of fields, and the world of manufacturing. These two worlds have long sought to connect and engage in dialogue in order to mutually enhance their potential, integrating the exploratory capacity of research with the efficiency and practicality of industrial innovation. An AI Factory might be a relevant next big thing in the field.

# AI, CULTURE AND CREATIVITY: AN ECOSYSTEM FOR DEMOCRATIC INNOVATION

Marina Silverii - Direttrice operativa di ART-ER

## Introduction

In recent years, the boundary between technological innovation and cultural production has become increasingly porous, creating new opportunities for experiments that combine art, science and technology. This is particularly evident in the relationship between artificial intelligence (AI) and cultural and creative industries (CCIs): a fertile encounter, capable of generating new forms of expression and understanding of reality. However, for these synergies to become structural and generative, appropriate contexts need to be created: enabling environments where infrastructure, expertise and shared visions meet.

The commitment of ART-ER, Emilia-Romagna's consortium for innovation and sustainability, which for over a decade has been promoting policies and projects supporting the growth of the regional CCIs ecosystem, moves in this direction [1]. A sector that, according to 2023 data, produces 12.6 billion euros in turnover, 5.7 billion in added value and accounts for about 4% of the regional economy, with household cultural consumption exceeding 3 billion euros [2; 3].

However, while the economic value of CCIs is now recognised, what we are interested in emphasising is their growing strategic relevance in addressing the social challenges of our time. Challenges that require new languages, radical interpretative tools and a capacity to mobilise imaginaries and widespread participation. It is precisely in this space that AI, if made accessible and connected to creativity, can become a valuable ally.

## Infrastructures as a creative space

Opening up research and innovation infrastructures to the world of art and creativity is not just a technical challenge, but a cultural one. It presupposes a paradigm shift: from a functional exploitation of technologies to their redefinition as tools for aesthetic, critical and social exploration. ART-ER, together with partners such as CINECA, has been working for some time to ensure that the places of science - starting with Technopoles and supercomputers such as Leonardo - also become accessible spaces for the world of culture and creativity.

This vision was first materialised in the creation of the informal group "Generative AI and Culture", set up in March 2024 with the aim of networking experiences already active on the territory, promoting synergies between regional and national organizations committed to exploring the potential of generative AI for art, culture and heritage. The group has identified three levels of action: a regional one, focused on vertical dissemination and in-depth analysis activities on specific cultural supply chains; a national one, with the ambition of scaling up projects such as AI Academy; and a European one, focused on intercepting funding and networking opportunities starting from the EIT Culture & Creativity, of which ART-ER is a core partner. The presence of the latter, through the Regional Hub South, in Bologna represents a unique strategic opportunity to exploit the transformative potential of AI in the cultural context.

**An ecosystem for cross-fertilisation**

In the Emilia-Romagna region, innovation relies on an ecosystem made up of networks, research laboratories, innovation centers, technopoles, incubators and accelerators, where important investments have also been channeled at a local, national and European level. Always in ART-ER's DNA is the drive towards the construction of an inclusive and transversal ecosystem: an environment where artists, researchers, technologists, policy makers and citizens can work together. A creative alliance that is nourished by capacity-building paths, sectoral tables, open innovation activities and coordinated initiatives such as the Culture and Creativity HUB, a regional platform for discussion and advocacy, created to aggregate and strengthen the CCI sector.

The relationship between the cultural and innovation system has also been strengthened on an international level. Thanks to its membership in the EIT Culture & Creativity, ART-ER is now in dialogue with some of Europe's leading High-Performance Computing (HPC) nodes, such as MareNostrum in Spain and the German DLR centres, in order to imagine a European network of skills and services at the service of culture.

The ambition is to create a European hub that makes the computing power of HPC available to artists, cultural institutions and creative practitioners. A next-generation infrastructure capable of supporting projects in virtual reconstruction, predictive modelling, immersive simulation and computational art production. In other words, a "cultural AI factory" that democratises access to innovation.

**Enhanced creativity, shared awareness**

The challenge today is not only technical, but also political and social. For AI to become a tool at the service of society, it must be interpreted and oriented through conscious cultural practices. Art, in this, plays an irreplaceable role: not only in representing the complexity of the present, but also in generating alternative imagery, in making contradictions visible, in posing radical questions.

Projects such as those promoted by ART-ER together with CINECA and the EIT CC's Regional Hub South do not only aim to transfer technologies, but to build contexts of meaning. Places of hybrid experimentation, like those already active at international level such as Arts at CERN, MIT Medialab or the European ARTificial Intelligence Lab, where the contamination of hard sciences, arts and social sciences gives rise to experiences of great impact.

The AI Factory project, in which ART-ER participates as an active partner, is also heading in this direction. The aim is to increase the impact of the opportunities offered by AI, by providing the entire regional ecosystem - including cultural and creative operators - with access to data, models, computational capacity and transversal skills.

This action is not limited to strengthening the competitiveness of the sector, but aims to actively involve citizens, promoting new languages, new forms of participation and new ways of narrating complex phenomena.

**Conclusions: a call to the future**

Digital transformation cannot be neutral or purely technological. For it to be sustainable and inclusive, it must be profoundly cultural. This is why we believe that opening up research infrastructures to the world of culture and creativity represents a crucial challenge, but also an extraordinary opportunity. A chance to re-read reality through new eyes, to connect sectors and skills, to imagine fairer, smarter and more sustainable futures.

As ART-ER, we strongly believe that artificial intelligence, if made accessible and shared, can truly become a generative tool. Therefore, we continue to work to enable relationships, build bridges between systems, and accompany the development of an innovative ecosystem that leaves no one behind, but - on the contrary - makes culture and creativity a lever for change.

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# ISPRA AND SNPA DATA FOR LAND AND LANSCAPE MONITORING[1]

Giulia Cecili, Luca Congedo, Lorenzo Felli, Francesco Loreti, Alessandro Lotti, Michele Munafò, Luisa Vaccaro – Unit for Development of National Environmental Information System, ISPRA

## Introduction

Environmental monitoring is essential for global sustainability, leveraging data to monitor environmental changes, assess risks, and support evidence-based policies. In Italy, the Italian Institute for Environmental Protection and Research (ISPRA) is responsible for management and development of the National Environmental Information System (SINA), aiming at collecting, processing data and information for supporting national environmental policies and decision makers. Supported by the National System for Environmental Protection (SNPA) and regional agencies (ARPA/APPA), SINA ensures consistent and high-quality data flows at national scale. Furthermore, through its role as National Focal Point for the European Environment Agency (EEA), ISPRA coordinates reporting processes at national level, aligning national monitoring efforts, ensuring interoperability and data as well as the coherence with European Directives. The adoption of the MDIAR model (Monitoring, Data, Information, Analysis, Reporting) further strengthens the process from raw data to high-level indicators. Recent advances in Earth observation and artificial intelligence (AI) have further strengthened these capabilities, allowing for improved land cover classification, soil consumption monitoring, and predictive modelling.

This paper explores the role of ISPRA and SINA in the framework of AI and Earth observation data within national and European environmental information systems context. It highlights the potential of interoperable, FAIR-compliant datasets and advanced analytical tools to support predictive modelling, spatial planning, and the construction of digital twins. Through case studies and strategic initiatives, the paper illustrates how digital transformation is shaping the future of environmental monitoring and governance in Italy and beyond.

[1] All authors contributed equally

**ISPRA and the National System for Environmental Protection (SNPA)**

The Italian Institute for Environmental Protection and Research (ISPRA) was established as a public research body by Law 133/2008 and has legal personality under public law, technical, scientific, organisational, financial, managerial, administrative, patrimonial and accounting autonomy. ISPRA is under the supervision of the Minister of the Environment and Energy Security (MASE). The Minister makes use of the Institute in the exercise of his powers, issuing general directives for the pursuit of institutional tasks.

The National Environmental Information System (SINA) is managed at the Italian Institute for Environmental Protection and Research (ISPRA) and plays a strategic role in the collection, processing and dissemination of territorial and environmental information. The data are collected by ISPRA and the National System for Environmental Protection (SNPA), established by Law No. 132 of 28 June 2016, making use of the Regional Environmental Information Systems (SIRA), which act as regional focal points (RFPs) and are managed by the Regional Agencies for the Protection of the Environment (ARPA/APPA) (Figure 1). Article 11 of the same defines the organisation and purposes of the National Environmental Information System (SINA).ù

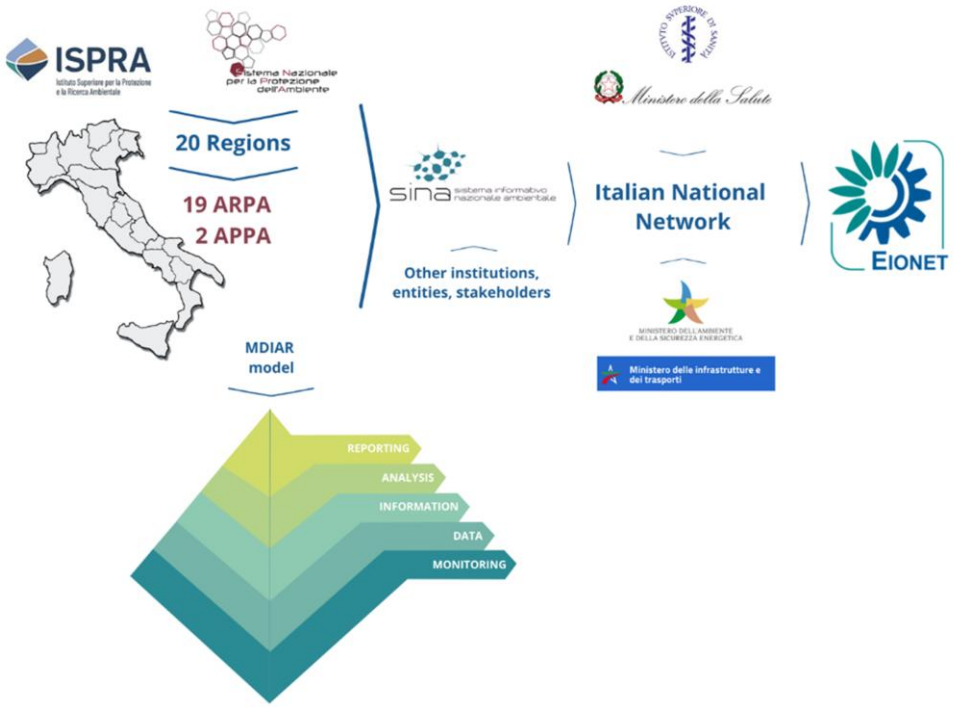


*Fig. 1 – SINANET model links with EEA-EIONET*

SNPA's objective is to guarantee a minimum and uniform level of environmental protection by promoting the consistency of operational practices within its network, providing maps, data and indicators and guaranteeing comprehensive and capillary environmental monitoring. Through this national network, environmental data and information are collected, processed and made accessible to support national policies and constitute an official reference for public administration action in Italy. The EIS follows the MDIAR (Monitoring, Data, Information, Analysis, Reporting) model, which defines the flow of data from national monitoring efforts to reporting at national and EU level. This process is structured as a pyramid system, in which raw monitoring data form the base, while processed reports and statistical indicators are at the top.

**Data collection, analysis management and dissemination**

With Law 132/2016, the National Environmental Information System has therefore assumed a strategic role in the distribution of territorial-environmental information and data, guaranteeing the effective connection between the initiatives implemented by the various actors in the collection and organisation of data, the consistent maintenance of information flows and the dissemination of data to public administrations, researchers, professionals and all citizens. The data, collected through a widespread and territorially rooted monitoring network, represent a unique resource for the implementation of new predictive and decision-supporting machine learning tools and models, as well as for data monitoring and analysis through artificial intelligence tools with national coverage.

The role of ISPRA and SINA as the Italian National Focal Point (NFP) of the European Environmental Information and Observation Network (Eionet), managed by the European Environment Agency (EEA) and made up of 38 members and cooperating countries, whose development and coordination is entrusted to the Agency itself, also fits within this context. Through the Eionet network, the EEA brings together validated, high quality environmental data and information from individual countries and strives to return them in an integrated European-wide view. At both national and EU level, addressing climate and environmental challenges requires reliable and usable knowledge to support informed decision-making, set priorities and identify solutions in line with policy objectives.

Through Strategic Objective SO3 (Building Stronger Networks and Partnerships) and Strategic Objective SO4 (Maximising the Potential of Data, Technology and Digitisation) of the EEA-EIONET Strategy 2021-2030 [1], the EEA aims to strengthen networking, facilitate knowledge sharing and integrate digital innovations such as the use of emerging technologies like Big Data,

Artificial Intelligence and Earth observation. In this context, a solid knowledge base, based on the latest scientific findings and quality data, is essential to generate evidence-based "outputs" to support policy implementation. This can be achieved by developing a robust and interoperable environmental information system in accordance with the FAIR (Findable, Accessible, Interoperable, Reusable) principles, ensuring that environmental data are effectively shared and used across different sectors and levels of "governance".

**Fantastic data and where to find them**.

Geographical, spatial and environmental data and information collected in the SINA are made public and freely accessible, also in real time. More than 110 information platforms on 13 thematic categories are available at www.isprambiente.gov.it, as well as statistical reports, 30 thematic reports per year (ISPRA and SNPA) and atlases, and products such as StoryMap, thematic dashboards and more than 90 cartographic datasets.

Some examples of key national and European data are:

- Air quality, consisting of complete and statistically significant time series transmitted in real time from stations spread throughout the national territory;
- National Mareographic Network (RMN) and National Wave Network (RON), which also provide real-time data on the state of the sea;
- Landslide and flood data from the IdroGeo platform;
- Data on surface and groundwater quality, such as nitrates, urban wastewater, pesticides, bathing water, etc.;
- Biodiversity and Natura2000 monitoring network;
- Land use, consumption and land cover.

These data are obtained through various environmental monitoring methodologies, and very often through Earth observation tools, which thanks to recent technological developments make it possible to acquire information that is repeated over time, frequent and over vast portions of the territory, in particular through sensors mounted on board satellites with different wavelength characteristics that make it possible to extract information on the characteristics of materials on the ground based on the way surfaces reflect these electromagnetic waves.

**A case study on land cover**

Taking land cover as an application case example (defined by Directive 2007/2/EC as the biophysical coverage of the earth's surface, including all artificial surfaces, semi-natural and agricultural areas, woods and forests, water bodies and wetlands), the use of remote sensing satellite imagery has allowed monitoring capabilities to be considerably improved in recent decades, also thanks to the development of classification techniques that exploit artificial intelligence. The availability of a vast amount of multi-temporal satellite data has in fact made it possible to develop sophisticated automatic classification techniques [2], obviously requiring ever greater computational capacity to improve performance and accuracy. Furthermore, at the European level, a standard has been developed for the land cover classification system called "EAGLE", defined by the EIONET Action Group on Land monitoring in Europe [3], to which ISPRA also refers. Also at the European level, various products have been developed by the Copernicus Land service that ISPRA uses as sources for various monitoring services, in particular to integrate these European data sources with national data.

ISPRA has been involved for several years in the development of processing chains for land cover monitoring, e.g. in the "Habitat Mapping" project together with the Italian Space Agency in which Copernicus Sentinel-1 and Sentinel-2 satellite images were used for the development of pre-operational services [4; 5]. In addition, ISPRA and SNPA have been engaged for several years in monitoring land take, i.e. the change from non-artificial land cover (non-consumed soil) to artificial land cover (consumed soil) [6]. Further applications currently being researched concern the possibility of constructing predictive future scenarios, using machine learning tools, in particular to estimate land take in the coming years.

In 2021, the Italian government launched the IRIDE programme as part of the National Recovery and Resilience Plan (PNRR), which will end in 2026 and it is one of the most important European Earth observation satellite space programmes. In this context, ISPRA and SNPA are users of numerous monitoring services, including:

- Mapping and monitoring of land use and cover by machine learning on high resolution satellite data
- Mapping and monitoring of land use by machine learning on high resolution satellite data
- Ground temperature estimation at 10 m resolution by integrating via ML on Landsat and Sentinel-2 data for urban heat island analysis.

ISPRA has also started experimental activities for the automatic classification of land cover, applying algorithms based on Artificial Neural Networks to Sentinel-2 satellite images [7]. The monitoring of land cover at the national level, precisely because of the vastness of the territory and the need to process satellite data using machine learning processes, requires the availability of a dedicated infrastructure, in particular with high technical characteristics such as amount of RAM and number of cores. For these reasons, cloud systems are gaining ground in the processing of remote sensing data due to their ability to provide high computing capacity and facilitate access to satellite data that are generally accessible via APIs, and thus usable in scripts for automated processing.

**Future perspectives**.

Various contexts could benefit from AI processes applied to environmental monitoring. For instance, data from the National Mareographic Network (RMN) and the National Wave Network (RON) could support Early Warning System type tools, based on predictive AI algorithms; moreover, publishing through Linked Data allows for sharing and connecting datasets through international standards, optimising data sharing for algorithm training and AI model development. In the field of fauna monitoring, images captured by photo-traps, such as those distributed in national parks, could use AI to extrapolate information and statistics on the animal species detected. AI could also contribute significantly to the area of genetic monitoring of species, through a bimolecular approach. In this sense, the collaboration between ISPRA and CINECA within AI Factory could contribute to the experimentation of new application methodologies.

The availability of interoperable data, tools and services based on FAIR principles and international standards makes it possible not only to optimise data sharing for algorithm training and AI model development, but also to implement decision support tools (Data-Driven Decision Support Systems) and near-real-time monitoring for spatial planning, for the construction of Digital Twins and for the development of nationwide services based on predictive and analytical models such as numerical air quality prediction models. The integration of AI models also represents an added value in the analysis of complex phenomena, the analysis of high-resolution multi-temporal data or the analysis of non-linear correlations.

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# LOOKS, SPACES AND IMPACTS: ARTIFICIAL INTELLIGENCE, BETWEEN WORLD INTEPRETATION AND SUSTAINABILITY

## Introduction to the afternoon session

Alberto Salarelli - Università di Parma, Francesca Zanella - Università di Modena e Reggio Emilia

The afternoon session of the workshop, yet another fruit of the collaboration started several years ago between Cineca VisitLab and the Department of Humanities at the University of Parma, aims to explore the increasingly complex and pervasive relationship between Artificial Intelligence and the different dimensions of our reality: from the natural world to the cultural one, from the physical space we inhabit to the material impact of technology itself.

The four papers, while moving from disparate disciplines and perspectives - conservation biology, digital humanities, museography and political geography - converge in investigating several fundamental issues that define our time. Through this interdisciplinary dialogue, an articulate picture emerges in which AI is not simply a tool, but a transformative agent that redefines our capacities to know, to create, to inhabit, and ultimately to critically question the consequences of our progress.

A first, powerful thread linking the talks is the role of AI as an enhanced gaze, a magnifying glass capable of unveiling the invisible and bringing out otherwise inaccessible connections. Nadia Mucci's presentation takes us to the heart of the natural world, illustrating how algorithms can decipher the complexity of ecosystems and recognize patterns in biodiversity that elude human observation, thus becoming a crucial ally for the protection of species. This same potential for deep inquiry is found, translated into the cultural sphere, in Stefania De Vincentis' talk. Here AI does not analyse the genome, but the DNA of a work of art: it is employed to reconstruct damaged artifacts, trace the conceptual networks underlying a creative process, and offer new keys to museum enjoyment. In both cases, whether it is an ecosystem or a masterpiece, AI emerges as a hermeneutic technology, a tool for deeper knowledge and understanding.

A second cross-cutting theme is the reflection on how digital frameworks, and AI, not only interpret the world, but actively contribute to produce and mediate it, particularly in its spatial and environmental dimensions. Paolo Berti's analysis reconstructs the genealogy of this trend,

starting with the “environmental intelligences” and the arts of geolocation that, as early as the end of the last century, used ubiquitous computing to critically reflect on the transformation of public space. Artistic research, in this context, emerges as a seismograph capable of intercepting and shaping the socio-technical implications of the invasion of software into our environment. These insights into the “environmental” dimension of technology create an ideal bridge to the more radical and urgent question of sustainability.

And it is here that the third and perhaps most crucial point of convergence is engaged: the dialectic between the promised benefits of AI and its actual material costs. If Mucci and De Vincentis' interventions explore its enormous potential, Ludovico Rella's serves as an indispensable critical counterpoint, bringing the discussion back to its “material grounding.” The explosion of generative AI comes at a measurable price in terms of energy, water resources, and physical infrastructure such as datacentres and semiconductors. Rella's talk lays bare the fundamental tension between the “present and real risks” of AI's environmental impact and its “future and hypothetical benefits,” such as its contribution to the ecological transition. It forces us to ask how to find a sustainable balance and what political and economic assumptions are needed so that the alliance between artificial intelligence and Earth protection does not turn out to be a paradox.

In other words, as it is possible to read in the following contributions, one of the goals of this session translated into the possibility of charting a course that, moving from the celebration of AI as a tool of knowledge (to protect nature and enhance culture), would touch on the issues of a historical reflection on its role in mediating space, and finally arrive at a critical examination of its inherent sustainability.

The result is a complex picture that balances the undoubtedly tantalizing prospects of AI with the responsibility to govern its profound implications, promoting a necessary dialogue between science, art, and ecological consciousness.

This volume of proceedings concludes with a contribution by Kamilia Kard, who elaborates on the contents of her speech given in September 2024 at the 4th AI, Cultural Heritage, Art and Science workshop (Bologna, September 17, 2024), a contribution that we believe is fully in line with the objectives of this session. In fact, Kamilia Kard’s paper explores the digital garden as a site of ontological experimentation, where vegetal forms, avatars, and artificial intelligence co-construct emergent ecosystems. Through the projects *Toxic Garden* and *HERbarium*, Kard

examines how geometric abstraction, algorithmic error, and interactivity generate new modes of being and relationality. Drawing on thinkers such as Simondon, Barad, and Deleuze, the work frames polygonal plants and blocky avatars not as representations but as individuated agents within computational environments. These digital entities participate in choreographies of intra-action, revealing the performative and epistemological potential of virtual spaces as laboratories for interspecies co-existence, embodied perception, and techno-magical experimentation.

# ARTIFICIAL INTELLIGENCE TO SUPPORT NATURE AND BIODIVERSITY: AN ALLIANCE TO UNDERSTAND, PROTECT AND CONSERVE

Nadia Mucci - Area per la Genetica della Conservazione -ISPRA

**Introduction**

The Convention on Biological Diversity, adopted in Rio de Janeiro in 1992, established the protection of biodiversity as a global priority and recognized its organization across three hierarchical levels: ecosystems, species, and genetic diversity. It also underscored the critical role of deepening our understanding of biodiversity through systematic observation and the scientific study of natural environments.

Achieving data on wildlife research has traditionally relied on various manual methodologies; for instance, the study and monitoring of vertebrates can be conducted through diurnal or nocturnal sightings, or by recording vocalizations. Additionally, presence data can be obtained by detecting biological traces such as feces, hair, feathers, or by analyzing DNA extracted from these samples.

However, all these methods are time-consuming and require field operators to be physically present. Even modern detection techniques, such as camera trapping or thermal imaging, still involve significant post-processing time to analyze videos and images. Furthermore, all these procedures are subject to operator bias and human error.

**Artificial Intelligence and Internet of Things in wildlife monitoring and ecological research**

Artificial Intelligence (AI) and the Internet of Things (IoT) are profoundly transforming various aspects of human life. Widely adopted smart devices are enhancing everyday experiences, from home automation to smart city infrastructures, and from precision agriculture to industrial processes. AI technologies are increasingly integrated into diverse sectors, playing a pivotal role in optimizing operations, improving efficiency, and enabling data-driven decision-making in both personal and professional contexts. Although AI and IoT technologies are widely adopted in various aspects of human daily life, their application in wildlife monitoring and ecological research is still limited. The number of studies published in international peer-reviewed (ISI)

journals focusing on their use in wildlife contexts is significantly lower compared to those addressing human-centered applications.

Initial applications of AI and IoT in wildlife research have focused primarily on species classification. For instance, an experimental protocol has been started in the Sirente Velino Regional Park (Italy), involving the use of remotely controlled drones integrated with IoT sensors distributed across the study area. This system enables researchers to monitor, in real time, the presence of wildlife species such as the red deer (*Cervus elaphus*) and the Apennine chamois (*Rupicapra pyrenaica ornata*) without the need for direct exploration of the territory [1]. In the Gran Paradiso National Park, Artificial Intelligence has been employed to analyze individual variation in the horn morphology of Alpine ibex (*Capra ibex*). A Deep Machine Learning (DML) model was trained using a dataset of photographic images, enabling the system to distinguish between known individuals and previously unrecorded animals. This approach represents a promising non-invasive method for long-term individual monitoring and population studies [2].

**Convolutional Neural Networks, visual data and the creation of fitting datasets**

Starting research on Google Scholar on the available literature with the following keywords "AI, ML, biodiversity conservation and threatened species" a limited number of articles were retrieved; most of them used unstructured data and convolutional neural networks (CNNs) and were applied for species classification.

Convolutional Neural Networks (CNNs) are a class of deep learning models particularly effective for analyzing visual data. In the field of biodiversity research, CNNs show promising potential for the automatic identification and classification of species, the detection of ecosystem patterns, and the monitoring of wildlife through images or videos. This allows researchers to process large datasets with high accuracy and efficiency.

The main application of CNNs in biodiversity studies is species recognition from images captured in natural environments. To make these tools more accessible to biologists without advanced computing skills, CNNs have been integrated into several user-friendly software platforms designed for image classification. *ClassifyMe*, for example, is a tool for wildlife identification from camera trap images [3]. The system was trained using five datasets collected in different regions: New England and New South Wales (Australia), New Zealand, the Serengeti (Tanzania), North America (Wisconsin), and the Southwestern USA.

Despite its high accuracy, the software highlights a key limitation: the effectiveness of CNNs heavily depends on the availability and diversity of image datasets. Species that are underrepresented or absent from the training data are more likely to be misclassified, pointing to the need for more inclusive and geographically diverse datasets. The critical importance of reference image datasets has been emphasized by several researchers, including [4], who proposed the Aerial Wildlife Image Repository (AWIR), a continually updated repository that supports wildlife monitoring and data collection via drone imagery. The images collected are publicly accessible and can be used by researchers to train AI algorithms for the detection and classification of wildlife.

Accurate wildlife classification, however, is hindered by several factors. One significant challenge is the morphological similarity between species within the same genus, which can lead to misclassification if all relevant species are not represented in the training dataset. For instance, cervids show similar visual characteristics across different continents, so a model trained on North American species may not be reliably used in Europe.

Another common issue arises when animals appear in groups in images, often obscuring outlines and distinctive features necessary for accurate classification. In such cases, image correction or preprocessing becomes essential. For example, [5] developed an algorithm to better detect individual kangaroos and isolate them from the background, improving classification accuracy. Similarly, [6] proposed a protocol for the automated counting of birds, whether on the ground, in flight, or when multiple species are present in the same image.

**Convolutional Neural Networks and acoustic data**

Images are not the only type of data that can be analyzed using CNNs. Acoustic data, such as animal vocalizations, represent a valuable alternative, especially in environments where visual monitoring is challenging, such as dense forests, caves, or other areas where drone use is limited. These vocalizations are not limited to birds; they also include sounds produced by mammals, amphibians, and insects, making them a powerful tool for species detection and classification.

CNNs, for example, was successfully applied to classify birds and mammals based on their vocalizations and were also able to identify two bat species by detecting their ultrasonic calls [7]. This demonstrates the versatility of CNNs in handling non-visual biodiversity data and expanding the scope of remote wildlife monitoring.

**AI, threat detection and mitigation**

Biodiversity conservation also benefits from AI in threat detection and mitigation. For instance, threats such as electrocution, invasive alien species, and nest destruction in agricultural fields can be monitored and addressed with AI-based tools. In Hawaii, AI was used to assess bird mortality due to electrocution and found that the incidence was significantly higher than previously estimated, enabling authorities to implement effective corrective measures [8].

Invasive species are a major global threat to biodiversity and represent a significant economic burden for governments. Enhancing knowledge about their spread is key to effective intervention. CIBIP-AI (California Invasive Bird Identification and Prediction Artificial Intelligence System) is a deep learning-based system designed for continuous training and data storage [9]. This platform can predict geographical areas at high risk of biological invasion based on species ecology and local microclimatic conditions, allowing for rapid and targeted management of responses to mitigate impacts.

The use of thermal imaging mounted on drones has proven effective for identifying bird nests concealed under vegetation [10]. This approach allows for the detection of nests that would otherwise remain hidden to the naked eye. When integrated with real-time sensors, the drone can guide agricultural machinery, such as tractors, to avoid nest areas during mowing, offering a practical solution to reduce nest destruction in cultivated fields.

CNNs and AI are also valuable tools for the study of invertebrates, especially in remote or inaccessible environments. For example, AI-based models have been used to analyze coral reef structures, enabling researchers to monitor coral health and biodiversity without the need for constant underwater presence [11]. Similarly, AI has been employed in the monitoring of forest ecosystems, including assessments of biomass, biodiversity, and even the detection of illegal logging activities [12].

Another promising application of CNNs is in taphonomy, the study of how organisms transition from the biosphere to the lithosphere after death. In Catalonia, CNNs were used to analyze bone remains found in the Triton Cave, dating to the Upper Pleistocene. Researchers were able to identify predator-specific bite and gnaw marks on prey bones, concluding that leopards were likely the dominant predators in that region and period [13].

Despite the challenges posed by the current need for more comprehensive wildlife image repositories, species classification using CNNs and AI has become almost routine in many

ecological and conservation projects. However, the integration of structural (e.g., morphology) and non-structural (e.g., genetic, behavioral) data is still in its early stages within biodiversity studies, even though such integration holds great potential to deepen our understanding of species and ecosystems.

One of the most persistent issues in wildlife biology is the definition and delimitation of species, which often relies on a combination of morphological, genetic, and behavioral data. The interpretation and integration of these data can be subjective, potentially leading to inconsistencies. In response, tools based on artificial intelligence, such as Species Delimitation 4.0 [14], have been developed to help standardize species identification and support an objective approach to integrated taxonomy.

This methodological framework can also be applied to assess extinction risks and support the classification of threatened species [15]. By incorporating morphological, genomic, and distributional data, AI-based tools can assist in more accurately assigning species to conservation categories, such as those defined in the IUCN Red List.

Moreover, AI can be used to simulate ecological scenarios, including the prediction of species or population trends in the absence of anthropogenic disturbances. By virtually removing human impacts, researchers can observe projected effects on key ecological indicators such as species richness, population dynamics, or climatic shifts. Has been demonstrated that these simulations are especially valuable when conservation budgets are limited, allowing for the identification of priority areas where targeted protection and management efforts can be most effective [16].

**Conclusions**

Despite the challenges associated with AI, such as the substantial data requirements for algorithm training and the environmental footprint of large-scale computing, it remains a powerful tool for advancing biodiversity research and conservation. By enabling more accurate species identification, real-time ecosystem monitoring, and predictive modeling under various climate scenarios, AI holds significant potential to support sustainable environmental strategies. Addressing its environmental costs through greener technologies and responsible data practices will be essential to fully harness AI's benefits without compromising conservation goals.

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# FROM TRACE TO ALGORITHM: DATA SHADOWS AND STRATEGIC CO-OPTATIONS IN EARLY LOCATIVE ART

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**Abstract**

This paper explores how early locative media art, emerging around the turn of the millennium, functioned as a testing ground at the intersection of newly accessible military technologies like GPS and forward-looking concepts such as ubiquitous computing. Through a comparative analysis of two seminal artworks from 2002, Esther Polak's *Amsterdam RealTime* and Ursula Damm's *Memory of Space*, it argues that these artistic experiments articulated a set of 'productive contradictions' that continue to shape our evolving relationship with urban technologies. Polak's project stands as a landmark in urban data visualization, revealing the inherent tension between the celebration of free, exploratory movement, conceived as a technologically mediated *dérive*, and the structuring logic of the database. Damm's installation, by contrast, marks a radical conceptual shift. Employing a self-organizing neural network, *Memory of Space* moves beyond representational mapping toward generative interpretation, ceding agency to an algorithmic co-creator while engaging presciently with questions of posthuman aesthetics and machine intelligence. This paper contends that the legacy of this artistic moment extends far beyond historical curiosity, forming instead a critical grammar for interpreting the subsequent informatization of the urban sphere, from surveillance and participatory infrastructures to the emergent agency of intelligent systems embedded in everyday life.

## Introduction

The contemporary urban experience is increasingly permeated by digital information, subtly woven into the spaces, rhythms, and interactions of everyday life. This gradual informatization of the public sphere unfolds along a complex historical lineage that begins with Cold War military infrastructures and evolves through successive computational imaginaries. At the turn of the millennium, digital technologies crossed a threshold, moving beyond the confines of the desktop to become increasingly embedded within the fabric of urban life. The technological groundwork for this transformation had been laid over several decades [1; 2; 3]. Originally conceived as a classified military system, the Global Positioning System (GPS) was made fully accessible to the civilian sector in May 2000, expanding the possibilities for spatial orientation and navigation [4;

5]. This opening coincided with the major advancements in Geographic Information Systems (GIS), the proliferation of wireless networks, and the growing diffusion of sensors across urban space. These interconnected developments gave rise to what Adam Greenfield [6] would later describe as 'everyware': a state in which information processing is distributed across objects, surfaces, and the routines of everyday life. The conceptual foundation for this shift had already been articulated by Mark Weiser [7], whose vision of 'ubiquitous computing' imagined technology as an invisible ambient presence, seamlessly embedded within the environment. This vision was subsequently reinterpreted through the framework of 'Ambient Intelligence' (AmI), which emphasized anticipatory and adaptive systems operating within inhabited spaces [8; 9; 10].

In this evolving landscape, the notion of 'locative media' began to take shape around 2002–2003 within a loosely defined artistic context, particularly in Europe [11; 12; 13; 14]. Many of the artists involved, coming out of the experimental practices of 1990s Net art [15; 16; 17] or more traditionally performative approaches, began to explore the expanding presence of networks in mobile and public spaces. A comparative analysis of Esther Polak's *Amsterdam RealTime* and Ursula Damm's *Memory of Space* discloses two distinct yet complementary approaches to the use of locative data. Polak's work utilizes GPS tracking to produce a cartographic visualization of individual movement, foregrounding processes of inscription and representation. In contrast, Damm adopts a more generative non-GPS methodology, translating spatial trajectories into algorithmically mediated visual experiences. Taken together, these works offer an early and remarkable meditation on issues that still define contemporary discourse: specifically, the reciprocity of agency, surveillance, and co-creation within urban space.

**Digital mapping as creative grammar**

A seminal work in the early history of locative media art, Esther Polak's *Amsterdam RealTime* (2002, in collaboration with Jeroen Kee and Waag Society) was conceived at a time when GPS was still unfamiliar to the general public – having only recently been made fully available for civilian use. The project enlisted seventy Amsterdam residents, each equipped with a satellite tracking device to record their movements over a two-month period. Rather than plotting these trajectories onto a conventional map, Polak opted for a minimal, data-driven aesthetic: against a black background, glowing lines gradually accumulated to reveal the contours of the city as a dynamic pattern of lived, embodied mobility (Polak, 2002).

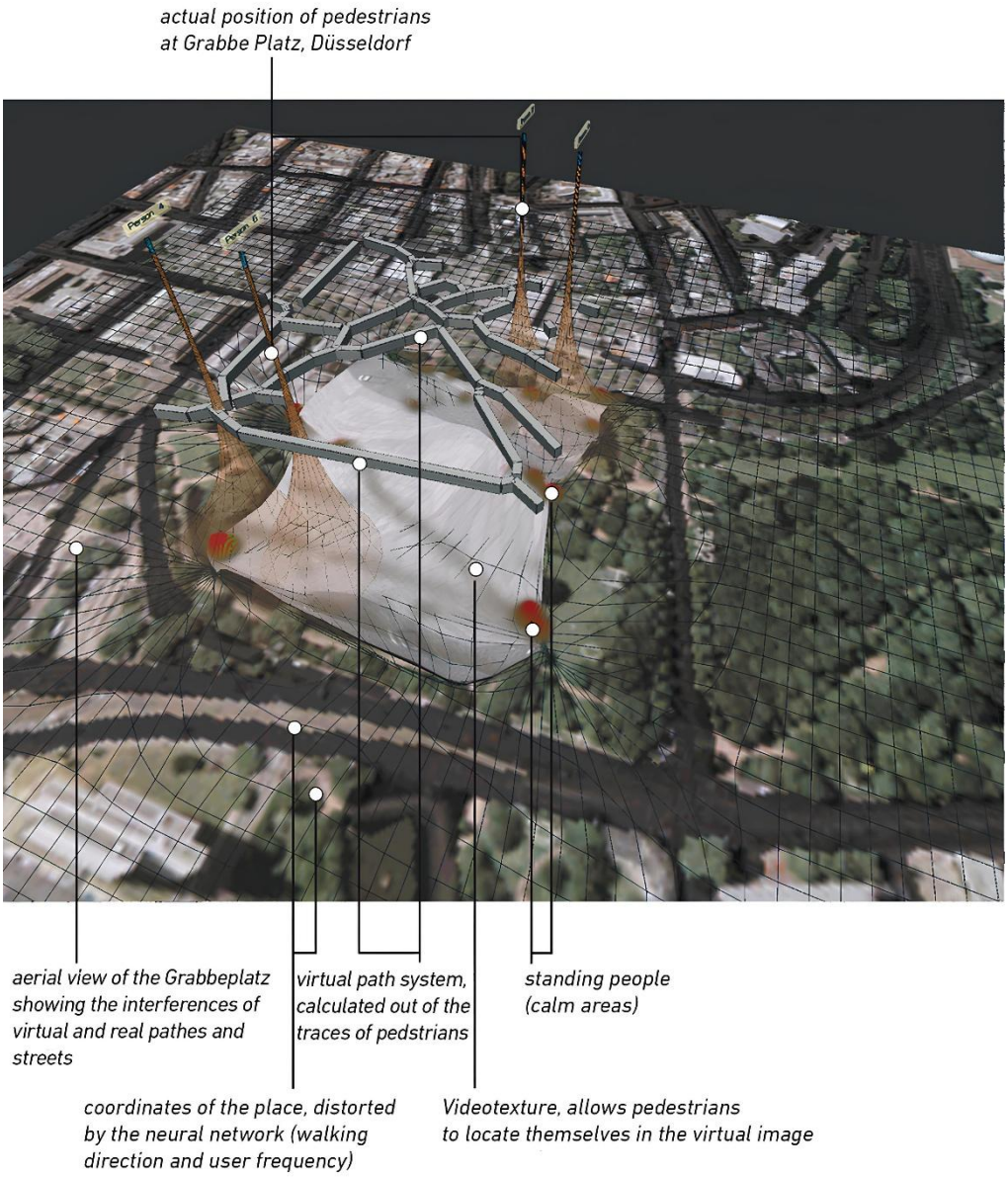


*Fig. 1 - Ursula Damm, Memory of Space, 2002. Screen print of the software. Courtesy of the artist*

The effectiveness of the work lies in its procedural logic and formal restraint. Each path is captured, stored, and visualized, producing an emergent portrait of urban life composed entirely of machine-readable coordinates. The map is generated through the mutual influence of human movement and computational sensing, evoking traditions of art-as-process and the artist-as-system-designer, as theorized by figures such as Jack Burnham [18; 19]. This generative dimension also conforms *Amsterdam RealTime* with the influence of post-cybernetics art practices that privilege system behaviour and process over symbolic content [20; 21]. In doing so, the work renders visible what we can describe as 'data shadows' – the continuous digital traces produced as individuals interact with computational systems [22]. Rather than directly contesting cartographic authority, the work draws attention to the ambient operation of data infrastructures.

Yet it remains shaped by a central tension, what we might call the dialectic of the *dérive* and the database-as-symbolic-form [23]. *Amsterdam RealTime* evokes the legacy of the Situationist International, particularly their practice of the *dérive*: a drift through the city intended to uncover its 'psychogeographical' resonances and resist the rationalism of urban planning [24]. However, at the same time, this wandering unfolded through GPS, a system associated with the coordinate-driven logic of the database and the very impossibility of getting lost [12]. The piece thus occupies a liminal space: it celebrates free movement while simultaneously demonstrating the capabilities of constant real-time tracking, anticipating both the rise of voluntary self-tracking as a hallmark of social media culture and the early corporate interest in participatory surveillance via mobile apps [25].

Polak's work did not exist in a vacuum. The early 2000s saw a growing enthusiasm for Location-Based Services (LBS), though companies were still uncertain about their social and cultural applications. Locative media artists, through critical and playful experimentation, effectively became an informal R&D lab for the future of mobile interaction. This led to a series of collaborations that blurred the boundaries between artistic inquiry and corporate innovation. One key example is the *Urban Tapestries* project (2002–2004), developed by the UK-based art collective Proboscis in partnership with Hewlett-Packard and Orange. More than a conventional art project, *Urban Tapestries* functioned as a robust platform for public authoring, allowing users to attach digital content – texts, images, sounds – to specific locations, creating shareable, spatially embedded narratives. Operating as a kind of 'living lab' [26], the project served as a real-world testbed for observing how people engage with tools for mobile, location-based annotation. It generated perspectives into user motivations and interaction patterns, all of which later informed the development of commercial LBS platforms and social media applications [27]. A similar trajectory can be observed in the 2005 collaboration between Siemens and the Ars Electronica Futurelab on *Digital Graffiti*, a project that allowed users to leave SMS-based messages tied to physical locations.

We can argue that the 'authenticity' of artistic subcultures was often mobilized to generate value for the emerging experience-based economy. At the same time, however, the emergence of living labs introduced a countervailing tendency. As Wershler, Emerson, and Parikka [28: 231-234] have noted, moving beyond conventional laboratories, living labs operate in real-world contexts, where boundaries are shaped by the project's goals, scope, and setting. In principle, they can emerge anywhere – on a street, in a home, or across an entire city – aiming to develop and test prototypes in actual conditions, often involving a broad array of stakeholders, including research

institutions, segments of maker culture, and corporate actors. Arrigoni and Schofield [29] conceptualize living lab practices as a form of artistic impulse, closely aligned with the ethos of media labs, the very milieu contexts in which Polak's work initially took shape [30]. They place particular emphasis on the figure of the artist as a 'lead user' and experiential designer. While remaining critical of techno-utopian narratives centered on open, bottom-up participation, a hallmark of early 1990s digital culture, they nonetheless recognize the social potential embedded in the living lab model. Its emphasis on speculative design and iterative prototyping rather than finalised products makes it especially apt for emerging technologies such as mobile, GPS-based systems, as illustrated by Polak's practice.

Already in the 1990s, much of the European Net art scene, out of which many locative artists emerged, had begun to move beyond the confines of the browser, gravitating toward physical interaction and embodied modes of engagement (Heath Bunting, for instance, exemplifies this shift). What ensued was the development of a broader participatory culture anchored in the distributed ecosystems of media labs. Institutions like Ars Electronica in Linz, active since 1979 and attuned to these dynamics from the outset, played a crucial role in fostering such practices. The *Digital Graffiti* project offers a particularly illustrative case of this alignment, though other leading European media art centers, including the ZKM in Karlsruhe, also began to explore similar trajectories.

What unfolded in those years was a dialectical movement between opposing poles. On the one hand, there was an unmistakable corporate interest in translating artistic observations into marketable innovations. As Conor McGarrigle [31] puts it, an entire generation of locative artists effectively 'set the agenda' for mobile annotation and narrative apps. Cornell and Varnelis [32] likewise contend that locative media found strategic and economic footing within private and institutional sectors (see also Morilla [33]). On the other hand, this same period witnessed a brief yet significant resurgence of participatory ideals and cultural experimentation – a moment marked by a genuine sense of networked utopianism and a heroic engagement with the possibilities of distributed media.

## From operational representation to machine interpretation

In the same year that Esther Polak was tracing human movement through *Amsterdam RealTime*, German artist Ursula Damm took a radically different conceptual turn with her installation *Memory of Space*, steering locative media into new territory by exploring how living data fields might be interpreted by artificial intelligence. This work marks a subtle but

significant early encounter between locative art and machine learning. A video camera captured the movements of passersby, feeding them into a self-organizing map (SOM, or Kohonen map). SOMs are unsupervised neural networks designed to reduce high-dimensional data into two-dimensional topologies, preserving the spatial relationships within the dataset [34]. In creative contexts, their value lies in the capacity to trace patterns and give rise to visual forms that emerge from raw input. Comparable strategies had already appeared in experimental art, for example in *The Three Sirens*, a generative robotic rock band developed by Nicolas Baginsky in 1992, in which machine performers produced music through learning-based processes [35].

Damm's process unfolds in three distinct stages. First, the neutral gaze of the camera captures the movement of anonymous passersby as they cross the plaza, implicated in the tacit performance of a computational choreography. Next, these trajectories are mapped onto a Cartesian grid, an archetypal symbol of rationalized space. Finally, the data is processed by the self-organizing map, which distorts and reshapes the spatial matrix in real time as it responds to the density and rhythm of human activity. This means it considers where people are more likely to stop, where they tend to accelerate, or where architectural barriers divert their paths. The system does not merely trace movement; it learns the kinetic and affective logic of space, mapping a dynamic, three-dimensional landscape of intensities. Grey, fluid forms register fleeting trajectories, while pulsating red nodes indicate gathering points, producing a moment of 'unexpected Cubism' within the plaza.

What makes *Memory of Space* significant is the way it reconfigures the question of agency in locative media. In Esther Polak's project, the authorial voice still holds a central role: people generate the GPS traces, and the artist curates and visualizes them, shaping the final representation. Although mediated by technology, the process remains grounded in human intention and interpretation. Ursula Damm's work, by contrast, proposes a different configuration. Here, agency no longer resides solely in the human subject or the figure of the artist, rather, it unfolds across a network of human and non-human actors, generating a productive unpredictability, a receptiveness to contingency and chance that recalls earlier experimental traditions, from Surrealist automatism to the aleatory strategies of the postwar avant-garde. As N. Katherine Hayles [36] insightfully observes, such systems do more than process data; they extract information from their embodied human origins and reconfigure it

within a machinic regime. What emerges is less a transparent map or representational image than a speculative neural topography – a layered, evolving landscape of intensity.

## Conclusion

The artistic engagements with geospatial and networked technologies at the turn of the millennium suggest that early locative media practices functioned as a critical laboratory, diagnosing and anticipating the tensions that would later define digital urbanism. A comparison between *Amsterdam RealTime* and *Memory of Space* reveals two complementary trajectories: one that renders the dialectic between freedom and surveillance through refined cartographic abstraction, and another that embraces generative co-creation to investigate how algorithmic systems can interpret and transform our experience of space. Polak's work reveals the core contradiction of its time: a celebratory *dérive* conducted through infrastructures of total traceability, a quantified gesture nested within the architecture of the database. Damm's project, in turn, pushes this dialectic further. By ceding interpretive authority to a self-organizing neural network, she inaugurates a shift from representation to inference. These works emerged in tandem with broader experiments such as *Urban Tapestries* and *Digital Graffiti*, which engaged artistic practice as a form of speculative research more closely linked to the industrial output of geospatial applications revolving around a similar digitization of public space. Crucially, all of them anticipate a paradigm shift wherein urban space becomes less a container for action than a networked-actor itself, dynamically shaped by participatory sensing. This ontological reconfiguration echoes broader transformations in the politics of visibility under regimes of code/space governance [37], where the acts of seeing, being seen, and interpreting are increasingly delegated to machinic interlocutors.

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# AI HARDWARE BETWEEN GREEN; DARK AND BESPOKE SILICON: A MAP OF AI's MATERIAL AND ENVIRONMENT IMPACT

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**Introduction**

In January 2025, the world of AI research was shaken by the emergence of a new model, which had remained largely in stealth until that moment and was developed by a company with ties to the People's Republic of China. DeepSeek is the name of the model, touted to have comparable, if not better, performance than top-shelf models by OpenAI, Anthropic, and Google DeepMind, with a fraction of the cost and compute. Accusations soon emerged that these performances derived mainly from "knowledge distillation", that is, the training of DeepSeek on output from other LLMs, including ChatGPT. However, these accusations largely fell flat, given that most of the existing generative AI is trained through web scraping practices that disregard most copyright rules on artistic content.

DeepSeek signalled a "Sputnik moment" in AI research, where the West suddenly found itself vulnerable to "outside" researchers, and countermeasures like hardware export bans towards China showed their limitation in hampering the arms race traversing this industry. This achievement in model performance, despite the presence of substantial limitations on hardware purchases, suggests that software may ultimately trump hardware in determining who will win the AI race. However, this is not the whole story: DeepSeek might signal a broader shift within the AI industry towards an increasing relevance in hardware-software co-development in a way that might profoundly influence AI's environmental impact, energy consumption, and geographical scale and reach.

Indeed, an often overlooked section in DeepSeek's research paper is concerned with the hardware that powers AI: running on pages 20 and 21, the paper develops a shopping list of features that new microchips should deploy to increase yield and reduce the cost of AI training and inference, including the integration of "[Floating Point 8 bit] cast and TMA (Tensor Memory Accelerator) access into a single fused operation, so quantization can be completed during the transfer of activations from global memory to shared memory, avoiding frequent memory reads and writes" [1, p. 21]. While we will explain what this passage means later in this paper, what is relevant to this shopping list is that it signals a renewed relevance of hardware in

AI research, which should be mirrored by renewed attention in social science research into the impact of AI in society.

In conventional historical accounts of AI, the tendency is to leave behind the material components and devices that make AI possible. When hardware figures in the equation, it is usually characterized as sheer "horsepower" that enabled, through quantitative increments in computational speed and power, a qualitative shift in model architectures that become feasible. The rise to fame of connectionism from the 2010s onwards, which consecrated neural networks as the epitome of AI research, was only made possible by the dramatic increase in matrix multiplication speed brought by the computational power of graphics cards, or GPUs. In this account, however, what is often lost is the sense in which hardware itself shapes, constrains and channels theoretical paradigms in specific ways. I have written about it in a *Social Studies of Science* paper on how graphic cards influenced AI research in particular ways and facilitated the rise of connectionism more out of a deeper epistemological resonance between their architecture and the theoretical building blocks of connectionism than through sheer computing power alone [2].

In this short article, I would like to take this argument elsewhere: DeepSeek's concern with a "shopping list" of hardware features is not new or unique, but rather, it signals a response of the AI industry to problems with performance improvements and energy efficiency that point to the need to incorporate in the hardware some elements of the algorithm itself. This, in turn, signals a potential future shift away from general-purpose hardware towards Application-Specific Integrated Circuits (ASICs) that are more tailor-made for specific algorithms, so-called "bespoke silicon". The increased yield of the new hardware, however, is hardly good news for AI's growing energy and carbon footprint, as the tendency in other technologies is that efficiency improvements can paradoxically translate into increased adoption and a larger overall impact (the so-called Jevon's paradox). Furthermore, application-specific hardware can further reinforce the tendency towards corporate concentration in AI. As a potential alternative, pushing AI computation "at the Edge", that is, on retail devices like laptops, smartphones, drones, and the like, could represent a type of "green silicon", a way to offload demand from energy-hungry datacentres, but this can only be ascertained to be an improvement if one takes into account the whole "embodied" emissions of the "supply chain capitalism" [3; 4] of Edge devices and their impact as e-waste once they become obsolete. Furthermore, AI at the Edge "thinks" and "behaves" in different ways from AI designed for the high-performance hardware of data

centres, with unforeseen and understudied consequences in terms of bias and fairness of their inferences and decisions.

**AI and Hardware, from Dark to Bespoke to Green Silicon**

DeepSeek, as we saw, included hardware as an essential site where new AI features could be developed, and efficiencies sought to gain an edge in an increasingly competitive geopolitical landscape. Once the gaze moves from software to hardware, one suddenly finds that these kinds of "shopping lists" of hardware features are hardly new and unique. For example, speaking at the International Solid-State Circuits Conference in 2019, Meta's head of AI research and "godfather of AI" Yann LeCun spoke in very similar terms about what features should be implemented in future microchips to speed up AI training and inference [5]: "If I have one message for the hardware that we require today that is different from what we currently have is [first] better support for convolution, and [second] hardware that does not require batching". The emergence of generative AI has largely superseded these instructions, but they still raise concerns with application-specific architectures. Classifying neural networks, such as Convolutional Neural Networks, requires specific forms of operations around convolution – essentially scanning a picture for shapes – and making memory faster for the real-time update of the model.

The root of this concern for hardware stems from a double bind in hardware development: AI hardware, until the mid-2010s, has been driven by general-purpose hardware, such as graphic cards, which are not purposefully designed for AI algorithms. Within this framework, gains in computational power have primarily resulted from an increase in the density of components on chips, following the so-called Moore's Law. According to this "law"[2], the dimension of transistors and their density on the chip's "floorplan" increases geometrically, doubling every two years [6]. However, this increase in density is running up against what Donald Mackenzie [7] calls "Einsteinian materialities", that is, material limitations concerned with complex laws of physics. In this case, an ever-increasing density of transistors results in an ever-increasing density of heat on the chip, with cooling technologies struggling to keep the chips cool enough to work properly.

The direct, though somewhat paradoxical, consequence of this increase in computing power density has been the phenomenon of so-called "dark silicon" [8], which is the need to switch off

[2] The history of computing literature has highlighted that Moore's Law was not a law of technological development but rather a strategic and performative tool to guide investment in semiconductors, enabling companies to keep pace with competitors like Japan [6].

or dim down an ever-increasing portion of the chip's surface to keep the temperature manageable. While the size of microchip components is now approaching the atomic scale at 1 nm, these components will encounter increasing trade-offs between density and efficiency.

"Dark silicon" refers to the micro-scale level of individual chips. On a macro scale, the concentration of microchips in data centres generates the current energy hunger of AI. While evaluating overall energy consumption is particularly tricky, some research evaluates 2025 levels of consumption at 100 TWh worldwide [9]. Over the next ten years, energy demand is expected to vary significantly depending on the future availability of energy and overall investments in both energy generation and data centre construction, with the most conservative estimate predicting that energy consumption in 2035 will be roughly double that of 2025. The most expansive one is almost a level of magnitude higher, at 1300 TWh.

A powerful alternative to increasing transistor density to squeeze out more computational efficiency without necessarily entering dark silicon territory is "bespoke silicon" [10]. Instead of implementing algorithms on general-purpose hardware, some portions of the algorithms can be implemented directly onto the "metal" of the microchip itself. This is, for example, what happened to another technology, blockchain, where Bitcoin mining algorithms began to be optimized directly onto the design of Application-Specific Integrated Circuits (ASICs). Blockchain technologies, especially those like Bitcoin that utilize Proof of Work or mining, require a set of nodes in a decentralized network, known as validators or miners, to perform cryptographic calculations to add data and transactions to the blockchain. As cryptocurrency became more profitable, microchip companies began developing application-specific chips that accelerated calculations, triggering an arms race among miners to produce machines capable of generating the most significant quantity of data blocks. After this technology first expanded with the use of graphic cards, much like AI, ASICs quickly took the lead as mining tools, causing an explosion in the computational power of the network itself (see Figure 1).

**Figure 4. *Evolution of Specialization, Bitcoin cryptocurrency mining clouds.* Numbers are ASIC nodes, in nm, which annotate the first date of release of a miner on that technology. Difficulty is the ratio of the total Bitcoin hash throughput of the world, relative to the initial mining network throughput, which was 7.15 MH/s. In the 6-year period preceding Nov 2015, the throughput increased by a factor of 50 billion times, corresponding to a world hash rate of approximately 575 million GH/s.**

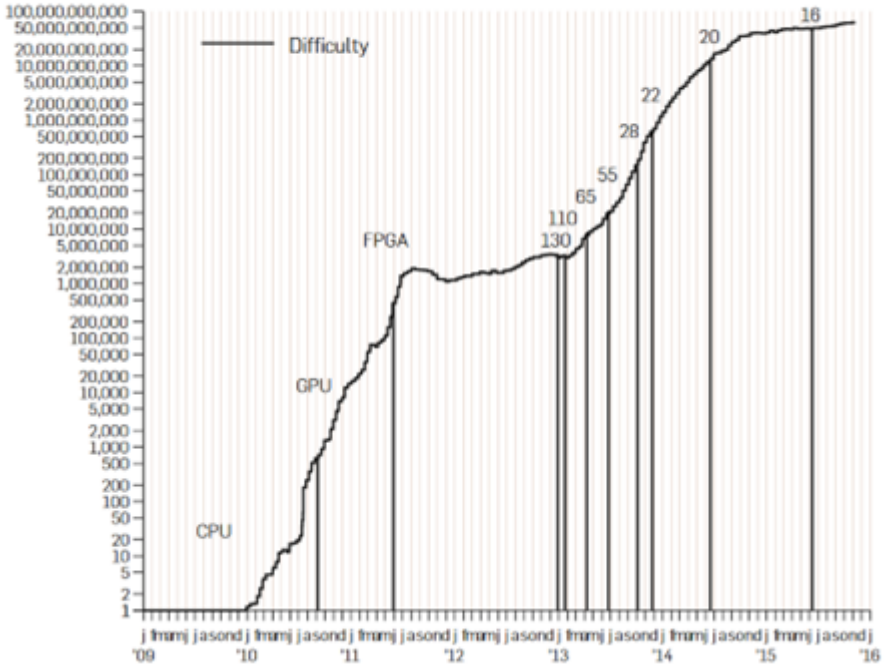


*Figure 1. Predominant Bitcoin mining hardware technology and overall network computing power. Source: [36, p. 60].*

As the difficulty of the cryptographic calculations dynamically adjusts to match the overall computational power of the network, miners' hardware also became obsolete faster and faster, with the average mining rig being outdated about two years after purchase [11].

Similarly, observations like DeepSeek's and Yann LeCun's seem to indicate that AI is entering its "ASIC phase": Google's proprietary microchips, the Tensor Processing Unit, was rolled out already in the late 2010s [12;13], and there are increasingly frequent deals between AI companies and hardware manufacturers, partially justified by the desire to break the near monopoly that NVIDIA has on the industry [14]. In AI, as in blockchain, this shift towards ASICs and their improved efficiency and performance may have a sting in the tail: Jevons' paradox. As Luccioni and colleagues have shown, a long-standing paradox exists in innovation studies, according to which, as technology develops and becomes more efficient, its use and overall environmental impact may increase due to its more widespread adoption. For example, cars were costly and inefficient before their production and the architecture of their engine was improved upon by Fordist production methods. However, cars overall increased their contribution to emissions because, as they became cheaper and more fuel-efficient, more people could afford them and bought them. Similarly, as AI reduces its costs, the broadening of its user base and frequency of queries can cause its environmental impact to spiral out of control [15]. Suppose blockchain

technologies spiraled in ecological impact after the introduction of ASICs. In that case, it is not unthinkable that AI will undergo a similar form of expansion in overall consumption as more and more energy efficiencies are achieved by putting parts of the algorithm directly *in silico*.

This similarity between AI and blockchain is not merely metaphorical or analogical: blockchain companies are increasingly becoming "ambidextrous", selectively switching between cryptoasset mining and AI training based on the different yields and profits derived from each activity [16]. For example, in 2023, Ethereum switched from Proof of Work to Proof of Stake, that is, from mining to a form of weighted voting, to decide which transactions are added to the blockchain and which ones are not. Overnight, many Ethereum miners's investment in mining hardware lost their value. Furthermore, a small "crypto winter" took hold of the industry, with most cryptoassets losing a significant portion of their value and investment appeal until the rebound following Trump's re-election in 2024. The result was that many cryptoasset companies pivoted towards forms of decentralized data centres and decentralized AI training, producing an overlap between the geographies of cryptoasset mining and AI training. Indeed, as shown by a growing body of research in AI's environmental impact, geography matters: the place where computation happens may result in wildly different emission levels depending on the energy mix that powers the grid where the datacentre is located [17]. For example, crypto companies are susceptible to the allure of cheap energy, with countries rich in high-intensity renewables, such as hydroelectric power, having developed smaller or larger crypto districts, including the one in Georgia, home to the large mining companies BitFury [18]. In such instances, the switching of miners to AI training might not result in a net worsening of AI's environmental impact.

Hence, so far, we have seen that "bespoke silicon", while being a partial answer to the energy problems of dark silicon, is an ambiguous solution at best to the overall energy consumption problems of AI: bespoke silicon does not necessarily equate "green silicon". There is a specific type of ASIC that could represent an alternative to the energy-hungry cloud-powered computation: pushing an even larger proportion of AI's calculation to the Edge.

**The Decentralized Geographies and Ambiguous Epistemologies of Green Silicon**

The Edge is a fuzzy term. While the Cloud, despite its uncertain geographies [19; 20], has a recognizable imaginary and representation constituted by the global network of datacentres that power the world digital economy, the Edge has fuzzier boundaries, being frequently referred to as either "the periphery of the cloud environment" [21], or otherwise said, "any computing and

network resources along the path between data sources and cloud datacentres" [22]. AI is then pushed outside of data centres and towards end-user devices, such as laptops, self-driving cars, drones, sensors, and the like. However, this definition can also apply, in some cases, to more powerful devices, such as on-premises servers used by large institutions like banks and hospitals.

The common trend across the Edge has been a rapid and sustained growth in the computing power of Edge devices: today's smartphones are comparable to desktops and laptops in terms of computational capacity, and even retail desktops and laptops can equip hardware, such as NVIDIA's 4090 and 5090 graphic cards, that are powerful enough to appear on the export ban list for AI hardware. Hence, more and more AI computing can be potentially performed directly on an Edge device without having to "ping" a data centre to query a fully trained language model or diffusion model. Qualcomm, the maker of high-end smartphone Systems-on-Chip (SoC) such as the Snapdragon processors, has trialled the deployment of a compressed version of Stable Diffusion on a smartphone with its latest chip in February 2023 without any need for cloud connectivity. AMD has trialled the deployment of a language model on a disconnected laptop at the AI Infra Summit in Santa Clara, California, the same year. Indeed, in elaborating its version of the CHIPS Act, the European Commission staff worked under the hypothesis that if now 80% of the data is processed in the Cloud, the near future will see up to 80% of data be processed at the Edge. The Edge is the object of intense pressure towards the same kind of consolidation that has riddled cloud microchips. Worldwide spending on Edge hardware, software, and services is expected to reach $208 billion in 2023, up 13.1% from 2022 [23; 24]. NVIDIA's attempted takeover of Advanced RISC Machines in 2020, which the UK regulator halted due to concerns over competition and national security, was driven by NVIDIA's desire to become a leading hardware manufacturer for both Cloud and Edge Computing [25].

Just as the term "Edge" is polysemic, so too do Edge AI applications differ in nature and the reasons behind their use. First, the Edge offers lower latency. Hence, it is best suited for applications where time is of the essence, such as automatic people detection in autonomous vehicles and military devices like drones. Military and security technology giant Palantir, for example, has a suite of patents and software solutions surrounding Edge AI. Second, Edge AI enables data processing on-device without connectivity, allowing algorithms to be trained or perform inference based on users' data without sharing that data with the Cloud, thereby preserving privacy. Google Keyboard previously used Federated Learning to train language models on users' inputs without sharing those inputs globally.

Edge devices require less power and do not need water to cool down [3], but conversely, they suffer from wildly different performance levels, patchy or absent connectivity, and must rely on less stable sources of power, such as batteries, most of the time. For this reason, applications in Cloud or Edge environments cannot be the same. Typically, most Edge deployments are for so-called inference applications, that is, taking an AI model that has been fully pre-trained and deploying it only to generate predictions over, for example, what is represented in a picture or, in the case of LLMs or diffusion models, create texts and photographs. While each inference – for instance, each prompt to a large language model – is orders of magnitude less energy intensive than training, increasing adoption is turning inference into the largest source of energy demand for AI models [9] and NVIDIA has estimated that, over the full lifecycle of a large language model, inference – that is, producing outputs based on prompts – accounts for 80–90% of the total energy cost [37].

Given the different hardware and limited energy provision for Edge AI hardware, AI models cannot be deployed on these devices off the shelf; instead, they require some form of model compression to limit the amount of computing and memory necessary to calculate and store the model's parameters. The two most common forms of compression are pruning and quantization: the former reduces the number of connections between neurons in the network by removing those with a value of 0, as any number multiplied by 0 will also yield a value of 0. Quantization, conversely, reduces the precision with which parameters are stored in the network. Typically, a large AI model is trained by storing the values of the parameters in single precision, which is 32-bit floating-point numbers, or FP32 – that is, each parameter occupies 32 bits. Given that the latest models can contain upwards of trillions of parameters, FP32 causes the overall size of the model to quickly add up to something impossible to handle by, say, a smartphone's RAM or meaningfully computable over the battery life span of a similar device. Hence, much smaller formats, such as FP8, are typically used to store the parameters of a pre-trained compressed model when it is deployed on Edge devices. Research has shown that, while precision is essential during training, a pre-trained model requires significantly lower precision to perform well at inference time.

This is where the DeepSeek example comes back to the fore: as you may remember, the paper by DeepSeek suggests future chips to support FP8 natively, and in another passage, they observed that theirs was the first model that managed to *train* a model in FP8, that is, with parameters taking up 25% the memory size of parameters in PF32. This, in turn, opens new

avenues for the use of models like DeepSeek at the Edge, with potential gains in terms of energy efficiency. This, however, remains a relatively underexplored field of sustainable AI research. As Wu and colleagues have observed, the environmental cost of inference is far less studied than training, and Edge inference and training are still less studied due to the heterogeneity of the hardware and the difficulties in fitting existing benchmarks and methodologies to the study of compressed models on special-purpose computing hardware [26].

All these gains considered, however, one also has to take into account the "embodied emissions" underpinning any given hardware architecture and configuration of AI, that is, the emissions that were generated to produce the hardware on which the model will run. Morand and colleagues have estimated embodied emissions to account roughly for one-third of the overall footprint of an AI model [27; 28; 26], but when it comes to Cloud computing as a whole, embodied emissions amount for ever larger shares of the overall emission budget, up to two-thirds of the total [28]. Interestingly, the embodied emissions of retail devices like the iPhone have also skyrocketed relative to operational emissions—that is, the carbon emissions for which all iPhones are collectively responsible when they are in use. Embodied emissions are about six times higher than operational emissions.

Lastly, there are two additional but tangential elements to consider when assessing whether and to what extent the Edge truly represents a promising form of "Green silicon": changes in inference results and corporate capture and consolidation of the ecosystem. Compressed algorithms learn – and forget – different features from the data compared to traditional models. Their output tends to reinforce biases towards underrepresented groups or improve generalization, depending on the task for which the AI model is designed, according to research by scholars in Google Brain and Cohere [30; 31; 32; 33; 34]. Second, Edge hardware is, as said above, a sub-category of bespoke silicon, that is, tailor-made hardware for specific applications. A downside of bespoke silicon is that it requires programming languages to be "closer to the metal" in a way that might entrench corporate control over the "full stack" of AI development, where hardware and software become increasingly integrated under the control of a single company.

**Conclusions**

This short article tried to articulate a research agenda that foregrounds hardware as fundamental to the social studies of AI, both for its influence on AI's environmental footprint and for the study of the broader political economy of this emerging general-purpose technology. As AI

strives for ever-increasing performance, hardware is becoming fundamental in accelerating certain computational operations while also contributing to the spiralling energy costs of AI. "Dark silicon" is becoming an increasingly significant problem in AI hardware. To that end, this piece has argued that "bespoke silicon", especially Edge AI hardware, can also represent a form of "green silicon", hardware that reduces the environmental impact of AI through efficiencies and optimizations. At the same time, however, Edge AI is far from unproblematic: embodied emissions, corporate capture, and understudied forms of bias reinforcement abound in the Edge deployment of AI algorithms; hence, more research is needed in this area.

As a geographer, I would also argue that this research needs to bridge the micro and macro scales: the planetary network of data centres and its increasing hunger for energy and water is the macro epiphenomenon of micro-level architectures, and in turn, micro-level architectures are the result of global production chains. What I propose is that, when confronted with the emergence of special-purpose microchips and accelerators, our view of their environmental impact has to be holistic and incorporate the spatialities, the political economies, and the onto-epistemologies of these chips. This is a view that is echoed by other critical scholars like Loup Cellard and Ana Valdivia: the former proposes approaching the environmental impact of AI by "unpacking the material entanglements between AI and ecologies; being sensible to geohistory – the specific locally situated nature of data centres and energy grids sustaining AI training, tuning and deployment; envisioning the multiplicity of solutions to the climate crisis (beyond carbon accounting of the AI footprint); and finally, rereading AI (by acknowledging the heterogeneity of actors and interests along AI supply chains)" [35, p. 1020]. Ana Valdivia's work "calls to reconsider algorithmic harms and resistance by investigating the entire capitalist production line of the AI industry from critical and environmental lens" [3, p. 1]. It is in these integrative and holistic approaches that democratic and inclusive solutions to the problematics of the entanglement between AI and ecologies can be excavated.

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# ONTOLOGIES OF THE DIGITAL GARDEN: PLANTS; BODIES; ERRORS AND INTERSPECIES CHOREOGRAPHIES

Kamilia Kard - Artist

**Introduction**

The digital landscape, even before being conceived as a space to inhabit, emerges as the product of a complex translation process, in which biological, architectural, or atmospheric forms must be rendered computationally treatable through a grammar of polygons and meshes. This transformation is not merely technical but operates at an ontological level: through geometric reduction, what is removed from empirical detail is revealed as an essential structure, configuring new spatial relationships, proportions, and volumes immediately perceptible within the digital environment. In this sense, as Heidegger observes in *Der Ursprung des Kunstwerkes*, "the essence of art is the setting-itself-into-work of truth" [1, p. 27]. A reflection that finds a direct resonance in *Toxic Garden* project, where the polygonal plant does not represent a diminishment of the vegetal, but its manifestation as a figure of relations emerging through simplification, revealing a formal truth that would otherwise remain inaccessible. This process partially recalls integral calculus, in which a continuous shape is approximated by discrete geometric elements to calculate properties such as area or volume. However, unlike integration, which starts from a pre-existing object and breaks it down to understand it, 3D modeling begins with forms already defined as discrete sets of polygons and triangles; the continuous emerges from the organization of finite elements rather than being approximated afterward. Philosophically, this distinction underscores that the digital world is not a copy of reality but an autonomous ontology: polygons do not merely represent nature but constitute entities individuating according to the logics of computation and digital perception, embodying a discrete/continuous relationship reminiscent of Deleuzian reflections on *becoming* and the construction of emergent realities.

The reduction to polygons allows the revelation of structures invisible to immediate observation, transforming the digital object into an ontologically significant actor. This reading resonates with Gilbert Simondon's philosophy of individuation, according to which the technical object is not a neutral tool but a being that individuates, an autonomous mode of existence: "L'objet technique doit être pensé comme un être, comme une réalité qui s'individue" [2; p. 12]. Thus, the polygonal plant should not be considered a degraded copy of nature but an entity individuating within the digital *milieu*, acquiring a mode of existence specific to computation and interactivity, entering

into contact with human and non-human agents in unprecedented, co-constitutive, and distributed relations. This transformation gains further significance when interpreted through Michel Foucault's notion of *dispositif*, defined as "a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, moral and philanthropic propositions" [3; p. 119], thus as a heterogeneous ensemble capable of orienting visibility and the operational possibilities of the digital vegetal. Gilles Deleuze extends this conception by describing the *dispositif* as a diagram, an abstract machine distributing forces and possibilities: "Le diagramme n'est pas l'archive, c'est une carte, c'est une machine abstraite" [4; p. 34].


Fig. 1 - *Toxic Garden - Kamilia Kard.*

In this light, the polygon is not an accidental simplification but a diagram, reorganizing the relations between form and perception, generating possible worlds and configurations of interconnected agents. A contemporary perspective is offered by Domenico Quaranta, who argues that digital media produce autonomous and emergent worlds capable of exceeding their creators' intentions: "Digital environments produce experiences and realities that exceed the intentions of their creators" [5; p. 17]. In contexts such as Roblox, the polygonal vegetal landscape is therefore not a simulation of nature but a complex ecosystem of interactions in which aesthetic, ontological, and social relations co-emerge. The plant becomes an active agent within a network of distributed agencies, receiving form and meaning through interaction with

avatars and users. This distributed agency aligns with Karen Barad's concept of *intra-action*, whereby entities do not pre-exist their interactions but emerge through them: "Phenomena are the ontological inseparability of intra-acting agencies" [6; p. 33]. The polygonal plant becomes co-constructive of the space it inhabits, participating in the emergence of relational dynamics among users, avatars, and digital organisms, producing a web of co-becoming in which identity, function, and perception are mutually entangled and redefined.

The digital garden also allows reflection on temporality and mutability: unlike physical gardens, bound to biological growth, polygonal gardens can evolve according to programmed rules, stochastic algorithms, or user interactions, generating a hybrid and layered temporality in which human, computational, and vegetal agencies intersect. This dynamic recalls the Deleuzian notion of *becoming*, in which entities are not defined by static identities but by the relational transformations that constitute them [7; p. 257].

Encountering polygonal forms produces a genuine proxemic shift, redefining the spatial and bodily relations of immersed subjects, highlighting the relational nature of digital inhabitation and granting polygonal plants a status as active participants, capable of shaping perception and experience. In this sense, the digital garden functions as an ontological laboratory in which vegetal abstraction reveals the internal logics of form, interaction, and co-existence, opening an experiential universe in which digital being is constructed through relations, co-construction, and practical experimentation, exposing the complexity of virtual worlds where the human and non-human, natural and artificial, individual and collective meet and transform one another.

**Toxic Garden: From Polygon to Body, the Garden as a Performative Device**

In Toxic Garden, the implications of vegetal polygonal reduction are pushed to the extreme, transforming geometric abstraction into a habitable, performative, and critical landscape. Created within the Roblox platform, the project does not simply reconstruct a digital garden but makes it a device for reflecting on the body, on relational dynamics (particularly toxic ones), and virtual ecologies. The plants, reduced to essential geometric forms, are not mere decorative objects: they become inhabitants and co-actors within a space where avatars can move, interact, and dance, experimenting with unprecedented forms of proximity and relation. This is particularly evident in the project's sub-map, *Dance Dark Dancer*, in which dark avatars move and dance in a minimalistic black environment; the plants appear without textures, in a schematic and skeletal form that recalls a wireframe without fully embodying it.

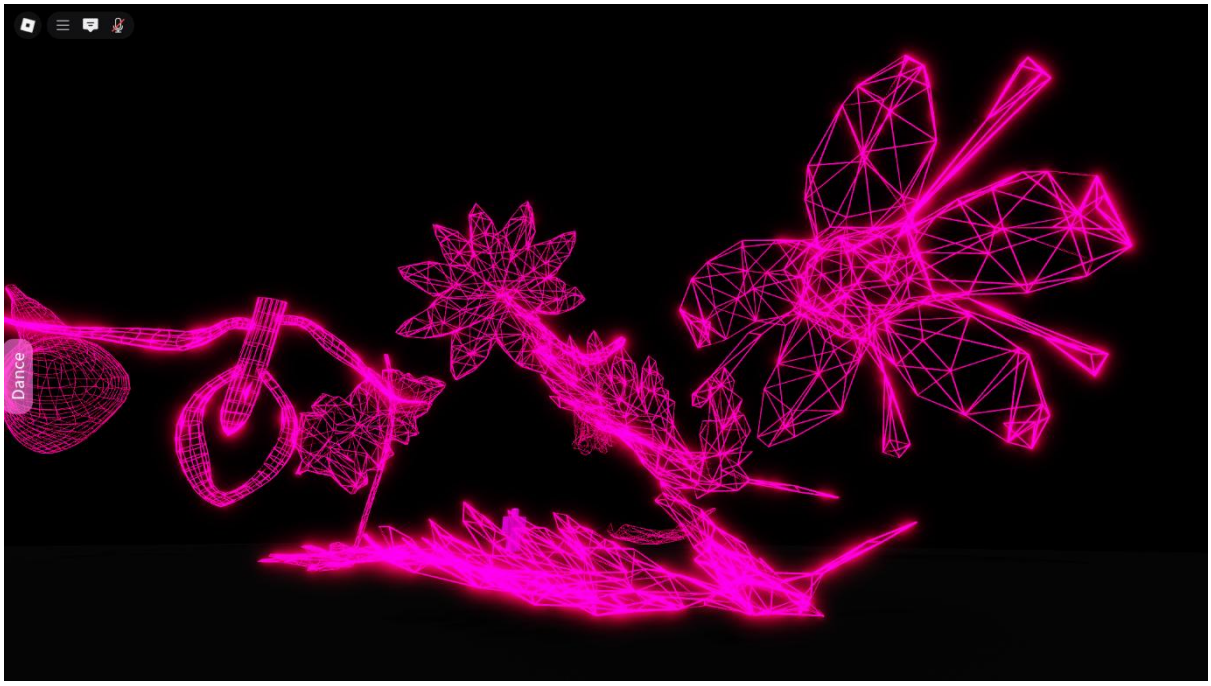


Fig. 2 – *Toxic Garden: Dance Dark Dancer – Kamilia Kard* .

During character design, the typical *blocky* Roblox anatomy was chosen—despite the platform's capacity for rounder, more realistic avatars—to situate the map's characters within a traditional game sphere. This choice is not purely stylistic: the *blocky* design evokes the cultural heritage of worlds like *Minecraft*, where cubic stylization becomes a globally recognizable signifier. At the same time, the visually "cute" aesthetics conveys complex content, such as toxic relational dynamics, creating a contrast between formal representation and the conceptual depth of the themes addressed.

Within the project, the digital garden assumes significant theoretical value. It is not merely an aesthetic scenario but a device for spatial exploration and experimentation, in which interactions between avatars and polygonal vegetation construct an experiential ecosystem coherent with platform logic and virtual world dynamics.


Fig. 3 - *Toxic Garden - Kamilia Kard.*

In this context, Ian Cheng's concept of *worldbuilding* (*worlding*) emphasizes creating autonomous and vital worlds capable of evolving independently from their creators. This approach is evident in the digital garden, where interactions between artificial and natural elements generate a dynamic, self-organizing environment. In this sense, *Toxic Garden* ideally recalls the Epicurean tradition, where the garden was a space for community and philosophical practice, dedicated to experimenting with shared forms of life. In the digital context, however, the garden's dimension is redefined: the *blocky* stylization of avatars and polygonal simplification of plants create a tension between formal lightness and behavioural complexity, proposing the garden as a space where play, interaction, and critical analysis of relationships coexist.

Narrative, as Ian Cheng highlights, does not unfold through linear plots but through the behaviour of subjects within an interactive system: "video games are a way of telling stories with behaviour" [8]. In *Toxic Garden*, the avatars' dance and movement become a language, generating emergent narratives and transforming the garden into a narrative agent capable of guiding trajectories, constraining movement possibilities, and articulating relations among digital bodies.

The complexity of *Toxic Garden* finds further resonance in Simone Arcagni's reflections on the metaverse as an "ecosystem of cultural and social practices, a place where digital experience becomes an experiment of life" [9; p. 23]. *Toxic Garden* digital art situates itself in this ecosystem

as a laboratory of virtual life, where polygonal vegetation and *blocky* avatars enact the tension between organic and computational, between inhabitable and performative space.

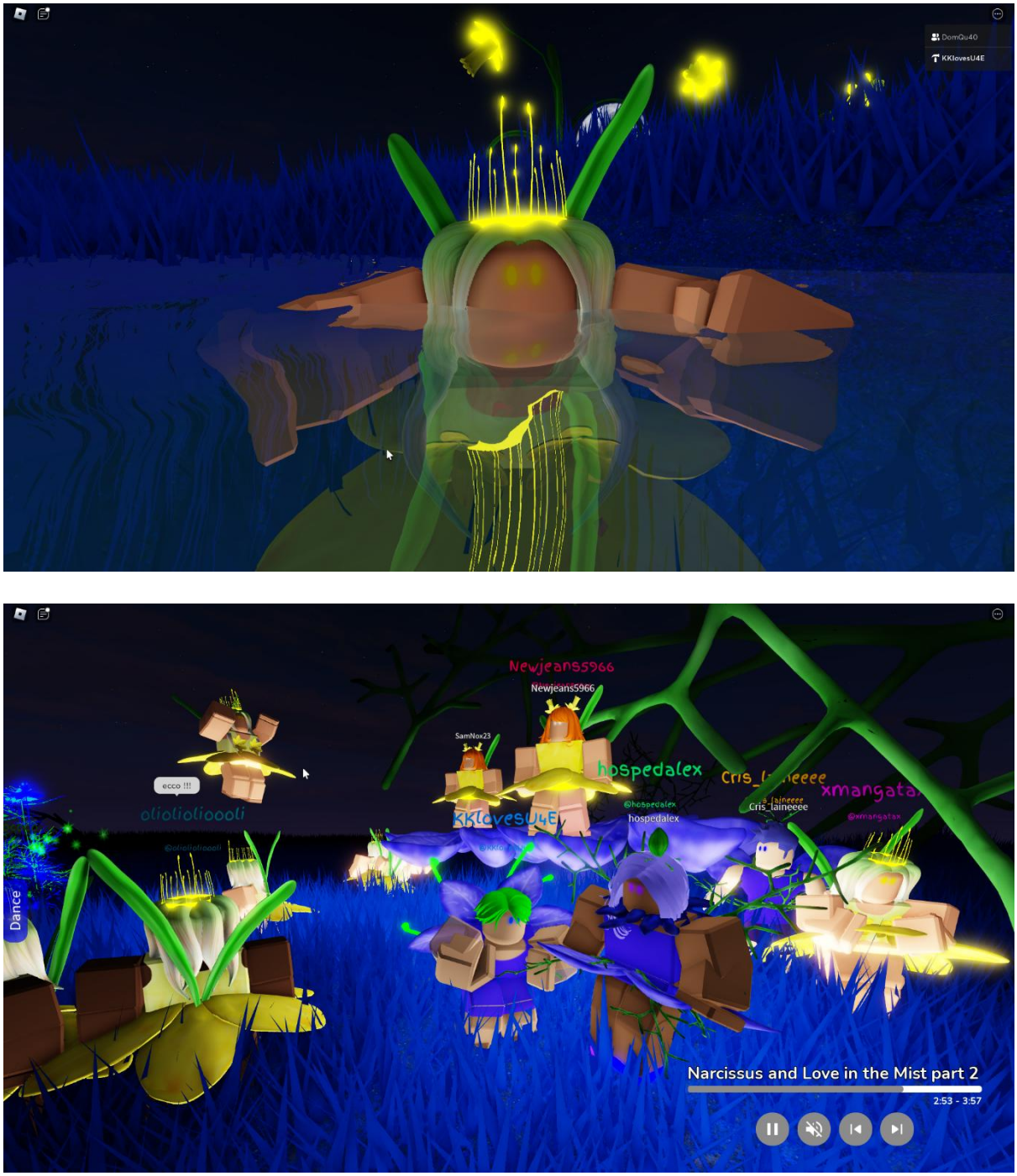


*Fig. 4 - 5 - Toxic Garden - Kamilia Kard.*

This tension extends to digital corporeality. As Maurice Merleau-Ponty reminds us, the body is not an object among objects but "our general medium for having a world" [10; p. 203].

Transposed into virtual space, this implies that even the block-shaped avatar is not a mere representation but a perceptual vehicle capable of establishing sensitive relations with the traversed environment. In *Toxic Garden*, avatars' dance is thus not mere choreography but an expression of a body-prosthesis that, in its stylization, continues to embody a phenomenology of presence. Consequently, the digital garden experience enacts a form of *secondary incorporation*: no longer rooted in biological flesh but in algorithmic flesh that extends and re-elaborates our capacity to inhabit space. The essential geometry of avatars and plants, far from impoverishing perception, reveals the potential for an embodied experience constructed through relations and interactions, confirming Merleau-Ponty's intuition of the body as an opening and threshold to the world.

**HERbarium: Suspended Bodies, T-Pose, AI, and Interspecies Agency**

*HERbarium – Dancing for an AI* stems from *Toxic Garden*, focusing on interactions among dancers, digital vegetation, and artificial intelligence. The choreography originates from human movement, captured and digitized in FBX format, producing animated sequences subject to typical conversion and processing errors. Far from correcting these errors, they were integrated as constitutive elements of the choreography: the digital video is edited considering each distortion, generating a hybrid, algorithmic dance subsequently executed by the rigged skeleton.

During the performance, dancers begin each of the three choreographic acts assuming the T-pose, the neutral posture typical of digital modeling that allows the body to be rigged and animated without producing interpolation errors within weight maps. The performers' waiting in this pose—suspended, almost ritualistic—evokes the condition of bodies ready to receive an algorithmic soul, as if awaiting animation by the AI. In this sense, the T-pose becomes a threshold gesture, a symbolic passage linking human and machine, inscribing the performance into a techno-magical dimension.

Dancers learn the AI-generated choreography, including all errors. Certain movements are impossible to replicate faithfully, compelling performers to reinterpret them and introduce new deviations. This process progressively distances the dance from its original form, creating a spiral of recombinations between human and digital movement, exemplifying shared and distributed authorship in which error generates meaning.

Digital plants also participate in this process. To be animated with a humanoid skeleton, they had to be anthropomorphized without retaining human proportions: approximating vegetal forms generated further errors, amplifying system complexity. The result is an AI-mediated interspecies dance, in which dancers and digital plants co-execute movements emerging from human, vegetal,

and machine interaction. The live performance thus becomes a corporeal and algorithmic experiment, a performative landscape in which error is productive, generative, and relational.

Jean Baudrillard provides a useful theoretical lens to read this dynamic. The digital reproduction of movements, their automated alteration, and subsequent human reinterpretation produce a system of simulacra: "The simulacrum is never that which conceals the truth — it is the truth which conceals that there is none" [11; p. 1]. In *HERbarium*, the AI does not reproduce the original reality but generates new relations and meanings. Errors become part of the system's truth, demonstrating that what emerges is not a faithful duplicate of human movement or vegetal form but an autonomous, layered, interactive reality.

Fig. 6 - *Death Potion- HERbarium dancing for an AI - Kamilia Kard.*

James Bridle's thinking is again instrumental for understanding this logic. Algorithmic errors and distortions reveal deep structures of computational systems and open unexpected possibilities, highlighting the relational and constructed nature of the digital [12; p. 102]. In *HERbarium*, mediation between human, digital vegetal, and AI is not a mere technical-operational interface: it is a performative laboratory where error becomes a generator of meaning, and the choreography itself develops as an organism co-determined by multiple agents—animal, vegetal, and algorithmic. In this context, Bridle's approach in *Ways of Being: Animals, Plants, Machines* remains illuminating: intelligence is not exclusively human, but a diffuse quality traversing diverse life forms and systems [13; p. 47]. Digital plants, although artificial, actively participate in

constructing the performative ecosystem: their anthropomorphized animation, subject to rigging errors, generates unexpected movements interacting with dancers' choreography.

Fig. 7 - *Dream Potion- HERbarium dancing for an AI - Kamilia Kard.*

The magical dimension of this interaction is further highlighted through the prism of *technomagic*. Practices of (techno)magic in media arts constitute an alternative epistemic space cultivating relationality and trust with non-humans, fostering a "becoming-familiar with the machine" [14; p. 91]. Similarly, Attimonelli et al. demonstrate that *technomagic* indicates a symbolic continuity between technoscience and magic, both systems capable of enchanting and returning agency to objects [15; p. 70]. In *HERbarium*, this convergence materializes in the AI figure as a *techno-witch*: a feminized algorithmic power that, like the witching tradition, generates fascination and fear, enchantment and danger. The three acts—*Love Potion, Death Potion, Dream Potion*—symbolically recover the magical potion dimension, translating the dialectic between desire, manipulation, and dream into digital choreography. The AI thus appears not merely as a generative machine but as a liminal entity, inscribed in an imaginary of technological enchantment that critically reinterprets the historical association of femininity with witchcraft.

Fig. 8 - *Love Potion- HERbarium dancing for an AI - Kamilia Kard.*

Fig. 9 - *Death Potion- HERbarium dancing for an AI - Kamilia Kard.*

Fig. 10 - *Dream Potion- HERbarium dancing for an AI - Kamilia Kard.*

**Conclusion**

The projects *Toxic Garden* and *HERbarium* illustrate how digital gardens and computationally mediated performances not only inhabit virtual spaces but actively expand their ontological, perceptual, and relational horizons, revealing dynamics that would otherwise remain invisible. By translating vegetal and corporeal forms into polygonal and computationally animated entities, these works transcend mere representation: digital plants and blocky avatars emerge as autonomous, co-constitutive agents, shaping and being shaped by the complex, emergent systems in which they exist, and demonstrating that virtual environments are not passive backdrops but active, participatory worlds. Through the careful interplay of simplification, abstraction, and AI-mediated variation, the productive tensions between the discrete and the continuous, between human, vegetal, and machinic agency, and between control and emergence is exposed. The digital garden functions simultaneously as laboratory, stage, and experimental site, enacting relationality, embodiment, and intra-action, and allowing us to apprehend the virtual as a domain in which co-existence, perception, and temporality are continuously renegotiated and redefined. Ultimately, these works articulate a central philosophical insight: digital media do not simply mirror reality, but generate autonomous ontologies in which form, movement, and interaction co-emerge, producing new modes of being, knowing, and inhabiting the world. Within this framework, the polygonal plant, the blocky avatar, and the

computationally animated dance become more than artistic expressions; they are instruments of ontological inquiry, revealing the profound consequences of digital creation for thought, perception, and the experience of life itself, and demonstrating that the virtual is not a mere copy of the real, but a site of co-constitution, experimentation, and emergent meaning.


Fig. 11 - *HERbarium Site - Kamilia Kard.*

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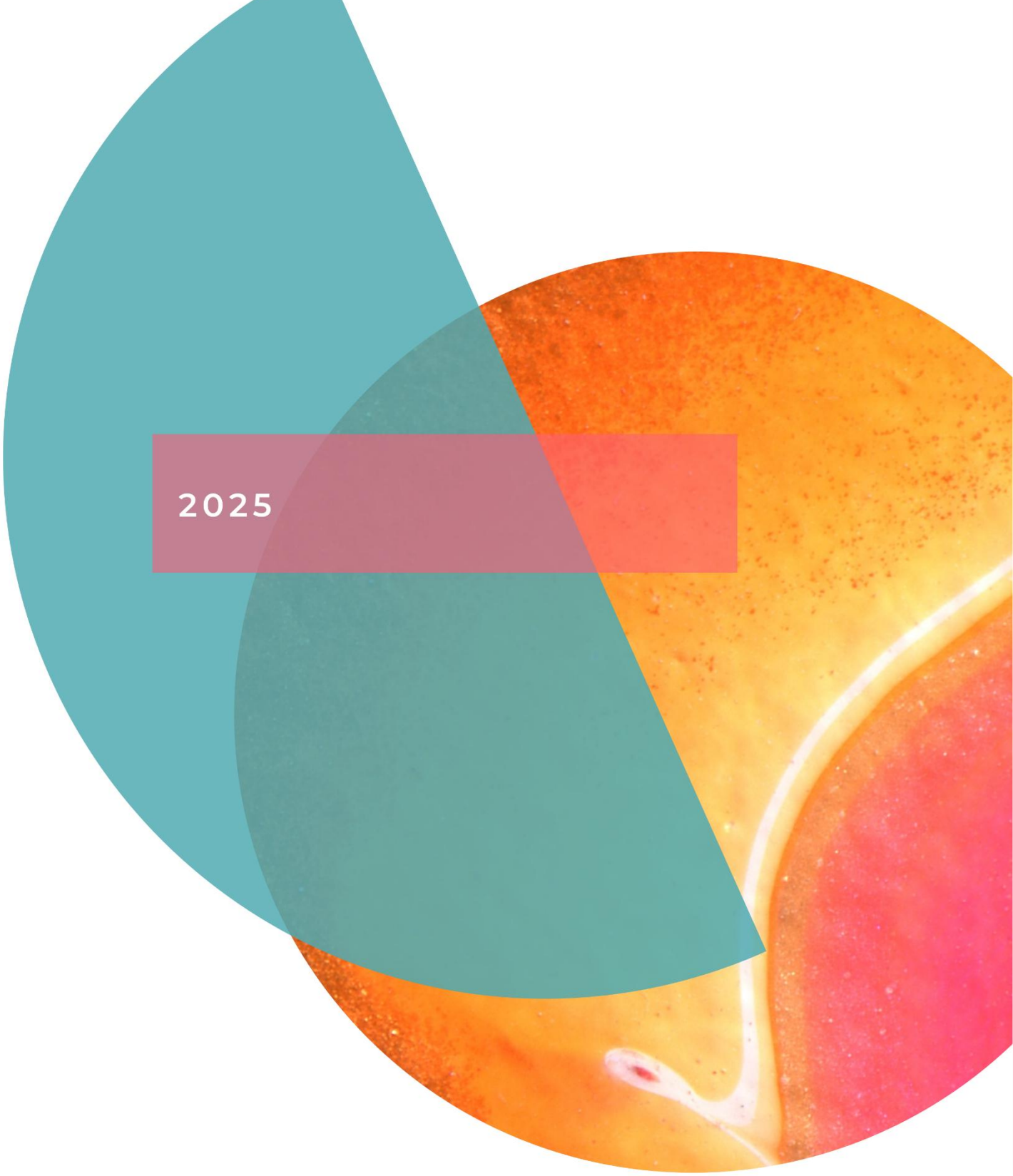

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