Figure 1: *Beyond pervasive sensing: harnessing camera and Earth observation satellite sensors to apprehend environmental changes (The Blue Marble Earth Image: NASA)*

Beyond Boundaries: Towards Symbiotic Relationship Between Ecological Arts and Computational Thinking for Sustainability

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ABSTRACT

In today's Anthropocene era, human-and-climate induced sustainability challenges threaten the livelihood of vulnerable communities across the planet. To mitigate the risks of sustainability threats, data-and-theory driven scientific models, artistic practices, and environment designs play a critical role. However, these methods alone fail to reach a broader audience and translate into public discourse for participatory collective action. In this paper, we present Beyond Boundaries, a renaissance that re-envisions the relationship between ecological arts and computational thinking to contextualize threats to sustainability at regional and global scales. We establish an integrated framework combining Earth remote sensing satellite time-series, half a decade of ecological arts, and a public exhibition to curate the symbiotic relationship between arts and science. Beyond Boundaries sheds new light on how synergistic associations among disciplines can inspire scientific inquiry, artistic imaginations, and civic engagement-and-discourse for sustainability.

KEYWORDS

Sustainability; computations, data science, and society; ecological arts; remote sensing; climate justice and civic engagement

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Figure 2: *Beyond Boundaries: A non-anthropocentric perspective and framework to create a symbiotic relationship between scientific methods and artistic processes. The project encompasses half a decade of ecological arts, along with historical remote sensing data collected by Earth observation satellites (Fig. 1). The artwork geographies include the glaciers of Alaska, vulnerable agricultural communities in the Western Ghats of India, and the deserts of New Mexico (Satellite images: Google Maps).*

Figure 3: *Beyond Boundaries: Public exhibition to facilitate civic engagement-and-discourse on climate justice and sustainability.*

Goals and Contributions:

- Establish a framework for a symbiotic relationship between scientific and artistic processes to facilitate inclusive public dialogues among diverse communities.
- Create a shared consciousness of sustainability risks to develop society-wide empathy for the environment.
- Innovate ecological arts (e.g., landscape/aerial photography) and remote sensing methods to inspire critical scientific inquiry, technology innovations, and collective actions by uncovering the wicked nature of sustainability problems.

INTRODUCTION

Extreme social and physical processes—global temperature change, climate-induced displacements, climate injustice—threaten the socioeconomic and environmental sustainability of our planet. These high-risk threats to sustainability raise pressing worldwide concerns and receive considerable critical attention among researchers, artists, policymakers, and environmental designers across the world. In response, researchers develop data-and-theory driven models and computational tools to understand and mitigate the underlying perils to sustainability.

Sustainable HCI and computational sustainability research demonstrate prominent significance as it marks the first stride for harnessing computations and interaction design to address environmental threats. A growing body of literature recognizes the significance of sustainable computing, modeling, and interaction designs [1, 3, 9, 10, 16]. The past decade has witnessed notable development of environmentally friendly ubiquitous computing interventions for sensing local surroundings [23], modeling [9], and nudging individual behavior towards sustainable practices [6]. Despite the scientific underpinning of sustainable HCI and computational sustainability, pervasive interventions extensively focus on behavior change at individual levels and remain underexplored in the context of shared cognizance at a societal scale [5].

Difficulties arise when upstream research interventions on individual behavior change deficiently transcend towards downstream participatory collective actions to safeguard the environment. Modern political propaganda, historical inequalities, and anthropocentric viewpoints dominate how communication on environmental concerns takes place, and technological interventions—AI surveillance—transpire in the world [2, 15, 18, 20, 21]. Our means of grassroots civic engagement and participatory actions remain confined to create a society-wide collective consciousness of human-induced environmental threats. Computer-supported civic participation exists, but it mostly concentrates on employing citizen scientists as agents for maximizing information gain in data collection processes. Consequently, the gap between research-based outcomes, technology design, and people's collective perception of sustainability risks widens.

While arts can play a vital role in creating empathy for the environment and shared consciousness about sustainability risks at individual and societal scales, prior literature suggests that arts and science share a conflicting relationship [4, 11, 19]. Given this friction, how can we design the symbiotic relationship between arts and science, with a focus on sustainability? In this paper, we present Beyond Boundaries, a novel framework that drops the divergence between arts and sciences to establish a synergistic alliance between computations and ecological arts. This association enables us to devise creative processes to contextualize computational findings on environmental risks at the subconscious levels and facilitate public dialogue to inspire participatory collective actions. We manifest the principle concept of Beyond Boundaries through an exhibition at MIT (Fig. 2 and 3). The exhibition, attended by over 100 people, encompasses ecological artwork and illustrates the threats to sustainability, with examples of extreme climate events. Beyond Boundaries exhibits the first scientific and artistic inquiry that fuses computational methods (such as remotely sensed dynamics in Earth' environment) with ecological arts (such as landscape and aerial photography of the Earth). We conceive our research will inspire scientific inquiry, artistic imaginations, and participatory engagements for sustainability.

Figure 4: *Sawyer Glacier Calving: ecological artwork highlights the visual evidence of environmental changes. © Neil Gaikwad*

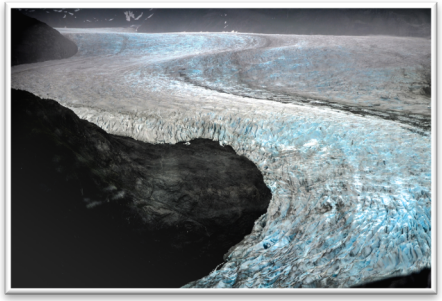

Figure 5: *Glacial Place: Aerial photograph of 3,000 years old Mendenhall Glacier, artwork published in National Geographic [8]. © Neil Gaikwad*

Figure 6: *Journey on a Melting Glacier, ecological artwork for contextualizing retractions © Neil Gaikwad*

FROM VISION TO CREATION: SYMBIOTIC RELATIONSHIP BETWEEN ECOLOGICAL ARTS AND COMPUTATIONAL THINKING

Beyond Boundaries framework harnesses ecological arts, remote sensing Landsat satellite time-series datasets, and civic engagement-and-discourse, facilitated through a public exhibition, to increase shared consciousness on climate-and-human induced threats to sustainability.

The artistic facade of the Beyond Boundaries framework extends Tolstoy's theory of artistic practice. In 'What Is Art?' Tolstoy articulated the practice of art as *"To call up in oneself a feeling once experienced [...], to transmit it by means of movements, lines, colors, sounds, images expressed in words, so that others experience the same feeling-in this consists the activity of art. Art is that human activity which consists in one's person consciously transmitting to others, by certain external signs, the feelings he has experienced, and in others being infected by those feelings and experiencing them* [22, p. 39-40]." Through Beyond Boundaries, we present ecological arts practice—landscape and aerial photography—to capture visual shreds of rapidly changing environment; we seize the landscape of Sawyer and Mendenhall glaciers in Alaska (Fig. 4, 5, 6). The glaciers remain vulnerable to the adverse effect of climate extremes; their retraction impacts the global sea-level rise [14]. The visual evidence generated by the ecological arts captures a state of the landscape and expresses the author's concerns about climate change (see table 2 for reflexivity). For transmitting the artist's sentiments into collective empathy, it is essential to fathom the artistic creations through the lens of the historical dynamics of the changing topology. Towards this goal, we harness data-and-computational science.

The computational facade of Beyond Boundaries framework broadens the existing practice of pervasive sensing in sustainable HCI by looking at the Earth from the top of the atmosphere. We harness time-series data captured by Landsat satellites to remotely sense the Earth's environment beyond the visible range of an artist (400 nm-700 nm of the electromagnetic spectrum). We collect and analyze this historical data of remote sensing images of the corresponding location of Sawyer glacier for which the author has seized the visual evidence. To illustrate, figure 7 shows the glacier boundaries as logged into the Global Land Ice Measurements from Space (GLIMS) database [7, 17]. Figures 8 and 9 show changes in the glacier's environment, computed using Landsat 5 and 7 satellite data, with a top-of-atmosphere reflectance (TOA) composite for 1985 and 2018. We use Google Earth Engine to obtain the Landsat data from the U.S. Geological Survey.

Civic engagement-and-discourse, the third facade of Beyond Boundaries framework, radically shifts the conversation from "*how science can amplify arts"* [11] *or "how arts can inspire science"* [4] to establish a profound harmonious relationship between arts and science. We curate a public exhibition to intertwine arts and science for disseminating the impact of climate extremes on sustainability to a broader society. We conducted semi-structured interviews with randomly selected exhibition visitors to learn about their perception of environmental threats at a local and global scale. Table 1 summarizes sample responses of attendees' perceptions about climate extremes when they were shown ecological artwork and remote sensing analysis (Fig. 3, 4, 5, 6, 7, 8).

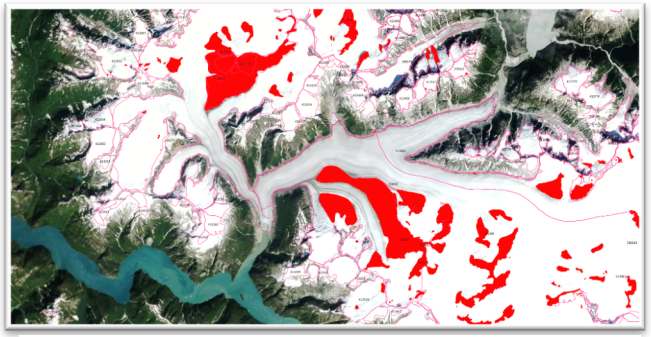

Figure 7: *GLIMS Sawyer Glacier outline. Solid red fill indicates internal rocks. Total area: 196.53 km², according to Randolph Glacier Inventory (2010-09-19)*
www.glims.org/maps/glims

Table 1. Sample response from the exhibition visitors

- "There are multiple narratives about climate change out there. I find statistics and satellite data fascinating, but it didn't move me on the personal level because I don't perceive the everyday world through this means. However, when I saw the combination of satellite images and the photograph showing the melting of the glaciers together, it felt very real. The combination gave me a bigger sense of what is happening in nature and helped me witness how global warming can impact my hometown near the coast."
- "During the exhibition, I saw glaciers, deserts, and mountains where I cannot go. I learned more about rapid changes in these places from conversations with other attendees."

Table 2. Reflexivity and author's self-disclosure
The author is an art scholar and a researcher of machine learning and public policy, with a focus on social equity and sustainable development. The author reports personal concerns regarding the adverse impact of climate change and inequity on vulnerable populations. The idea, concept, and locations of Beyond Boundaries originated from the author's vision, research, ecological artistic practice, research, and climate justice interests.

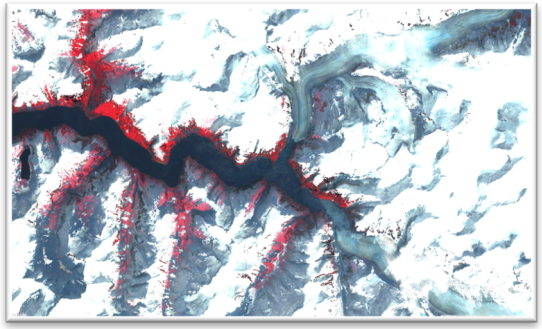

Figure 8: *Sawyer Glacier Landsat 5 Satellite cloud-free TOA composite 1985.*

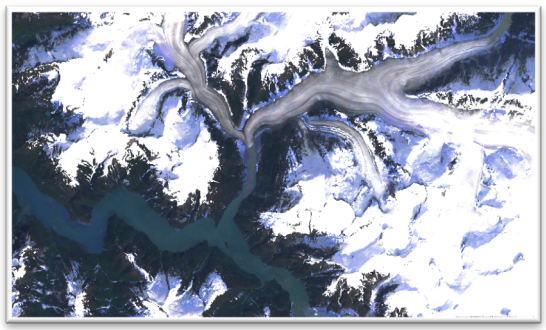

Figure 9: *Sawyer Glacier Landsat 8 Satellite cloud-free TOA composite 2018 showcasing the glacier retreat.*

DISCUSSION AND CONCLUSION

Through Beyond Boundaries, we put unexplored research on the map of Sustainable HCI [3, 10] and computational sustainability [9]. We cross narrow disciplinary peripheries and switch the focal point towards creating a framework to collectively tackle the wicked problem of sustainability. It is now well established that computational or artistic methods alone remain inadequate for addressing perils to sustainability [4, 11]; there is a need to facilitate a bottom-up collective action on a global scale. This global movement is possible if individuals recognize the climate risks at subconscious levels and engage with broader communities. Beyond Boundaries creates a path to transform this need in reality by extending our knowledge of participatory engagements [12, 13]. The pilot execution of the project suggests that the symbiotic association between scientific and artistic practices establishes a framework for scientists, artists, and broader society. The framework helps recognize climate-and-human induced threats to sustainability while fostering public dialogues, empathy, and a shared consciousness (Table 1). In future investigations, we plan to harness Beyond Boundaries to conduct a longitudinal evaluation to comprehend how socio-political and economic factors influence people's perceptions and civic dialogue on environmental justice. The ongoing crisis of the COVID-19 pandemic limits human mobility and epitomizes the criticality of developing immersive experiences to create empathy towards the planet. The exhibition attendees' experiences inform our research on designing mixed reality and participatory virtual spaces to contextualize scientific findings, human-induced environmental risks, and social inequality.

In conclusion, Beyond Boundaries framework provides a new understanding to establish the synergistic bond between ecological arts and computational thinking for sustainability. It suggests that the key innovations and participatory civic engagements for sustainability can emerge from the concourse of practices at the convergence of arts and sciences.

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