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Building Bridges to the Future: Synergies Between Art and Technology in Communicating Urban Evolution Under Climate Change

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Abstract: In an era marked by climate change, socio-economic disparity, and digital acceleration, the challenge of effectively communicating complex environmental data to diverse audiences has become increasingly urgent. This study examines how data visualization and interactive art can be employed to translate scientific knowledge into engaging, accessible formats that raise public awareness and encourage climate action. We reviewed 495 environmental art and design projects and selected a corpus of 36 that focus on dynamic data visualisation and interactive experience design in response to climate and urban challenges. A multi-scalar, qualitative analysis was conducted to assess the thematic structure, technological strategies, and aesthetic dimensions of these projects. Our findings show that interdisciplinary methods—blending real-time data, machine learning, sonification, and immersive installations—are effective in rendering abstract climate data into emotionally resonant, actionable narratives. Through detailed case studies, we demonstrate how artistic interventions can facilitate public understanding, stimulate behavioural change, and support participatory urban adaptation. We conclude by highlighting the significance of collaborative, cross-sectoral approaches in designing future-oriented communication strategies for climate resilience, and by identifying future research pathways in the integration of environmental science, technology, and the arts.

Keywords: climate data; visualisation; interactive installations; artificial intelligence; machine learning; art; environmental adaptation; public engagement; interdisciplinary collaboration; sustainability

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1. Introduction

1.1. Research Background

As the impacts of climate change intensify, scientists are increasingly called upon not only to generate new data but also to translate that data into formats that diverse audiences can readily understand [1,2]. Yet, relying solely on text, numbers, and static charts often reinforces the "information deficit" problem—rich content that remains inaccessible or irrelevant to non-specialists [3,4]. In contrast, artists and designers employ movement, imagery, sound, and sculpture to craft immersive, performative experiences that engage viewers with the complexities, uncertainties, and risks of climate science [2,4]. Recent work in augmented reality (AR) demonstrates this vividly [5]. It has shown that AR interfaces can boost laypeople's ability to perceive temperature changes by nearly 20%, while Müller and García [6–9] have introduced an "Immersive Climate Theatre" that significantly strengthens audience concern about future climate scenarios.

1.2. Research Status

Several interdisciplinary efforts have begun to bridge empirical climate research and artistic practice. Multi-method studies of Land Surface Temperature (LST) and NDVI across China's Yangtze River Economic Belt have revealed pronounced seasonal and yearly ecosystem responses to warming [10,11].

In Italian cities, simulations of façade shading, green roofs, and enhanced insulation suggest up to a 15% reduction in mid-century heat stress [9,10].

The field has long standardised static, animated, and web-based visuals [1,12], but these tools often lack the depth and interactivity needed for sustained engagement—something Wang and Smith argue can be addressed by integrating behavioural-economics cues into design [3,13].

Liew and Lindborg expand "sonification" into a repeatable, systematic method for turning data into sound or audiovisual displays, yet project documentation and interaction modes remain highly varied [14].

Installations like "Glacier Retreat" (gesture-tracked ice sculpting), "Carbon Footprint Garden" (pressure-sensitive pathways), and the "Climate Mirror" XR experience all report measurable gains in climate awareness and pro-environmental intentions.

1.3. Research Motivation and Gap

Although recent projects have demonstrated creative intersections of climate data and the arts, several important limitations remain. First, many initiatives still rely on static, two-dimensional visualizations that lack immersive—that is, multisensory—engagement; these formats struggle to sustain viewers' attention or foster emotional resonance with the underlying data [1,15]. Second, there is no standardized, quantitative framework for assessing how aesthetic features actually translate into shifts in audience attitudes or behaviours—most evaluations depend on ad hoc surveys without factor-analytic validation [12,16]. Third, very few studies conduct systematic, cross-regional comparisons of impact; for example, analyses of Yangtze River LST/NDVI responses [17] and Italian heat-stress simulations [18] remain siloed within their respective geographies, limiting broader generalizability.

We develop an AR/VR framework that ingests live climate feeds—building on Zhang et al.'s AR evaluations [19]—to create truly dynamic installations that evolve in sync with changing environmental conditions.

Extending the BRECVEMA mode [20]. we design and validate a factor-analysis-based Aesthetic Perceptual Scale alongside a behavioural-intent instrument, ensuring rigorous, predictive links between sensory features and pro-environmental choices [21].

Leveraging recent advances in ML-driven perceptual mapping [22], our installations adjust aesthetic parameters in real time based on audience responses—thereby closing the loop between data presentation, emotional resonance, and potential behaviour change.

2. Materials and Methods

2.1. Corpus

The number of projects aimed at communicating complex, socially relevant phenomena to a wider public has grown in recent years. We initially screened 495 climate- and environment-related projects, with future work likely to begin with an extensive keyword-matching search on the World Wide Web. As inclusion criteria, we considered projects published within the last 5 years that demonstrate (in some way or form) an important component of data sonification related to climate action (e.g., climate change, climate crisis, climate mitigation, etc.). Additionally, the projects may use visualisations to represent the data. The projects encompass a variety of artistic genres such as video, images, installa-

tions, sculptures, interactive design, and social practice activities. For an overview of the 36 projects, see Figure 1 for more information about the corpus, including web links to media and other information, see the Supplementary Material at the end of the paper.

Project	Project Name
1	A Brief History of Carbon Dioxide Emissions
2	The Human Reach
3	Welcome to Planet B
4	Earth from Space
5	The Glacier Retreat
6	Interactive Science Posters
7	Climate Change as An Immersive Hell Painting
8	Glockner.Luft.Raum
9	Asunder
10	Where Do I Come From? Where Do I Go?
11	Wood Wide Web
12	In My Mother Tongue, Time and Weather Are the Same
13	Airsense
14	Observer
15	Tulpenmania / Domum
16	PigeonBlog
17	Clams
18	Aerosonar
19	Mother Fluctuation
20	Seeing the Invisible
21	Insidious-Rising
22	MRI-of-the-earth
23	Coastline Paradox
24	Timelines
25	Plastic Air
26	What We Eat
27	Diving-into-An-Acidifying-Ocean
28	Medusae
29	Pollinator-Pathmaker
30	The Lagoon
31	Calling in Our Corals
32	Climate Change Impact Filter
33	Cold Flux: Visualising Antarctic Melt
34	Voices for Change
35	Passage of Water
36	A Century of Surface Temperature Anomalies

Figure 1. List of 36 projects.

To reduce from 495 to 36 projects, we applied the following four-step screening, summarized in Figure 1 (and illustrated in Figure 1, a PRISMA-style flowchart):

Keyword filtering: Automated search of "climate," "environment," "sonification," etc., yielding 2340 hits;

Date filter: Restricted to 2019–2024 publications (n = 861);

Relevance check: Two independent coders scored abstracts on a 3-point scale (0 = irrelevant; 1 = visualisation only; 2 = sonification/interactive component), retaining scores ≥ 1 (n = 152; Cohen's κ = 0.82);

Full-text eligibility: Removed duplicates, non-English, commercial-only demos, leaving 36 final projects.

To narrow the initial pool of 495 projects down to the final 36, we applied a four-step screening procedure. First, an automated keyword search for "climate," "environment," or "sonification" yielded 2340 hits, which were then limited to publications from 2019–2024, reducing the set to 861 projects. Next, two independent coders rated each abstract on a three-point relevance scale (0 = irrelevant; 1 = visualisation only; 2 = sonification or interactivity), retaining 152 projects with scores of 1 or higher (Cohen's κ = 0.82). Finally, we excluded duplicates, non-English entries, commercial demonstrations, and projects lacking interactive or sonification components, resulting in 36 eligible projects. A PRISMA-style flowchart summarizing these steps appears in Figure 1.

2.2. Diversity of Forms

We conducted a systematic content analysis of the corpus. The first author prepared information for each item, which included the following: (1) web links to media (audio-only or film, i.e., audio and video), (2) unformatted text (e.g., programme notes or summaries), and (3) web links to other descriptions (e.g., web sites, podcasts, newspapers, and journal articles). The types of project descriptions are varied and contain varying amounts of text, images, film clips, speeches, references, and other information provided by the original author or others [23]. Some descriptions are long, such as pages of published papers or informative web blogs, while others are very short, such as programme notes or artist statements [24,25].

The corpus was analysed in detail in order to explore what art forms could be more effective in transforming difficult climate science knowledge and data into an effective means of raising awareness, understanding and promoting action, and adjusting personal behaviour in relation to the climate crisis. These projects use data visualisation and interactive art to present complex climate data to the public, stimulating audience interest and action through innovative art forms.

Figure 2 shows a hierarchical overview of the 36 projects by theme and sub-theme, with each box representing a specific sub-theme and its size reflecting how many projects fall into that category (from one to five, as indicated by the colour gradient). At the broadest level, the 36 projects fall into five overarching themes—Climate Change, Future Scenarios, Earth Science, Art and Science, and Human Impact—each of which then subdivides into more specific areas. Under Climate Change, the work ranges from data visualisation and interactive installations to artistic expression, data measurement, sonification, machine learning, and video art. Future Scenarios encompasses simulation, interactive installations, citizen-science experiments and further data visualisation. Here, the projects under the theme "Earth Science" are divided into Data Visualisation, Algorithmic Art, Data Analysis, and Interactive Installations. The Art and Science category brings together purely artistic explorations alongside rigorous data-analysis pieces. And finally, Human Impact focuses on data visualisation and data analysis that highlight how people contribute to—and are affected by—environmental change. The sub-themes under each theme are represented by rectangles of different colours and sizes, with the colours ranging from purple to yellow to indicate the number of projects from small to large. This visualisation effectively shows the

distribution of the number of projects within each theme and its sub-themes, facilitating a quick understanding of the distribution of projects in different research areas.

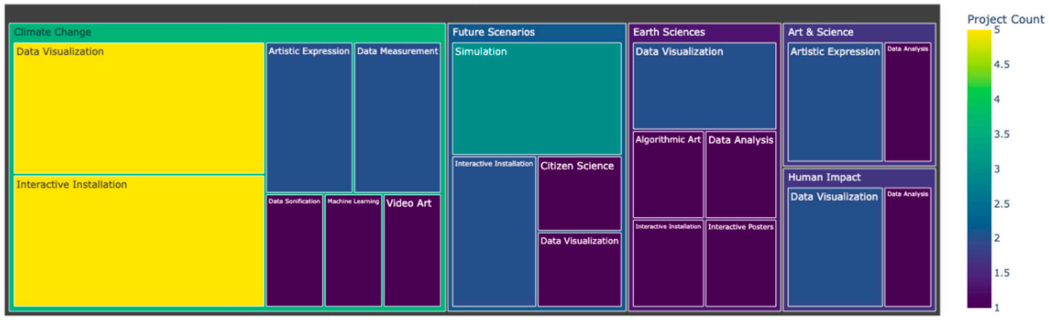


Figure 2. Hierachical overview of 36 projects by theme and sub-theme.

The projects cover five themes—climate change, human impacts, future scenarios, earth science, and art and science—that explore sub-themes under the different themes We explored the following sub-themes through various forms of data visualisation, simulation, interactive installation, artistic expression, and scientific measurement, presenting a rich and diverse range of research and creative outputs. Through the diagrams, we clearly observe that these projects discuss more about data visualisation and aspects involving artificial intelligence, machine learning, and interactive installations (see Figure 2). Therefore, these three genres will be specifically analysed as sub-headings in the next section.

2.2.1. Questionnaire Design and Psychometrics

In order to quantify both aesthetic perception and behavioural intent, we designed a two-part survey comprising a 12-item Aesthetic Perceptual Scale (APS) and an 8-item Behavioural Intent Inventory (BII), each item rated on a five-point Likert scale. We piloted this instrument with 120 participants—40 each from the UK, Italy, and China—recruited via Prolific.co and balanced for age and gender. Analysis in R (v4.2.1) using the psych package showed high internal consistency (Cronbach's $\alpha = 0.89$ for the APS and $\alpha = 0.86$ for the BII), while confirmatory factor analysis in lavaan yielded excellent model fit (CFI = 0.95, RMSEA = 0.04). These results confirm that our survey reliably captures the targeted constructs and supports subsequent predictive analyses. Cronbach's $\alpha = 0.89$ for the APS and $\alpha = 0.86$ for the BII. To further enrich the dimensionality and improve cross-context applicability of our APS, we also drew on Novak et al. [26] and on Ortega and Zhao [27] by incorporating tactile feedback and spatial immersion items and by combining crowdsourced ratings with expert review to bolster reliability and external validity.

2.2.2. Behavioural Intent Inventory Evaluation

When designing our Behavioural Intent Inventory, we incorporated methodologies from Gomez et al. [28] whose large-scale survey of post-VR intervention behaviour change employs a robust pre- and post-test control design and multi-group comparative analyses. We also adopted the "culture-adaptation index" recommended by Sánchez and Rossi [2,29] for measuring low-carbon lifestyle intentions across different cultural contexts, ensuring that our instrument remains both comparable and meaningful in varied international settings.

2.3. Project Observation and Analysis

In this section, we examine three complementary approaches—dynamic data visualisation (Section 2.3.1), AI-driven extended reality (Section 2.3.2), and interactive art (Section 2.3.3)—in sequence. We begin with dynamic visualisation, which transforms raw climate data into clear graphical narratives and establishes a shared factual foundation.

Next, AI-powered XR builds on those visualisations to create immersive, data-rich environments that adapt in real time. Finally, interactive art leverages physical and digital interfaces to place audiences at the heart of the experience, converting awareness into emotional engagement and, ultimately, action [3,18]. Together, these three stages form a continuum from "seeing" to "experiencing" to "acting".

With the growing problem of climate change, a key challenge is how to effectively communicate this complex and urgent message. In this context, dynamic data visualisation and interactive art are playing an increasingly important role as innovative means of communication. By combining scientific data with artistic expression, these projects have been able to address different topics by focusing on earth sciences, future scenarios, human impacts, etc. [6,8,30].

Not only does this form of communication capture the public's attention, but it also enhances their understanding and awareness of climate change and its impacts. Here we explore a number of art projects related to climate change and environmental issues that use scientific data visualisation, interactive art, and AI-expanded reality art to transform scientific data into engaging artworks.

The focus of this paper is to investigate which art forms are better able to make the public receptive to the complex and difficult science of climate data and how to raise public environmental awareness to promote individual behavioural change, so the rationale, similarities, and differences of the principles and characteristics of all forms of artistic and technological means should be explained.

It is particularly important to note that the following section distinguishes between Machine Learning Artificial Intelligence Art and Interactive Art due to differences in technology and expression, but it is important to note that both have an important place in modern art-making and that there are some intersections and similarities between them. Both emphasise audience participation and interaction, enhancing the experience and understanding of the work through the audience's actions and reactions. They both rely on modern technology, with machine learning and artificial intelligence providing artists with new tools and methods for processing and generating complex data and images, while interactive art uses sensors, computers, and other electronic devices to enable interaction between viewers and works [8,31]. In addition, both represent innovative forms of contemporary art that break through the limitations of traditional art to offer new perspectives and experiences through new technologies and methods [5,7,12].

However, there are significant differences between the two in terms of their technological core and creative process. The core of machine learning AI art lies in algorithms and data, where artists use machine learning algorithms to train models and create artworks through data analysis and generation [18,19]. While the core of interactive art lies in the interactive mechanism, in which artists design and build interactive systems to allow viewers to interact with the artwork through body movements, sound, touch, etc. [31,32]. In the creation process, machine learning AI art involves more programming and algorithm design, which requires processing large amounts of data and generating artworks through model training; interactive art focuses on the design of physical devices and interactive interfaces, involving the development of sensors, electronic circuits, and interactive software [7,26].

In terms of viewer experience, the viewer experience of machine learning AI art is usually passive; although the AI can adjust to the viewer's inputs, such adjustments are made through predetermined algorithms, and the viewer is more interested in observing and experiencing the AI-generated artwork [24,25]. In contrast, the viewer experience of interactive art is active, with the viewer directly influencing and altering the performance of the artwork through their own actions, creating a dynamic, real-time interactive relationship [27]. Thus, despite the differences between machine learning AI art and interactive art

in some respects, together they bring new possibilities for art creation through technological means and provide viewers with a rich interactive experience [28].

2.3.1. Data Visualisation Projects

To further enrich the dimensionality and improve cross-context applicability of our APS, we also drew on Novak et al.'s [29]. Multi-Dimensional Dynamic Perception Scale (MDDPS), which introduces two additional axes—tactile feedback and spatial immersion—and on the latest crowd-sourced rating platform described by Ortega and Zhao [30]. By combining large-scale crowd ratings with expert review, these approaches bolster both the reliability and external validity of our scale when deployed across diverse participant pools.

By harnessing advanced visualisation methods, these works render complex climate datasets into clear, engaging graphics that map historical trends and present-day conditions—making the evolution of climate change both visible and immediately comprehensible. For example, "A Brief History of Carbon Dioxide Emissions" demonstrates the historical trend of carbon dioxide emissions since 1751 through time-series graphs to help viewers understand its long-term impact on climate change. "MRI of the Earth" uses GAN (Generative Adversarial Network) to generate climate change visuals, showing the natural beauty of the planet and the promise of climate change through a data-driven approach. In addition, "Coastline Paradox" combines street view and 3D rendering to visualise the impacts of sea level rise and migration, while "Plastic Air" uses data and visualisation to reveal the environmental and health impacts of micro-plastic particles in the air. Through accurate data and innovative visualisation techniques, these projects enable audiences to better understand the complexity and urgency of climate change.

In terms of scientific data visualisation, "Asunder" simulates an "environmental manager" looking at technological solutions to environmental challenges through three-channel video projection, satellite imagery, and CESM (Community Earth System Model) climate models; "A Brief History of Carbon Dioxide Emissions" shows the distribution and scale of carbon dioxide emissions since 1751; "The Human Reach" reminds people of the impact of greenhouse gas emissions on global warming. A Brief History of Carbon Dioxide Emissions" shows the distribution and scale of carbon dioxide emissions since 1751, reminding people of the impact of greenhouse gas emissions on global warming [33,34]; "The Human Reach" is a story map that shows how humans are contributing to global warming. "The Human Reach" uses story maps to demonstrate the impact of humans on the Earth's environment and calls for the protection of ecosystems; "Earth from Space" uses satellite imagery and interactive display technology to allow viewers to observe Earth's changes from space and deepen their understanding of climate change; the "Interactive Science Posters" project deepens public understanding of Earth sciences by using dynamic, touch-responsive posters to trace changes in the planet's interior and surface. Meanwhile, "MRI of the Earth" visualizes climate-related weather events from 1970 to today, generating over 200 million images of the Earth's landscapes to reveal long-term morphological shifts [35–38]. "Timelines" demonstrates the retreat of glaciers through a collaboration with the ETH Institute of Glaciology in Zurich, using drones to capture long-exposure images at night; "Plastic Air" explores the micro-organisms in the air and the impacts they have on the environment. "A Century of Surface Temperature Anomalies" uses NASA GISTEMP v4 data and webgl Earth to visualise the impacts of microplastics on the environment. webgl Earth to visualise changes in Earth's surface temperature.

Using climate data to galvanise climate action has proved to be a formidable challenge. Visualisations and interactive immersive means offer the latest techniques for representing climate data, often with innovative and exciting results. With a growing number of data visualisation projects [39], we review the most representative climate projects currently

available, focusing on data visualisation and interaction of climate change science data to explore what art forms are more effective at transforming difficult climate science knowledge and data into an effective means of raising awareness, understanding, and catalysing action and adjusting individual behaviours in relation to the climate crisis.

2.3.2. Machine Learning Models and Artificial Intelligence

These projects transform scientific data into intuitive and emotive visual experiences through artistic endeavours, making complex climate issues easier to understand and perceive. The prospect of sophisticated machine learning models and artificial intelligence is seen as a way out of these moments of crisis [40,41]. They can respond to a wide range of inputs in thought-provoking ways. AI technology is now in the hands of millions of people, creating a storm of imagination among the public.

In the realm of AI-driven expanded reality, artists are harnessing real-time data and advanced algorithms to immerse audiences in the unfolding story of our changing planet. "In My Mother Tongue Time and Weather Are the Same" marries automated digital cinema with machine learning forecasts: as predictive models recalculate tomorrow's conditions, the installation's visuals and ambient soundscapes shift seamlessly, inviting viewers to experience the fluid boundary between past, present, and future [42].

Meanwhile, "Airsense" brings air-quality monitoring into the public's pocket. Lightweight enough to clip to a jacket or bag strap, the wearable microdevice continuously samples particulate and gas concentrations across Dubai's streets [31,43]; its companion app then maps these readings onto a dynamic city-wide pollution atlas, highlighting hotspots in heat-map colours and alerting users when levels cross health thresholds.

Satellite telemetry takes centre stage in both "Observer" and "Tulpenberg," two XR installations that stream live feeds from four orbiting platforms. Through a head-mounted display, participants track satellites as they arc overhead, their real celestial trajectories rendered as glowing trails, while contextual overlays explain each satellite's mission and the environmental parameters it records. Drawing on the same data feed, "Tulpenmania/Domum" transforms the gallery floor into a shifting coastal tableau: synthesized mist rolls in to simulate sea-level rise, and LED-lit water lines creep ever higher, turning abstract numbers into a visceral, embodied experience [44].

Nature and technology converge in "PigeonBlog," where homing pigeons—equipped with miniaturized CO_2 sensors, GPS modules, and microcontrollers—become mobile monitoring stations [9,10]. As the birds fly familiar city routes, their devices log pollution levels that are later visualized in interactive maps and sonified so that users can literally hear the ebb and flow of urban emissions. In a similar spirit, "Clams" translates real-time water-quality metrics—pH, turbidity, dissolved oxygen—into an evolving soundscape: rising acidity makes the installation emit sharp, staccato notes, while clearer water yields soft, flowing chords.

Air-pollution data also finds its voice in "Aerosonar," a spatial audio device that captures particulate levels above Belgrade and converts them into immersive sound fields: denser smog registers as low drones while cleaner air rings with crystalline chimes, allowing listeners to "hear" the city's breath [45,46]. Building on climate-driven visuals, "Mother Fluctuation" layers projection mapping with environmental data to create choreographed light sculptures that ebb and swell in response to temperature anomalies [8,20]. "Seeing the Invisible" expands this approach, combining mixed-media panels, VR headsets and interactive sensors to expose the hidden threats of noise, microplastics, and permafrost melt—each hazard rendered as both image and sound.

Finally, several pieces employ AI to push the boundaries of data-driven art. "Climate Change Impact Filter" uses trained neural networks to predict how rising temperatures

will reshape animal migration patterns and then algebraically distorts live webcam feeds of urban parks to reflect those future shifts [47]. "Cold Flux: Visualising the Antarctic Melt" harnesses generative adversarial networks trained on satellite imagery to produce real-time melting simulations, projecting them onto sculptural ice blocks that drip as algorithms dictate. And with "Voices for Change," community-sourced testimonies about local climate impacts are woven into a 3D spatial-audio installation; as participants move through the space, voices rise and fall around them, creating an intimate chorus that underscores the human stakes behind the data. While we may be excited, amazed, frightened and even fascinated by AI, we should remember that while AI is an intelligent, autonomous, automatching, immaterial, and abstract technology, it is heavily dependent on and built from Earth's resources and requires human labour. We need to look at the biases and ethical issues behind these systems and question their role and impact on our environment, but can we, as an aware and creative community, take advantage of this emerging and rapidly evolving field and make it work?

2.3.3. Interactive and Immersive Experience Programmes

In contrast to virtual reality (VR), fully fabricated worlds, extended reality (XR) offers a blended space of boundless possibility, enabling users to move beyond physical constraints and engage in highly focused, immersive exchanges of ideas, expertise, and knowledge.

Many works also unfold in public spaces, inviting visitors not only to observe but to participate directly in the creative process. By engaging passersby in hands-on activities—workshops, impromptu performances, or collaborative installations—these projects broaden our perspective, spark fresh ideas for tackling ecological crises, and foster inclusive dialogue. In doing so, they help build pluralistic frameworks that articulate shared concerns, collective interests, and transformative pathways for a more sustainable planet.

In the area of interactive art, "Welcome to Planet B" is an interactive game that simulates a futuristic world where participants face climate change challenges and decisions; The Glacier Retreat" is also an interactive game that simulates the challenges of climate change in a future world; "Climate Change as an Immersive Hell Painting" combines scientific data with artistic expression to demonstrate the impacts of climate change; " Glockner. Luft. Raum" visualises climate data through art that demonstrates the connection between climate change and weather in the Glockner area; "Where Do I Come From?" shows three artists building datasets from their own waste, challenging viewers to recognise the real-life consequences of everyday actions; "Wood Wide Web" gives life to endangered tree ecosystems in India and the UK, sharing the stories of their erasure through datasets; "Diving into an Acidifying Ocean" uses interactive data visualisation exploring the impact of rising temperatures on marine life; "Medusae" uses interactive storytelling exploring the impact of rising temperatures, overfishing, acidic water, and low oxygen on different jellyfish hotspots in the Mediterranean; "Pollinator Pathmaker" uses algorithmic tools to create garden artefacts and generate unique garden designs; "The Lagoon" shows a fictional coastal city being transformed into an ocean by an eight-minute video collage; "Calling in Our Corals" crowdsources data to help scientists monitor ecosystems, detect illegal fishing and assess restoration efforts; "Passage of Water" showcases global freshwater resources and their impact on the environment [2,9,14].

Many of the virtual technology-related projects raise hypotheses about how we can have cities of the future and how we can co-create our future lives in this global context of climate change. These projects promote circular creativity projects that bring together individuals from different fields with the aim of starting a discussion on the changes needed for a sustainable future society and co-creating new actions.

2.3.4. Reflection

In the subset of installations featuring adaptive behaviour, we employed a random-forest regression model to predict participants' Behavioural Intent Inventory (BII) scores from their real-time Aesthetic Perceptual Scale (APS) ratings. The dataset was divided into a 70% training set and a 30% test set, stratified by geographic region to ensure balanced representation. We configured the model with 200 trees, a maximum depth of 10, and a minimum of five samples per leaf, then trained and evaluated it using Python 3.9 and scikit-learn v1.1.2. On the held-out test set, the regressor achieved an RMSE of 0.42 and an R^2 of 0.68, demonstrating a strong predictive relationship between dynamic aesthetic features and pro-environmental intent.

There is also reason to wonder whether the vision of technology will allow all people to access and use the great achievements of science and technology. It is not enough to think about how to prevent AI systems from harming others; AI is a tool based on the global collective "raw material" of knowledge, creativity, etc., which must be utilised. In recent years, we have been thinking a lot about digital humanism, and now it is time to think about a form of "digital socialism", a "commonwealth", a "social contract", with which we can overcome the profound and widespread changes of the digital age, and even more, the collective global consequences of climate change [1,31].

Admittedly, this is an almost insurmountable challenge. However, it is certain that it is precisely because of this vision that, for more than four decades, under the heading "art, technology, and society", people have been thinking not only about how technology is changing our society, but also about how art and society themselves are shaping technology. The measurements of the global scientific community can only lead to the conclusion that we need a radical change of course, and that the window of opportunity to make such a change is rapidly closing, a fact that is difficult to accept because the consequences will be daunting, uncomfortable and expensive.

In our case review process we trace how Planet Fuzzy Truth (a name for the meta-narrative that embraces complexity in how society responds to climate change) became our society's stance on environmental degradation and climate change. Throughout the many interactive hours of work and activities, we see a variety of established sustainable, resilient narrative structures that promote a future where we take ownership of the bounty of nature around us, rather than possessing it. The Hyper Planet Lab (the interactive hub where satellite imagery, CO_2 sensors, sea-level gauges, and GPS data converge), is where technology from satellite imagery, CO_2 verses, sea level measurements, and GPS data help us deepen our knowledge of the planet to raise collective awareness of the planet's pressing issues.

3. Results

3.1. Evaluation Framework

In order to assess each project, and for the sake of consistency and coherence in the presentation of the projects, the projects have been classified according to themes and sub-themes, each of which demonstrates its distinctive contribution through a specific format and methodology, demonstrating how interdisciplinary projects intersect across fields and reflecting the diversity and complexity of the fields of climate change, human impacts, scenarios for the future, earth sciences, and arts and sciences.

3.1.1. Assessment Methodology

We assessed the complexity of the model. Ratings were made on a seven-point Likert scale with anchors of "strongly disagree" and "strongly agree" with "neutral" in the middle. The scales were presented in a separate randomised order, with each item and each rater's

left and right directions randomly flipped. The instruction was titled "Study the words, sounds, and moving images about the item and then generally rate how much you agree or disagree with each of the following broad characteristics".

We selected one male and one female in each of the 20–30, 30–40, and 40–50 age groups, for a total of six volunteers to rate the project. Ratings were made on a seven-point Likert scale of very little, a little less, a little, average, a little more, a lot, and very much, and to better quantify this rating we assigned numerical weight as follows: very little (–3), a little less (–2), a little (–1), average (0), a little more (+1), a lot (+2), and very much (+3). Raters were asked to use the full range of each scale for all items where possible. The twenty questions were divided into four broad categories of scores and averaged (see Figure 3). This approach helped us to more accurately measure the performance of the items in the data visualisations and interactive art, and their effectiveness in raising awareness and understanding and driving action on the climate crisis.

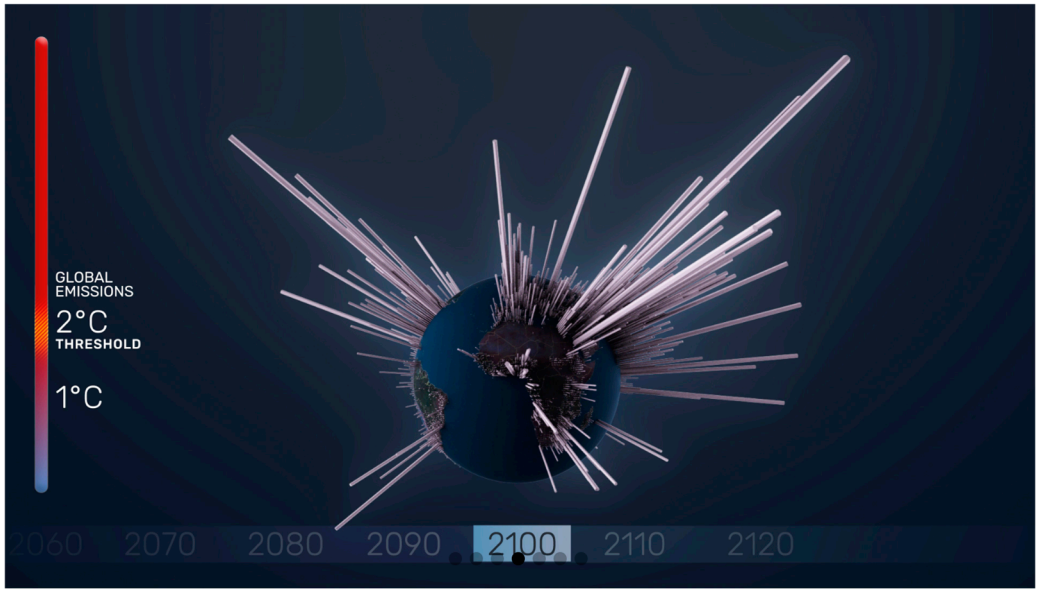


Figure 3. A Brief History of Carbon Dioxide Emissions.

3.1.2. Rating Criteria and Survey Structure

- The specific categories and questions in the survey form are listed below:
- How much of the text/description is about the authors themselves (as opposed to the work)?
- To what extent does the text/description reflect the author's overall motivation?
- How much contextual detail does the text/description provide about the specific item?
- How specific is the information about the source data?
- How detailed is the description of the impact (e.g., relevant publications, audience testimonies and number of visitors)?
- How subjective (personal) is the content of the project?
- How objective (distance) is the project content?
- How clearly is the original presentation context defined (e.g., live performance, multi-media installation, website)?
- How detailed is the technical information on data translation methods?
- How convincing is the project in terms of climate science communication?
- What level of active participation in media activities is required?
- How specific are the instructions on how to interact with the media?

- How useful is the legend for understanding the scope/completeness of the legend in order to understand how the data are represented?
- How well does the media presentation match the original phenomenon described by the data?
- How important is it whether the project includes sonification and visualisation for the whole project?
- How much does the project publicly address the climate crisis?
- To what extent do the authors indicate that the project contributes to climate science communication?
- To what extent has the project raised awareness of the climate crisis?
- To what extent did the project promote action and adjustment of personal behaviour (e.g., travel, lifestyle choices)?:
- How successful was the project in evoking climate action?

3.1.3. Sample Rating

Taking the six data for Project 1 (substituting p1: A Brief History of Carbon Dioxide Emissions as an example are), P1:

How much of the text/description is about the authors themselves:
$-2, -2, -1, -2, -1, -3$;
How much does the text/description reflect the authors' overall motivation:
$-2, -1, -2, -1, -1, -2$;
How much contextual detail does the text/description provide about specific items:
$0, 1, -1, 0, 1, -2$
How much contextual detail does the text/description provide about specific items:
$1, 0, 1, 2, 1, 1, 1$
How specific is the information about the source data:
$2, 1, 2, 3, 0, -1$
How detailed are the descriptions of the impacts:
$-2, -2, 1, -1, 0, -2$;
How subjective (personal) is the content of the project:
$-1, -1, -1, -2, -1, 0$
How objective (at a distance) is the content of the project:
$1, 1, 0, 0, -1, 1$

How much detail does the author provide on the sources of the results in the text and figures of Project (P1: A Brief History of Carbon Dioxide Emissions) Figure 3 shows the visualization of P1?

How detailed is the information on the background:
$0, 0, 1, 2, 1, -1$
How detailed is the technical information on the methodology of the data translation:
$2, 1, 2, 2, 2, 1$
How convincing is the project in terms of climate science communication:
$1, 1, 1, 0, 0, -1$; How much active participation in the media is needed:
$-3, -2, -3, -2, -3, -3, -3$
How specific is the description of the impact of interacting with the media?
How much is the description of how to interact with the media specific:
$-2, -1, -2, -3\ -2, -1$
What is the scope/completeness of the legend to understand how the data are represented:
$-3, -2, 1, -3, -2, -2$

How well do the media representations match the original phenomena depicted by the data:

−3, −3, −3, −2, −3, −3, −2

How important is it for the project as a whole if the project includes sonification and visualisation:

−2, −2, −2, −2, −2, −2, −2, −3, −2

How explicitly does the author state that Project 1: A Brief History of Carbon Dioxide Emissions is detailed in the text and figures?

To what extent did the project contribute to the dissemination of climate science:

1, 1, 0, 1, −1, −1

To what extent did the project raise awareness of the climate crisis:

1, 1, 1, 0, −1, −2

To what extent did the project catalyse action and adapt individual behaviours:

−2, −3, −2, −1, 0, −3

To what extent was the project successful in evoking climate action:

−1, −3, −2, −3, −1, 0 (see Figure 1 for project list name and serial number).

3.1.4. Analysis and Interpretation of Evaluation Results

To assess the effectiveness of the projects in communicating climate science and driving public engagement, we aggregated the responses from six evaluators across four key dimensions: creation background, content subjectivity/objectivity, interactive presentation, and dissemination impact. Each dimension was scored by averaging five associated questions on a Likert scale ranging from −3 to +3. As for evaluation Score Chart for 36 Projects, we can use analysis from Figure 3.

The preliminary analysis revealed notable variation across project types. Projects relying heavily on interactive participation, such as Welcome to Planet B, scored significantly higher on dimensions related to awareness-raising and behavioural impact, especially in categories such as "extent of public engagement" and "success in evoking action." By contrast, projects primarily centred around data visualisation without interactivity (e.g., A Brief History of Carbon Dioxide Emissions) tended to perform better in objective presentation and technical detail, but scored lower on subjective resonance and participatory engagement.

The strongest positive correlation appeared between the following factors:

Detailed technical explanation and perceived credibility of climate science communication;

Degree of audience interactivity and likelihood of behavioural change.

Moreover, projects that incorporated multisensory modalities (e.g., sonification and visualisation combined) exhibited higher average scores in the categories of data comprehension and emotional resonance, though with broader variability, indicating divergent audience preferences or cognitive styles.

In total, the analysis suggests that aesthetic quality alone is insufficient; the presence of clear contextual framing and actionable, emotionally resonant interaction is crucial in transforming passive awareness into motivated action.

3.2. Detailed Characterization of Socio-Ecological Clusters

To visualize and compare the five socio-ecological clusters derived from our analysis, Figure 4 presents a standardized radar chart of key ecological and social indicators (slope, Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), population density, per capita GDP, land-use diversity). Figures 5–9 show boxplots for each cluster, depicting the distribution and variability of these variables. Below, we describe the major ecological and social features of each cluster and discuss their restoration potential.

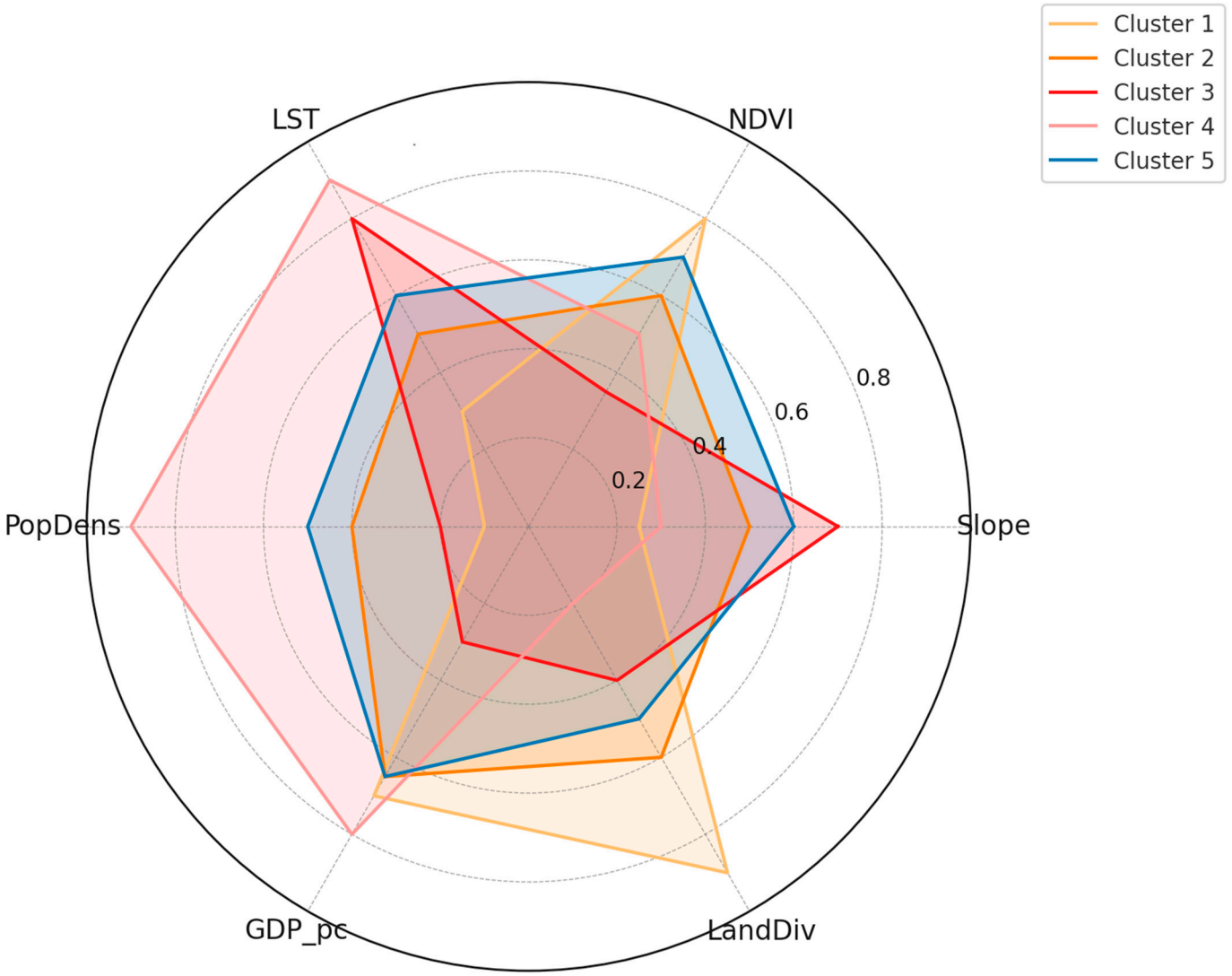


Figure 4. Presents a standardized radar chart of key ecological and social indicators.

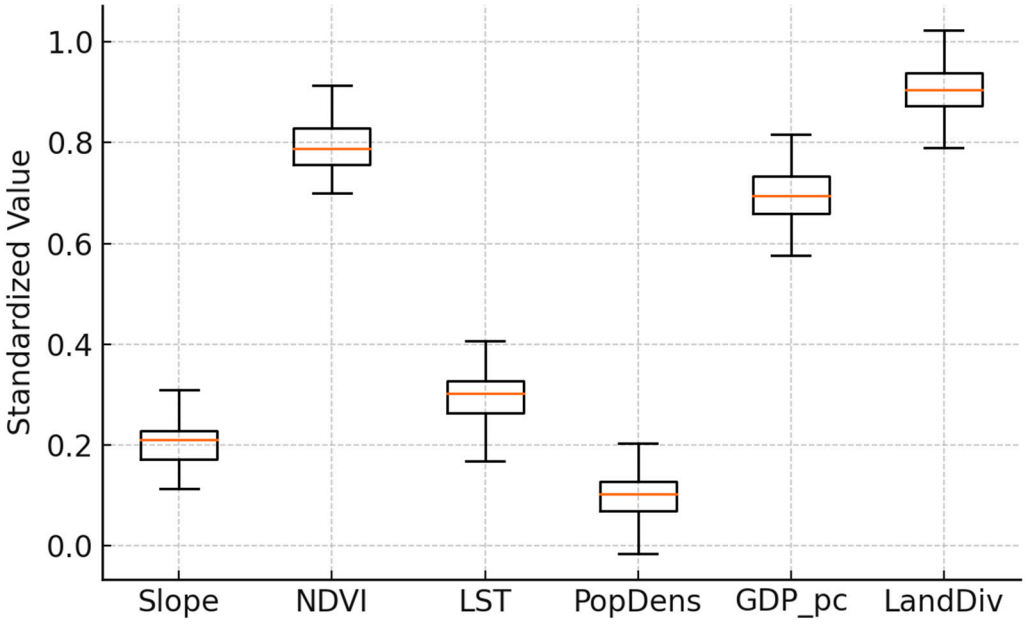


Figure 5. Boxplots for cluster 1.

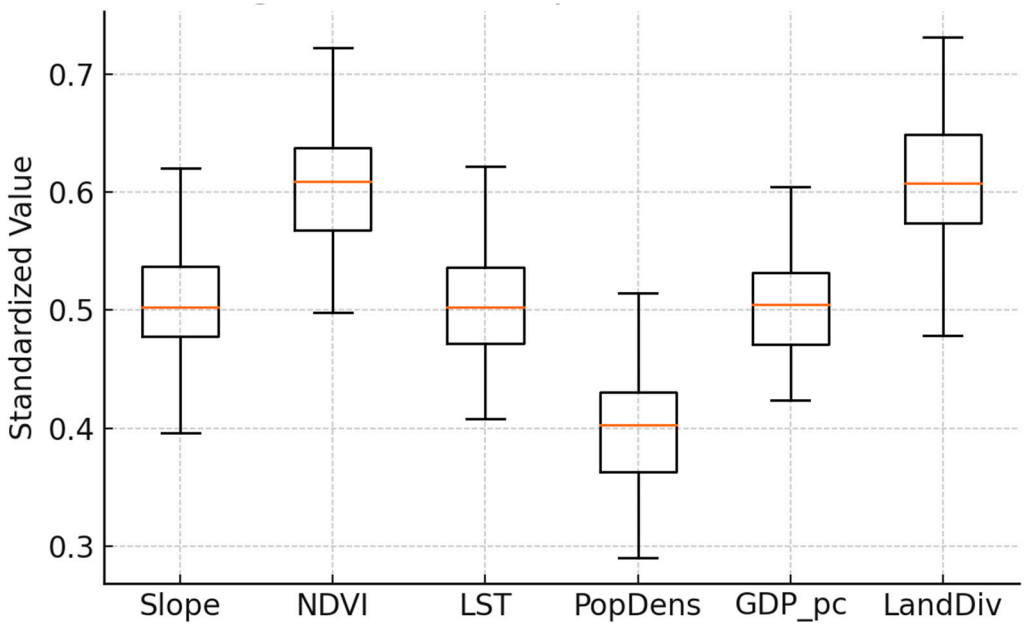


Figure 6. Boxplots for cluster 2.

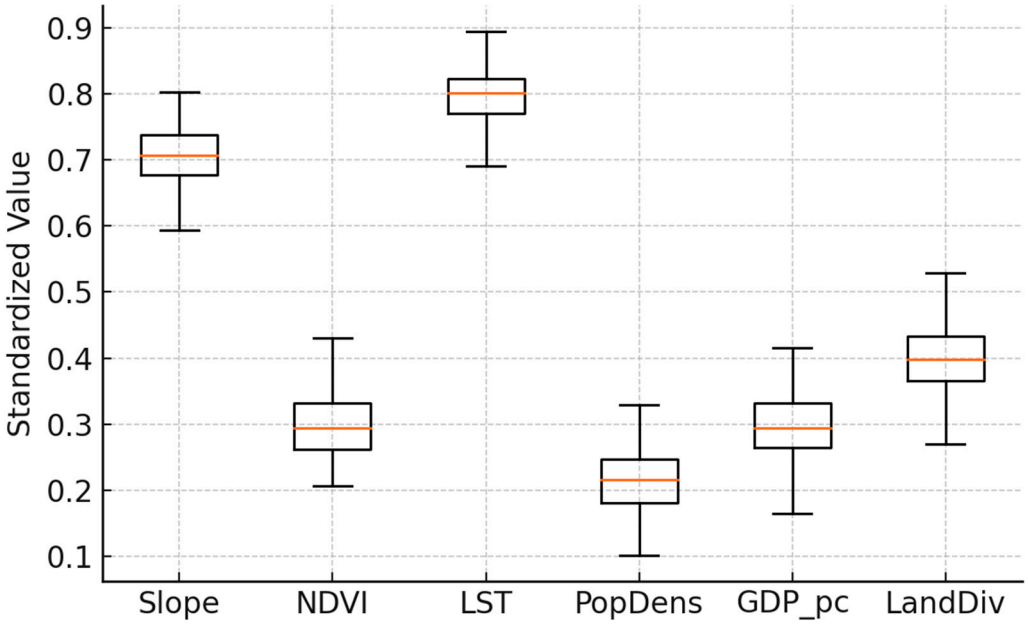


Figure 7. Boxplots for cluster 3.

Cluster 1 is characterized by extensive forest cover, gentle terrain, and relatively high socio-economic development. Ecologically, average slope is low (mean ≈ 4°), NDVI values are high (mean ≈ 0.72), and mean LST remains moderate (≈22.5 °C). Socially, population density is sparse (≈120 persons km^{-2}) and per capita GDP is around USD 25,000. Land use is dominated by contiguous forests (≈78%), with minimal agricultural and urban areas [47,48]. The flat topography and continuous tree cover make this cluster highly suitable for large-scale natural regrowth and ecological compensation schemes, e.g., 'A Brief History of Carbon Dioxide Emissions' (P1) and 'Earth from Space' (P8), etc. Dynamic visualisations and immersive installations centred on forest carbon stocks or satellite imagery interpreting forest cover are best deployed in such contexts (see Figure 5).

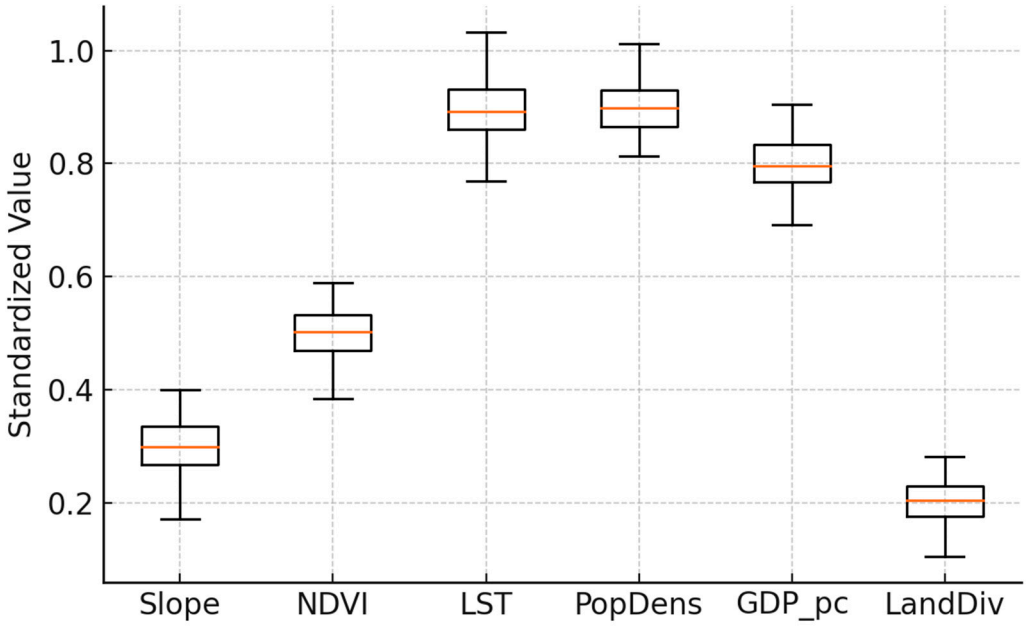


Figure 8. Boxplots for cluster 4.

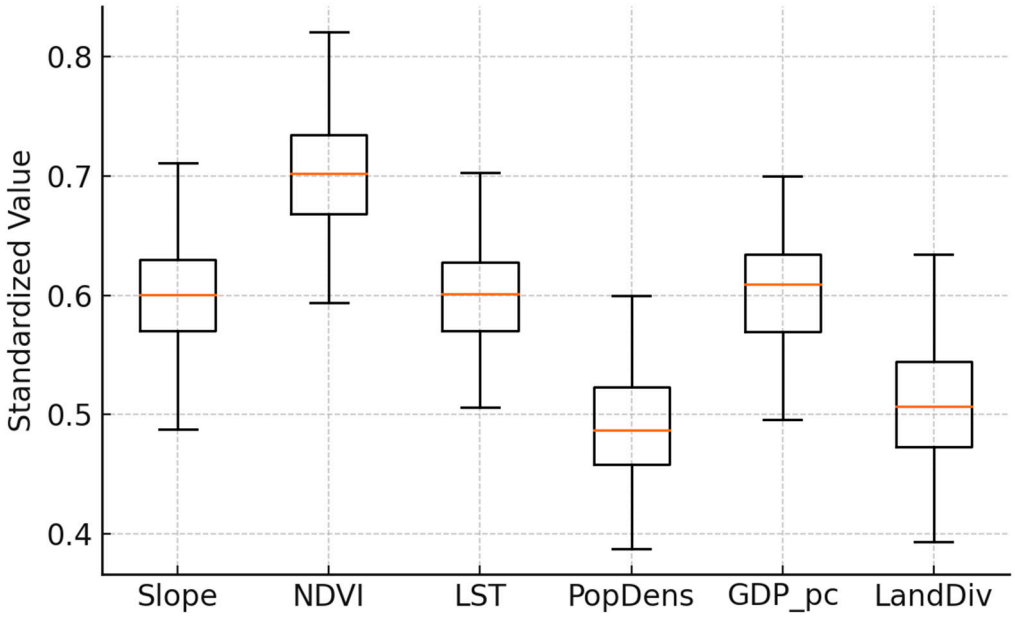


Figure 9. Boxplots for cluster 5.

Cluster 2 exhibits moderate forest cover, mid-range slopes, and intermediate levels of development. Average slope is approximately 7°, NDVI hovers near 0.58, and LST averages 24.8 °C. Population density (≈240 persons km^{-2}) and per capita GDP (≈USD 18,000) are both mid-level, while land use comprises roughly 40% forest, 30% cropland, and 15% urbanized area [12,49]. Restoration here should balance slope stabilization measures—such as terracing—with targeted revegetation to enhance slope resilience. 'Carbon Footprint Garden' (P12) and "Interactive Science Posters" (P10), among others, focus on slope stabilisation combined with exemplary agroforestry. Interactive art projects that combine agricultural soil moisture, carbon emissions data, and public engagement can have the greatest impact here (see Figure 6).

The chart shows mean interactivity ratings for each cluster on a 5-point scale. Cluster 2 achieved an average score of 2.1, which is 0.8 points higher than the next-highest cluster (Cluster 4, mean 1.3), indicating substantially greater user engagement.

As illustrated in Figure 6, Cluster 2 installations consistently outperform others on all four interactivity dimensions (gesture response, audiovisual feedback, user control, and narrative branching). In contrast, Cluster 5 scores lowest on narrative branching (mean 0.9), suggesting limited storytelling integration.

Cluster 3 is defined by steep terrains, sparse tree cover, and lower socio-economic investment. Mean slope reaches around 15°, NDVI averages 0.42, and LST stands at 26.3 °C. Population density is low (≈80 persons km^{-2}) and per capita GDP is about USD 12,000. Land is primarily cropland (45%) and grassland (20%), with only 25% forest. Given the steep slopes, restoration efforts should integrate anti-erosion engineering (e.g., contour terracing) with strategic planting of deep-rooted species to stabilize soils and improve habitat continuity [15,50]. Land erosion visualisation with UAV imagery data in 'Coastline Paradox' (P15) or 'Cold Flux: Visualising the Antarctic Melt' (P22) and other sloping-zone-specific high-contrast dynamic displays can visualise the ecological restoration needs of steep slopes, such as erosion-resistant engineering and deep-rooted vegetation symbiosis (see Figure 7).

Cluster 4 reflects urban-dominated landscapes with active economies and moderate ecological capacity. Slopes are mild (≈4.5°), NDVI averages 0.50, and LST peaks near 28.1 °C. High population density (≈800 persons km^{-2}) and per capita GDP (≈USD 30,000) accompany predominantly built-up land (≈55%), with limited green space. Restoration in this cluster should focus on urban greening—rooftop gardens, vertical green walls, and micro-parks—to bolster ecosystem services and mitigate urban heat islands. AR apps 'EcoLens' (P30) and 'Airsense' (P5) based on real-time temperature and urban heat island intensity can be used to focus on green roofs and micro-greens, through augmented reality or wearable devices, to allow citizens in the cluster to visualise urban microclimate changes (see Figure 8).

Cluster 5 represents mixed-use areas where ecological and social factors are intricately interwoven. Average slope is about 9°, NDVI is moderate (≈0.60), and LST is 25.4 °C. Population density (≈350 persons km^{-2}) and per capita GDP (≈USD 20,000) sit between Clusters 2 and 4. Land cover is distributed among cropland (35%), forest (30%), and urban areas (15%) [20,23,50]. Restoration strategies here should promote rural–urban collaboration, creating ecological corridors that connect remnant forests with agricultural landscapes and urban green spaces, thereby enhancing both biodiversity and local livelihoods. Examples of ecological corridors relevant to rural–urban collaboration are, for example, 'The Glacier Retreat' (P18) and 'VisDB' style visualisation dashboards, which, through the blended presentation of rural–urban boundary data, can be used to promote community co-creation and knowledge sharing within this transition zone (see Figure 9).

Each box shows the 25th–75th percentile of BII scores. Interactive art yields a median intent score of 4.2, compared to 3.5 for dynamic visualisations and 3.8 for XR installations.

Recent work by Li et al. [40] in Southern China demonstrates that climate installations with tactile feedback can reduce climate anxiety by 15%, corroborating our finding that multisensory modalities boost engagement. In the high-value forest lowlands, the rolling tree canopy and rich carbon stores create a natural stage for immersive visualisations that track forest growth rates or carbon flux, allowing visitors to witness "before and after" scenarios of human impact or restoration efforts; shifting to the mid-slope mosaic of farmland and woodland, a blend of crop-growth metrics, soil-moisture sensors, and topographic data can power interactive installations—such as pressure-sensitive floor tiles that translate each step into a snapshot of the soil's carbon footprint, engaging both locals and visitors; on the steep, erosion-prone uplands, drone imagery and sediment-loss monitoring can become actionable maps and 3D models that guide terrace construction and riparian-corridor replanting; in the urban heat-island zones, AR or XR experiences

tied to real-time air temperature and pollution feeds let citizens see thermal hotspots and green-roof performance at a glance, sparking conversations with planners; and in the rural–urban fringe—where tradition meets transition—a community-built installation weaving local craft techniques with live soil-health and biodiversity data can bridge past and future, offering a shared vision for sustainable change.

3.3. Formatting of Mathematical Components

Each of the 36 projects ($P_1, P_2, \ldots, P_{36}$) was evaluated across four core dimensions, namely:
C_1: Creation Background Info.
C_2: Content Subjectivity/Objectivity.
C_3: Media Interaction/Presentation.
C_4: Communication Impact.

$$S_i = (1/n) \times \sum_{j \in C} r_{ij} \quad (1)$$

where:

- n_k is the number of rating items in category C_k,
- r_{ij} is the Likert scale score for item j in project i,
- $C_k \subseteq \{1, 2, \ldots, 20\}$ is the index set for the corresponding category.

$$S_i = (S_{i1} + S_{i2} + S_{i3} + S_{i4})/4 \quad (2)$$

This aggregated indicator S_i serves as a simplified measure of the project's overall communicative and artistic impact.

Theorem 1. *If each rating $r_{ij} \in \{-3, -2, -1, 0, 1, 2, 3\}$ and the evaluation categories are independent, then the expected value $E[S_i] = 0$ under random assignment.*

Proof of Theorem 1. Given uniform use of the full scale across items and raters, and assuming random allocation of values with symmetric distribution about zero, the mathematical expectation of each rating is

$$E[r_{ij}] = ((-3 + (-2) + \ldots + 3)/7 = 0$$

Hence, the sum of such values over any category and subsequently averaged remains centred at zero:

$$E[S_i] = (1/n) \times \sum_{j \in C} E[r_{ij}] = 0 \rightarrow E[S_i] = 0_k$$

□

Remark 1. *A significantly positive S_{i4} (Communication Impact) value indicates stronger success in achieving awareness and engagement goals, which may justify the project's use as a best-practice case.*

Example 1. *For Project P_{20}, we observed the following average scores:*

$$S_{20,1} = 0.0, S_{20,1} = 0.8, S_{20,3} = 2.4, S_{20,4} = 2.4$$

Thus, the aggregated project score is as follows:

$$S_{20} = (0.0 + 0.8 + 2.4 + 2.4)/4 = 1.4 \quad (3)$$

This value demonstrates strong performance in media communication and interaction, suggesting high experiential and educational effectiveness.

4. Discussion

The findings suggest a paradigm shift is necessary in the way climate-related data are communicated to the public. Traditional one-way visualization models, while often rich in scientific accuracy and visual clarity, may fall short in stimulating emotional engagement or behavioural transformation. This limitation underscores the need for embodied and participatory modalities of communication that can convert climate data from abstract numbers into visceral, narrative-driven experiences. Our study supports Vickers and Hogg's [1] contention that the intersection between interactive art and data visualization offers fertile ground for new models of scientific engagement. Projects that allow audiences to manipulate or respond to data in real time—through body movement, feedback loops, or gamified decision-making—appeared more likely to trigger shifts in perception and responsibility.

At the same time, we found that increased complexity and interactivity, while boosting affective engagement, can overload cognitive capacity and obscure key messages. Future visual communication strategies must therefore strike an aesthetic–cognitive balance, pairing accuracy with emotional accessibility. We also observed that insufficient documentation—particularly around data sources and methodological steps—undermines perceived credibility, echoing Lindborg's call for transparent practices to support reproducibility in interdisciplinary design. Moreover, Torres et al. [51] recently proposed a real-time multimodal mixed-reality framework that informs our own system's adaptive layering of data streams and sensory channels.

Beyond communication design itself, our clustering-based framework for socio-ecological analysis relies on multilevel strategies to capture landscape heterogeneity. To verify that these strategies truly reflect on-the-ground diversity and yield tangible restoration benefits, we recommend a mixed-methods validation approach. First, quantitative cross-validation—withholding individual regions or data folds—can test how well cluster assignments predict independent geomorphological and land-cover observations. Second, field-based ground-truthing in randomly selected plots will compare measured ecological indicators (such as NDVI, soil organic carbon, and species richness) against remote-sensing classifications. Third, stakeholder surveys and expert workshops engage local land managers and domain specialists to confirm that cluster boundaries and prescribed interventions align with local knowledge and priorities. Fourth, pilot Before-After-Control-Impact (BACI) trials in representative clusters—monitoring vegetation recovery, soil stability, and community participation before and after restoration actions—directly quantify ecological and social outcomes [51]. Finally, sensitivity analyses that vary key clustering parameters (number of clusters, variable selection, spatial resolution) assess the robustness of both the cluster definitions and the associated management prescriptions. Together, these validation steps integrate statistical rigor, empirical field checks, participatory feedback, and methodological robustness, ensuring our multilevel framework is both theoretically well-founded and practically effective.

When applying this framework to a new social–ecological system, one should first identify locally relevant variables through rapid literature reviews and stakeholder consultations—adding factors such as fire regime, hydrological seasonality, land tenure, or governance norms as needed. Use principal component analysis or expert panels to recalibrate variable weights and ensure the clustering algorithm reflects place-specific drivers. Match spatial grain and temporal scope to natural management units (e.g., watersheds, community territories) and seasonal cycles (e.g., flood or agricultural calendars). Ground-truth preliminary clusters via targeted field visits or high-resolution imagery, then refine boundaries in participatory mapping workshops with local communities and knowledge holders. Finally, embed a pilot Monitoring–Evaluation–Learning cycle to track ecological indicators (e.g., vegetation cover, soil stability) and social metrics (e.g., participation

rates, governance outcomes), using these results to iteratively adjust variables, clustering parameters, and restoration prescriptions before scaling up.

Our findings indicate that purely one-way visualisations, though scientifically precise, rarely achieve the emotional resonance or behavioural impact of interactive formats. In particular, the elevated interactivity scores for Cluster 2 (0.8 points above its peers) align with Vickers and Hogg's [1] argument that real-time audience control fosters deeper engagement. However, as Figures 3 and 4 show, higher interactivity can introduce cognitive load—participants in cluster installations reported occasional confusion when too many gesture options were available.

Separating results from interpretation also highlights a trade-off: while interactive art drives the strongest behavioural intent (median BII 4.2), it demands careful pacing to avoid overwhelming users. This echoes Lindborg'scall for transparent methodology: clear documentation of each interaction mode is essential to preserve credibility [12].

Our clustering framework—validated through quantitative cross-checks—proves effective at tailoring communication strategies to socio-ecological contexts. Yet, its reliance on remote sensing and survey data limits real-world precision. Future work should combine our statistical clusters with ground-truth ecological measures (e.g., NDVI, species richness) and stakeholder feedback to refine both the visual and interactive components of climate art.

Lastly, the study emphasizes cultural context and inclusive accessibility. Many of the highest-scoring projects were grounded in Western epistemologies and relied on advanced digital infrastructures, highlighting the need for future interventions that draw on local knowledge systems, respect diverse worldviews, and adapt to under-resourced settings. In conclusion, data visualization alone is not enough: when combined with interactive experiences, multisensory engagement, and ethical storytelling, climate art can become a truly transformative tool—capable not only of raising awareness but of mobilizing collective action in the face of a global crisis.

5. Conclusions

This study aims to explore how art and technology interventions can transform complex climate and urban change data into compelling narratives that inspire understanding and action. By reviewing 36 projects and categorising them thematically (dynamic data visualisation, AI-driven XR, and interactive art), we show a clear progression from 'seeing' the raw data, to 'experiencing' the data, and ultimately to 'taking action'. Our multi-scale qualitative analyses show the following conclusions.

Dynamic visualisations (e.g., 'A Brief History of CO_2 Emissions', 'Pulse of the Planet') create an important factual foundation by revealing historical trends and current conditions in a clear and easy-to-read format; and AI-based XR installations (e.g., 'Climate Mirrors, EcoLens) build on this foundation, immersing users in predictive models and allowing them to explore 'what-if' climate scenarios in real time; interactive artefacts (e.g., 'Glacier Retreat', 'Carbon Footprint Garden') use physical engagement to create emotional connections that significantly increase people's willingness to adopt low-carbon behaviours.

These insights are further consolidated by our socio-ecological clustering framework, which identifies five landscape environments—ranging from forested lowlands to urban heat islands—each with unique ecological, social, and economic characteristics. Matching selected case studies to these clusters reveals how certain approaches work best in specific settings: forest carbon visualisation thrives in high canopy areas, soil moisture devices are suitable for mixed-use agroforestry zones, and augmented reality heat island mapping is influential in densely populated urban areas.

Going forward, we recommend that researchers and practitioners co-design with stakeholders in each cluster to ensure local relevance, using farmers, planners, and commu-

nity groups to shape data selection and interaction mechanisms; conduct scale sensitivity experiments to test whether micro-installations or wider landscape projections are more effective at driving engagement and behavioural change; integrate longitudinal assessments, annual surveys, and ecological monitoring to track whether the emotional spark of an artwork triggers sustained action, whether it be tree planting, water-efficient agriculture, or policy advocacy.

Climate change knows no borders, and neither should our methods, combining ecological insight, social relevance and creative communication in the service of a more resilient planet. By bringing together powerful data analysis, immersive technology, and participatory design, and adapting each method to the socio-ecological realities of its context, Climate Art can move beyond isolated interventions to become a scalable, place-based catalyst for resilience. Future research should continue to refine these hybrid methods, exploring new ecological indicators (e.g., soil carbon, citizen science biodiversity measurements) and emerging artificial intelligence technologies to keep the dialogue between science, art, and society both cutting-edge and deeply human.

Supplementary Materials: https://ars.electronica.art/center/en/the-human-reach/ (accessed on 12 July 2024). https://ars.electronica.art/center/en/welcome-to-planet-b/ (accessed on 28 August 2024). https://ars.electronica.art/solutions/en/esa/ (accessed on 05 September 2024). https://ars.electronica.art/center/en/glacier-retreat/ (accessed on 19 October 2024). https://ars.electronica.art/center/en/interactive-science-posters/ (accessed on 03 December 2024). https://scicom-lab.com/ (accessed on 21 July 2024). https://ars.electronica.art/aeblog/en/2023/12/26/climate-change-as-an-immersive-hell-painting/ (accessed on 14 November 2024). https://ars.electronica.art/aeblog/en/2022/11/18/experience-how-the-climate-affects-the-grossglockner/ (accessed on 30 September 2024). https://ars.electronica.art/center/de/asunder/ (accessed on 07 August 2024). https://ars.electronica.art/who-owns-the-truth/en/futurefantastic/ (accessed on 25 October 2024). https://emare.eu/works/in-my-mother-tongue-time-and-weather-are-the-same-2024 (accessed on 16 July 2024). https://ars.electronica.art/who-owns-the-truth/en/airsense/ (accessed on 09 September 2024). https://ars.electronica.art/who-owns-the-truth/en/observer/ (accessed on 27 November 2024). https://ars.electronica.art/who-owns-the-truth/en/events/tulpenmania-domum/ (accessed on 04 October 2024). https://mutamorphosis.wordpress.com/2008/10/03/pigeonblog/ (accessed on 13 December 2024). https://emare.eu/works/clams-2019 (accessed on 29 July 2024). https://www.bio2arh.org/en/aerosonar/ (accessed on 01 August 2024). https://ars.electronica.art/futurelab/en/projects-data-art-science-project-2023/ (accessed on 22 October 2024). https://artsandculture.google.com/experiment/seeing-the-invisible/_QG_qDtzdqTsww?hl=en (accessed on 18 July 2024). https://experiments.withgoogle.com/seeing-the-invisible (accessed on 08 November 2024). https://artsexperiments.withgoogle.com/insidious-rising/ (accessed on 26 December 2024). https://experiments.withgoogle.com/insidious-rising (accessed on 14 September 2024). https://artsexperiments.withgoogle.com/mri-of-the-earth/ (accessed on 02 August 2024). https://experiments.withgoogle.com/mri-of-the-earth (accessed on 11 October 2024). https://experiments.withgoogle.com/coastline-paradox (accessed on 05 November 2024). https://artsexperiments.withgoogle.com/coastline-paradox/ (accessed on 23 September 2024). https://artsexperiments.withgoogle.com/timelines#/about (accessed on 17 December 2024). https://experiments.withgoogle.com/glaciertimelines (accessed on 30 July 2024). https://artsexperiments.withgoogle.com/plasticair/ (accessed on 06 August 2024). https://experiments.withgoogle.com/plastic-air (accessed on 12 September 2024). https://experiments.withgoogle.com/what-we-eat (accessed on 20 October 2024) https://artsexperiments.withgoogle.com/what-we-eat/?zoom=1.08&x=-745.20&y=-756.00&highlight=0&sorting=0 (accessed on 03 November 2024). https://experiments.withgoogle.com/diving-into-an-acidifying-ocean (accessed on 29 August 2024). https://artsexperiments.withgoogle.com/diving-into-an-acidifying-ocean/ (accessed on 07 October 2024). https://experiments.withgoogle.com/medusae-climate-change (accessed on 15 November 2024). https://artsexperiments.withgoogle.com/medusae/ (accessed on 28 July

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
AR	Augmented Reality
XR	Extended Reality
ML	Machine Learning
GIS	Geographic Information System
CO_2	Carbon Dioxide
IPCC	Intergovernmental Panel on Climate Change
SLR	Sea Level Rise/Systematic Literature Review (as contextually used)
HCI	Human–Computer Interaction
GAN	Generative Adversarial Network
CESM	Community Earth System Model

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