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Multi-Neutrosophic Ayni Method Based on Ancestral Logic and N-Alectic Reasoning for Ethical AI and Sustainability

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Abstract: This article presents the Multi-Neutrosophic Ayni Method, a novel framework that integrates Latin American Indigenous philosophies with neutrosophic logic to guide ethical and sustainable AI development. Grounded in ancestral principles such as Ayni, Buen Vivir, In Lak'ech, ch'ixi, and nepantla, this approach models plural, ambiguous, and context-dependent ethical judgments through Multi-Neutrosophic Sets (MNS). A key contribution is the introduction of the Euclidean Multi-Neutrosophic Consensus Measure, which quantifies the degree of alignment among diverse stakeholders' evaluations without erasing epistemic differences. This measure enables the detection of convergence thresholds in intercultural deliberation, offering a rigorous yet flexible tool for decision-making. The method is illustrated through a case study evaluating the deployment of an AI diagnostic system in an Indigenous community. Results show how the iterative application of the Ayni principle—understood as reciprocal ethical negotiation—improves both alignment and legitimacy. This work demonstrates that Indigenous logics, when formalized through neutrosophy, are not only philosophically rich but also operationally valuable for developing just, inclusive, and context-sensitive technologies.

Keywords: Multi-Neutrosophic Sets; Ayni principle; n-alectic reasoning; intercultural AI ethics; Indigenous logic; sustainability; consensus measure

1. Introduction

The accelerated development of artificial intelligence (AI) has generated complex ethical and sustainability challenges that exceed the capacity of traditional binary frameworks to address. While dominant ethical models in AI tend to rely on utilitarian or deontological approaches rooted in Western epistemologies [1], these frameworks often fall short in culturally diverse contexts, especially when confronted with worldviews that prioritize community, spiritual reciprocity, and ecological interdependence [2].

Recent scholarship has begun to explore the ethical implications of AI in non-Western contexts [3,4], yet there remains a gap in formal tools capable of modeling Indigenous epistemologies in a rigorous and transdisciplinary manner. In particular, Latin American Indigenous philosophies—such as Buen Vivir (*Sumak Kawsay*) [5], *yanantin* [6], *ch'ixi* [7], *In Lak'ech* [8], and *nepantla* [9]—offer conceptual structures that transcend dualisms by embracing complementarity, ambiguity, and plural truths. These principles align

closely with n-alectic reasoning [10], a logic derived from neutrosophy that allows for the simultaneous presence of truth, falsity, and indeterminacy.

To address this gap, this article introduces a novel methodological framework—the Multi-Neutrosophic Ayni Method —designed to model and evaluate ethical dilemmas in culturally heterogeneous environments. Drawing from neutrosophic logic and Indigenous philosophies, this method integrates mathematical precision with epistemic pluralism, offering a formal structure to navigate complex intercultural decision-making.

The term *Ayni* [11, 12], an Andean principle of reciprocal relationality, underpins the ethical foundation of this method. In Andean thought, Ayni implies that all actions must be balanced by mutual care, dialogue, and contextual respect. Applied to AI ethics, Ayni encourages a co-designed, participatory approach that recognizes the dignity and agency of all actors—including Indigenous knowledge holders—as co-evaluators in technological decisions. Thus, the Multi-Neutrosophic Ayni Method honors difference without erasure, enabling consensus without requiring homogenization.

This study is structured as follows:

- Section 2 reviews key Indigenous cosmovisional principles and explains their n-alectic nature.
- Section 3 presents the proposed methodology, including the Euclidean Neutrosophic Consensus Measure.
- Section 4 applies the method to an illustrative case involving the integration of AI into an Indigenous healthcare system.
- Section 5 concludes with reflections on the potential of Indigenous logic and neutrosophic models to guide sustainable and ethical AI development.

Through this synthesis of ancestral wisdom and mathematical logic, the article contributes a transdisciplinary approach to ethical evaluation—one that is inclusive, pluralistic, and grounded in both formal rigor and intercultural sensitivity

2. Preliminaries

2.1 Cosmovisional Principles with an N-Alectic Structure

2.1.1 Buen Vivir (*Sumak Kawsay*)

Buen Vivir (in Quechua *sumak kawsay*, in Aymara *suma qamaña*)[13], as adopted in the constitutions of Andean countries, is a principle that proposes living in fullness and harmony with both the human community and nature. More than a simple ideal of life, it constitutes a holistic paradigm that rejects the dichotomies characteristic of Western models of development. In its original Andean meaning, *sumak* refers to the ideal and harmonious realization of the world, while *kawsay* means life understood as a dignified, balanced, and fulfilling existence. Other Indigenous peoples share similar notions of "good living" (e.g., *teko kavi* among the Guarani), based on collective harmony [14].

This worldview envisions the world as "a house where everyone lives," emphasizing community, family, and the vitality of the territory. In n-alectic terms, Buen Vivir integrates what we could call the "truths" of different domains: social well-being, environmental sustainability, and economic prosperity, avoiding the prioritization of one at the expense of the others. It recognizes that focusing solely on material profit while ignoring social health or the environment is "false" progress; at the same time, neglecting basic economic needs does not lead to a fulfilling life either (a "false" idealism) [15].

The virtue lies in complementarity: articulating an economy in service of the community and *Pachamama* (Mother Earth) [16], achieving social justice and ecological balance simultaneously. For this reason, Indigenous ethics presents itself as a unified system of values intertwining social cohesion, environmental sustainability, cultural respect, and spirituality. It is not about static balances, but a dynamic and contextual adjustment: each decision must weigh how it affects the entire fabric of life [17].

Andean cultures have traditionally prioritized decisions that integrate multiple dimensions—human, spiritual, and environmental—in order to maintain ecological and social harmony. This principle demands that AI, in order to be ethical, should not pursue an isolated goal (e.g., maximizing economic efficiency) at the expense of community well-being or nature. Rather, it should optimize solutions that yield shared gains across the social, environmental, and economic domains[18].

In practice, guiding AI by the principle of *Buen Vivir* means developing technologies centered on the common good—technologies that strengthen community health and education, respect the limits of ecosystems, and equitably distribute their benefits. Any AI system, no matter how powerful, should be evaluated by its contribution to this collective and sustainable fullness of life.

2.1.2 *Yanantin* – Andean Complementary Duality

In the Andean worldview, *yanantin* [19] represents the union of opposing yet interdependent energies—a Quechua principle often translated as the "complementarity of differences". Long before modern physics explored the concept of dualities or multi-valued logics emerged in philosophy, Andean peoples already conceived of reality as composed of mutually necessary pairs: feminine and masculine, light and darkness, sun and moon, mountain and valley. These opposites are neither irreconcilable nor hierarchically ordered; rather, they coexist harmoniously to form a unified whole.

Thus, the dynamic relationship of balanced polarities is considered the fundamental organizing principle of creation; existence itself depends on the harmonious exchange between opposing forces, which must interact without destroying one another [20]. Logically speaking, each element of the pair may be understood as a partial "truth": each contains valuable and genuine aspects in its own right but also remains "false" or incomplete if it attempts to encompass the whole without its counterpart. Greater truth emerges from the interaction of both sides. Andean reasoning, therefore, resists the notion that one must choose a single side of duality; instead, it seeks a third space of balance in which both halves coexist.

Neutrosophic logic [21] offers a formal model for this perspective, allowing for intermediate values that represent collaboration rather than exclusion between opposites. A "quadruple neutrosophic logic" has been proposed to mathematically represent Andean duality: truth (T) and falsity (F) are refined by introducing two types of indeterminacy—one inclined toward truth (I_T, symbolizing the complementary relationship where opposites support one another), and one inclined toward falsity (I_F, symbolizing contradictory tension when opposites clash) [10]. This formalization reflects the real-life complexity in which opposites may be simultaneously complementary and contradictory. For example, it is traditionally said that woman complements man, but she is also sometimes "his contradiction" in everyday coexistence—out of the friction between the two arises mutual adjustment and growth.

When applied to artificial intelligence, the principle of *yanantin* suggests that the design and deployment of technology should value multiple, opposing yet complementary perspectives. A truly ethical and effective AI could emerge from the integration of Western scientific knowledge with traditional Indigenous wisdom, rather than privileging one and discarding the other [22]. This also implies balancing automation with human intervention—not delegating all critical decisions to algorithms devoid of human judgment (blind technocracy), nor rejecting technological innovation altogether (sterile Luddism), but instead achieving complementary interaction.

This principle reminds us that in the face of ethical dilemmas, the optimal solution often lies not in choosing one extreme but in finding synergy between both [23]. Applied to AI decision-making, *yanantin* would encourage the development of hybrid systems in which AI enhances human capabilities while humans supervise and correct AI—creating balanced human-machine teams. Similarly, in AI regulation, we must reconcile the freedom of innovation (valued as truth by the economic sector) with social and cultural protection (valued as truth by communities and public ethics), aiming for a fertile middle ground.

In summary, *yanantin* invites us to conceive of AI not as a soloist, but as a duet—harmonizing different forces to achieve a result that is more complete and balanced than the sum of its parts.

2.1.3 Ch'ixi Thought – Complementary Contradiction and the Intermediate State

From the Andean–Aymara worldview emerges the concept of *ch'ixi*, popularized by Bolivian sociologist Silvia Rivera Cusicanqui [24]. *Ch'ixi* originally refers to a speckled or mottled color—a mixture of black and white in which the two do not blend but coexist without canceling one another (Figure 1). In cultural terms, Rivera employs the concept to describe a mestizo epistemology where Indigenous and Western elements are interwoven without fully synthesizing into a homogeneous whole. It is thus a way of being multiple at once: embracing internal contradiction as an integral part of identity. A *ch'ixi* world is one in which different truths and logics coexist in unresolved tension—a "weaving made from both conflict and complementarity" [25].

Figure 1. *Ch'ixi Harmony: Threads of Coexistence.* Image created using generative artificial intelligence (ChatGPT with DALL·E model, OpenAI, 2024). Graphic representation inspired by the Andean philosophy of *ch'ixi*, illustrating the coexistence of diverse identities without homogeneous mixing.

This intermediate space (*taypi* in Aymara) [26] is "full of tensions" but also of creative vitality, as new possibilities emerge from continuous friction without any one perspective establishing hegemony. In Andean textile metaphors, the *taypi ch'ixi* represents the center of the fabric, balancing symmetries and rhythms, allowing threads of opposing colors to form a complex pattern (Figure 1). As an n-alectical structure, *ch'ixi* embodies the idea that something can be both true and false depending on context, or that two contradictory statements may be simultaneously sustained without mutual cancellation. For instance, a person may feel fully Indigenous and yet modern, without needing to choose a singular identity—both "truths" coexist in the individual, even though they may appear mutually exclusive from the standpoint of classical logic [27].

This concept challenges the Aristotelian principle of non-contradiction, aligning more closely with fuzzy or paraconsistent logics [28], in which a proposition may be partially true and partially false at the same time. *Ch'ixi* thought invites one to "voluntarily inhabit discomfort and questioning," embracing ambiguity rather than rushing to resolve it. This discomfort is fertile—it enables antagonistic perspectives to coexist and engage in dialogue.

In the ethics of AI, a *ch'ixi* approach is valuable for addressing the uncertainties and incompatibilities that arise in the interaction between modern technologies and traditional cultures. For example, when introducing a medical diagnostic AI system into an Indigenous community, tensions may surface between the Western biomedical worldview (based on data and molecular biology) and the community's traditional

medicine (rooted in spirituality and herbal knowledge). A conventional approach might view these as mutually exclusive—one must be imposed as "true," the other dismissed as "false superstition." In contrast, a *ch'ixi* perspective would aim for coexistence [29]: AI might be used for rapid disease detection, while traditional treatments are simultaneously respected and practiced for other conditions or for the patient's spiritual balance. The two visions are not forcibly merged but allowed to interact in creative tension, combining the strengths of each.

This contradictory pluralism acknowledges that not everything can be perfectly integrated—ideological frictions will persist—yet collaboration in pursuit of shared goals (such as community health) remains possible. Similarly, in the realm of data, a *ch'ixi* approach would accept that the Western notion of individual data ownership and the Indigenous view of knowledge as sacred and communal may clash [30]. Rather than enforcing a single data policy, a dual system could be designed: some data are governed by traditional community protocols (e.g., prior consultation, collective consent), while others are managed through modern frameworks—both structures coexisting within the digital ecosystem.

Such "informational mestizaje" may seem inconsistent to purists on either side, but *ch'ixi* teaches that from apparent incoherence may arise a more inclusive and resilient practice, better adapted to real-world complexity. In sum, *ch'ixi* contributes to ethical AI by promoting comfort with contradiction: the capacity to design systems in which different logics coexist and solutions are not uniform but patchworked, flexible, and context-specific—reflecting diversity without erasing it.

2.1.4 In Lak'ech – Relationality and Universal Reciprocity

In Lak'ech is an expression of Mayan wisdom and simultaneously a deeply relational ethical principle. Commonly translated as "I am another you; you are another me," it encapsulates the notion that individual existence has no meaning in isolation from others. Although the authenticity of this exact phrase has been debated—and according to specialists, it is not commonly used in daily conversation among Maya speakers and may represent a very literal translation—the phrase still accurately conveys the essential Mayan philosophical idea of interconnectedness and collectivity. As the Yucatec tradition explains: "I do not exist without you, and you do not exist without me. Therefore, you and I exist through our relationship.

The Mayan worldview [32] conceives the universe as a vast web of interdependence: individuals, communities, animals, plants, winds, spirits, and ancestors are all interconnected, and nothing exists apart from its relationships. Each being exists because it participates in a greater we, which also includes nature. From this stems an ethic of reciprocity: "If I respect you, I respect myself; if I harm you, I harm myself." This is not merely a poetic metaphor but a literal understanding of reality: the harm done to another being—human or nonhuman—inevitably reflects back since individual identity is constituted by relational ties.

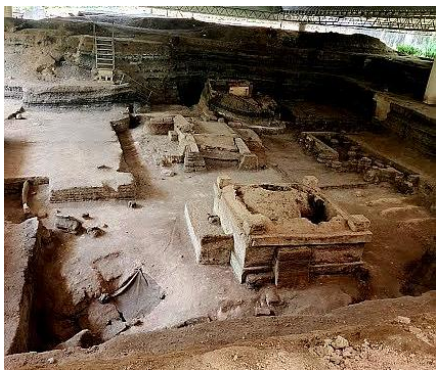

Figure 2. *Joya de Cerén archaeological site, known as the "Pompeii of the Americas," El Salvador.* Photograph taken by the authors, depicting Maya ruins with residential structures exceptionally preserved due to a volcanic eruption around 600 AD

In this context, the Mayan concept of zero (*nik'*), a mathematical and cosmological innovation, reinforces the non-dual and cyclical character of this worldview (Figure 3). Far from representing mere absence, the Mayan zero signifies a moment of transition, a state of potentiality from which life and time emerge and return. This idea resonates with neutrosophic logic, especially in its n-alethic formulation, which allows for the coexistence of truth (T), falsehood (F), and indeterminacy (I) within any proposition. Just as zero is not an absolute void but a threshold within a cycle, *In Lak'ech* reflects a relational ethics where meaning arises from dynamic interconnection rather than isolated certainty. Both systems—Mayan and neutrosophic—reject rigid binaries and embrace multiplicity, change, and contextual knowledge as fundamental. As Batz [33] explains, the Mayan zero is a vital symbol of interdependence, echoing the ontological commitments of relational philosophies like neutrosophy.

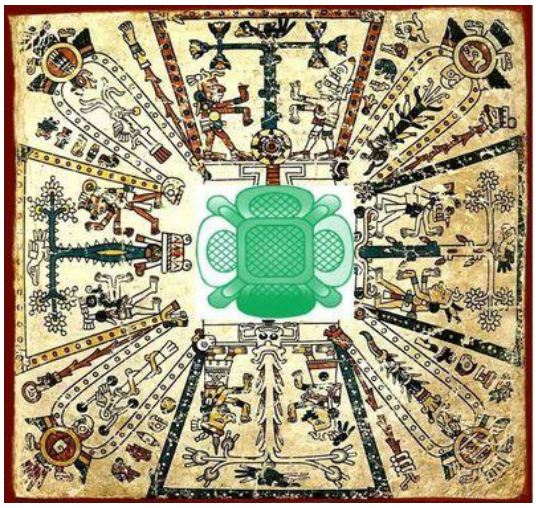

Figure 3. *Representation of the Maya zero (Nik) as a flower in the Codex Fejérváry-Mayer.* This image, taken from a pre-Columbian Aztec codex of central Mexico, illustrates cosmological and calendrical symbolism. The right panel emphasizes the depiction of *Nik*, the Maya concept of zero, as a floral glyph. Adapted from Batz [33], retrieved from https://baas.aas.org/pub/2021n1i336p03/release/2.

Within a neutrosophic n-alectical framework, In *Lak'ech* can be understood as a transcendence of the self–other duality through a third mediating term: the we. Rather than viewing the self and the other as mutually exclusive, this Mayan principle affirms both relational unity and individual distinctiveness—"you are another me" implies not fusion, but co-existence. This philosophical tension finds resolution in community, which functions as an inclusive middle ground. A powerful symbol of this duality-in-unity is the Maya concept of zero [34]. Far from denoting absolute nothingness, the Maya zero signifies a fertile void, a moment of pause, transition, and interconnected potentiality. This symbolic neutrality echoes the indeterminate (I) component in neutrosophic logic, where meaning and value exist in fluctuating degrees of truth, falsity, and indeterminacy, shaped by relational and contextual dynamics.

Applied to AI ethics, *In Lak'ech* demands a reorientation from extractive, anthropocentric approaches toward a relational ethics grounded in reciprocity and interconnectedness. Decisions must consider all members of the web of life—humans, nonhumans, and the environment—as part of a unified web. This principle calls for inclusive practices in data governance, especially with respect to Indigenous sovereignty and participatory design. Echoing the regenerative symbolism of the Maya zero, AI systems should be conceived not as tools of domination, but as technologies of care—restorative acts that reflect our interconnected self. In this sense, In *Lak'ech* becomes a guiding ethic for developing AI that nurtures rather than exploits, embedding in every algorithm a recognition of the Other as integral to the Self.

2.1.5 *Nepantla* as an N-Alethic Threshold: Creative Ambiguity and Sustained Transition

The concept of *nepantla*, originating from Nahuatl, refers to being "in-between" or in "no man's land"—a liminal space between two worlds, cultures, or states of being. Beyond its linguistic connotation, thinkers such as Gloria Anzaldúa [35] have reclaimed *nepantla* as an existential and political category that allows one to inhabit simultaneously both the old and the new, the imposed and the original, without erasing the tensions that arise between them. Nepantla thus becomes a state of fertile ambiguity, where certainties are fractured, but where new identities, expanded worldviews, or more integrative value systems can also emerge.

From the standpoint of n-alethic reasoning, *nepantla* is not a state of paralysis or irresolvable contradiction, but rather a complex configuration in which elements of truth (T), falsehood (F), and indeterminacy (I) coexist. This logic, developed within the framework of Florentin Smarandache's neutrosophy, breaks away from classical binary logics by allowing ideas, beliefs, or systems to be evaluated not only as true or false, but also as partially true, contradictory, or uncertain to varying degrees. In this sense, *nepantla* represents a genuinely neutrosophic space—where knowledges in tension coexist, and where the boundaries between opposites blur, giving rise to hybrid possibilities[36].

Applied to the field of sustainability, *nepantla* can be interpreted as the threshold of transition between an unsustainable paradigm and an emerging one. In this transitional zone, decisions and actions are imbued with uncertainty: old structures persist while new ones have yet to consolidate [37]. From a conventional logic perspective, this period might appear chaotic or unproductive; yet from an n-alethic standpoint, this intermediate state is both necessary and revealing. It allows us to recognize that there is no single pathway toward a sustainable future, but rather multiple trajectories that must engage in dialogue, complement, or even contradict one another in order to foster authentic transformation.

Nepantla, as experienced by many Indigenous communities, especially under the pressures of colonization and globalization, represents a cultural and epistemic space where ancestral knowledge and modern technologies like AI intersect. This "technological *nepantla*" embodies creative tension rather than contradiction, making it fertile ground for applied neutrosophy. Within an n-alethic framework, nepantla becomes a dynamic threshold—a space of ambiguity and coexistence—through which new, inclusive, and sustainable forms of knowledge and governance can emerge.

2.2 MultiNeutrosophic Sets and N-Alethic Logic to Represent Epistemic Plurality

In order to formally model the complex, fluid, and often contradictory structures that characterize Indigenous epistemologies—such as *Nepantla*, *In Lak'ech*, *Ch'ixi*, *Yanantin*, and *Buen Vivir*—we turn to the framework of Neutrosophic Logic. This advanced logic enables the simultaneous representation of truth, falsehood, and indeterminacy, offering a formal structure for n-alethic reasoning. The foundational elements of Neutrosophic Sets, along with their refined and multi-valued extensions, provide the mathematical tools necessary to express these ancestral concepts not as symbolic metaphors, but as rigorous components of ethical, sustainable, and intercultural systems design [38].

The following definitions outline the basic constructs of Neutrosophic Sets:

Definition 1 [39]: The Neutrosophic set N is defined by three membership functions: the truth-membership function $\boldsymbol{T_A}$, the indeterminacy-membership function $\boldsymbol{I_A}$, and the falsehood-membership function $\boldsymbol{F_A}$, with U representing the Universe of Discourse. and $\forall \mathbf{x} \in \mathbf{U},\ \boldsymbol{T_A}(\boldsymbol{x}), \boldsymbol{I_A}(\boldsymbol{x}), \boldsymbol{F_A}(\boldsymbol{x}) \subseteq\ ]^{-}\mathbf{0}, \mathbf{1}^{+}[$, and $^{-}\mathbf{0} \leq \mathbf{inf}\, \boldsymbol{T_A}(\boldsymbol{x}) + \mathbf{inf}\, \boldsymbol{I_A}(\boldsymbol{x}) + \mathbf{inf}\, \boldsymbol{F_A}(\mathbf{x}) \leq \mathbf{sup}\, \boldsymbol{T_A}(\mathbf{x}) + \mathbf{sup}\, \boldsymbol{I_A}(\mathbf{x}) + \mathbf{sup}\, \boldsymbol{F_A}(\mathbf{x}) \leq \mathbf{3}^{+}$.

According to the definition, $\boldsymbol{T_A}(\boldsymbol{x}), \boldsymbol{I_A}(\boldsymbol{x})$, and $\boldsymbol{F_A}(\boldsymbol{x})$ are real standard or non-standard subsets of $]^{-}\mathbf{0}, \mathbf{1}^{+}[$ and hence, $\boldsymbol{T_A}(\boldsymbol{x}), \boldsymbol{I_A}(\boldsymbol{x})$ and $\boldsymbol{F_A}(\boldsymbol{x})$ can be sub-intervals of $[\mathbf{0}, \mathbf{1}]$. $^{-}\mathbf{0}$ and $\mathbf{1}^{+}$ belong to the set of hyperreal numbers.

Definition 2 [40]: The Single-Valued Neutrosophic Set (SVNS) $\boldsymbol{A}$ over $\boldsymbol{U}$ is $\boldsymbol{A} = \{< \boldsymbol{x}, \boldsymbol{T_A}(\boldsymbol{x}), \boldsymbol{I_A}(\boldsymbol{x}), \boldsymbol{F_A}(\boldsymbol{x}) > : \boldsymbol{x} \in \boldsymbol{U}\}$, where $\boldsymbol{T_A}: \boldsymbol{U} \rightarrow [\boldsymbol{0}, \boldsymbol{1}]$, $\boldsymbol{I_A}: \boldsymbol{U} \rightarrow [\boldsymbol{0}, \boldsymbol{1}]$ and $\boldsymbol{F_A}: \boldsymbol{U} \rightarrow [\boldsymbol{0}, \boldsymbol{1}]$. $\boldsymbol{0} \leq \boldsymbol{T_A}(\boldsymbol{x}) + \boldsymbol{I_A}(\boldsymbol{x}) + \boldsymbol{F_A}(\boldsymbol{x}) \leq \boldsymbol{3}$.The Single-Valued Neutrosophic Number (SVNN) is symbolized by $\boldsymbol{N} = (\boldsymbol{t}, \boldsymbol{i}, \boldsymbol{f})$, such that $\boldsymbol{0} \leq \boldsymbol{t}, \boldsymbol{i}, \boldsymbol{f} \leq \boldsymbol{1}$ and $\boldsymbol{0} \leq \boldsymbol{t} + \boldsymbol{i} + \boldsymbol{f} \leq \boldsymbol{3}$.

Indigenous cosmovisional principles such as *nepantla*, *In Lak'ech*, *ch'ixi*, *yanantin*, and *Buen Vivir* (*Sumak Kawsay*) embody ways of thinking that challenge traditional binary logics by operating within an n-alethic structure—one in which truth, falsehood, and indeterminacy coexist. This logic can be formalized through the Refined Neutrosophic Set (RNS), which decomposes the classical components of neutrosophic logic into sublevels of truth (T_i), indeterminacy (I_i), and falsehood (F_i), along with its isomorphic model, the MultiNeutrosophic Set (MNS). These structures make it possible to accurately represent complex, ambiguous, or transitional contexts—precisely the types of realities described by these ancestral principles [10].

Thus, both Refined Neutrosophic Sets [41] and MultiNeutrosophic Sets[42] not only enable the representation of these n-alethic structures but also support their application in fields such as AI ethics, sustainability, and intercultural decision-making. This articulation between advanced mathematical logic and ancestral wisdom not only validates Indigenous epistemologies in formal terms but also enriches the understanding and design of technological systems that are more just, inclusive, and in harmony with life.

Definition 3 [42]. The Subset Refined Neutrosophic Set (SRNS). Let $\mathcal{U}$ be a universe of discourse, and a set $R \subset \mathcal{U}$. Then a Subset Refined Neutrosophic R is defined as follows: $R = \{x, x(T, I, F), x \in U\}$, where T is refined/split into p sub-truths, $T = \langle T_1, T_2, \dots T_p \rangle, T_j \subseteq [0,1], 1 \leq j \leq p$; I is refined/split into r sub-indeterminacies, $I = \langle I_1, I_2, \dots I_r \rangle, I_k \subseteq [0,1], 1 \leq k \leq r$, and F is refined/split into s sub-falsehoods, $F = \langle F_1, F_2, \dots F_l \rangle, F_s \subseteq [0,1], 1 \leq l \leq s$, where $p, r, s \geq 0$ are integers, and $p + r + s = n \geq 2$, and at least one of $p, r, s\ is \geq 2$ to ensure the existence of refinement (splitting).

Definition 4 [42]. The MultiNeutrosophic Set (or Subset MultiNeutrosophic Set SMNS). Let $\mathcal{U}$ be a universe of discourse and M a subset of it. Then, a MultiNeutrosophic Set is: $M = \{x, x(T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s)\}, x \in U$,where p, r, s are integers $\geq 0, p + r + s = n \geq 2$ and at least one of $p, r, s\ is \geq 2$, to ensure the existence of a multiplicity of at least one neutrosophic component: truth/membership, indeterminacy, or falsehood/non-membership; all subsets $T_1, T_2, \dots, T_p; I_1, I_2, \dots, I_r; F_1, F_2, \dots, F_s \subseteq [0,1]$; $0 \leq \sum_{j=1}^{p} inf\ T_j + \sum_{k=1}^{r} inf\ I_k + \sum_{l=1}^{s} inf\ F_l \leq \sum_{j=1}^{p} sup\ T_j + \sum_{k=1}^{r} sup\ I_k + \sum_{l=1}^{s} sup\ F_l \leq n.$

This expression establishes the general bounds for refined or multi-valued neutrosophic components. It states that the sum of the minimum values (infima) of all truth, indeterminacy, and falsehood components must be greater than or equal to zero, while the sum of their maximum values (suprema) must not exceed a total value n. This allows for flexible modeling of complex systems with multiple subcomponents of truth, uncertainty, and falsehood, without imposing additional restrictions on their distribution.

The element x, with respect to the set M, is characterized by a MultiDegree of Truth (or MultiMembership), represented by the values $T_1, T_2, \dots, T_p$; a MultiDegree of Indeterminacy (or MultiNeutrality), given by $I_1, I_2, \dots, I_r$ and a MultiDegree of Falsehood (or MultiNonmembership), expressed as $F_1, F_2, \dots, F_s$. Each of these values captures distinct contributions from various sources, enabling a more nuanced representation of the element's status within the set. All these $p + r + s = n \geq$

2 components are assigned by n sources—whether fully independent, partially interdependent, or entirely dependent—according to the needs of each specific application [43].

This multi-source structure resonates with the n-alethic logic of Indigenous philosophies, where multiple, sometimes contradictory, perspectives coexist without requiring resolution. Each truth, indeterminacy, or falsehood—provided by different experts or contexts—mirrors the plurivocality of ancestral thought, which values coexistence over binary reduction.

A generic element x with regard to the MultiNeutrosophic Set A has the form:

$$x(T_1, T_2, \ldots, T_p; \quad I_1, I_2, \ldots, I_r; \quad F_1, F_2, \ldots, F_s)$$

multi-truth multi-indeterminacy multi-falsehood

In many particular cases $p = r = s$, and a source (expert) assigns all three degrees of truth, indeterminacy, and falsehood T_j, I_j, F_j for the same element.

The ranking of n-valued MultiNeutrosophic types of the same (p, r, s)-form, $(T_1, T_2, \ldots, T_p; I_1, I_2, \ldots, I_r; F_1, F_2, \ldots, F_s)$, where p, r, s are integers ≥ 0, and $p + r + s = n \geq 2$, and at least one of $p, r, s \geq 2$ to be sure that it has multiplicity for at least one neutrosophic component (either truth, or indeterminacy, or falsehood).

For ranking two n-valued multi neutrosophic tuples of the forms (p_1, r_1, s_1) and respectively (p_2, r_2, s_2), where $p_1, r_1, s_1, p_2, r_2, s_2$ are integers ≥ 0, and $p_1 + r_1 + s_1 = n_1 \geq 2$, and at least one of $p_1, r_1, s_1 is \geq 2$, to be sure that there is multiplicity for at least one neutrosophic component (either truth, or indeterminacy, or falsehood); similarly $p_2 + r_2 + s_2 = n_2 \geq 2$, and at least one of $p_2, r_2, s_2 \; is \geq 2$.

Let's take the following Single-Valued Multi Neutrosophic Tuples (SVMNT):

$SVMNT = (T_1, T_2, \ldots, T_p; I_1, I_2, \ldots, I_r; F_1, F_2, \ldots, F_s)$ of $(p_1, r_1, s_1) - form$, and

$SVMNT' = (T'_1, T'_2, \ldots, T'_p; I'_1, I'_2, \ldots, I'_r; F'_1, F'_2, \ldots, F'_s)$ of $(p_1, r_1, s_1) - form$.

It makes the classical averages of truth (T_a), indeterminacies (I_a) and falsehood (F_a), respectively for $SVMNT = (T_a, I_a, F_a)$ and the averages of truths (T_a), indeterminacies (I_a) and falsehood (F_a) respectively for: $SVMNT = (T'_a, I'_a, F'_a)$. And then it applies the Score (S), Accuracy (A), and Certainty (C) Functions, as for the single-valued neutrosophic set:

Compute the Score Function (average of positiveness) (7).

$$S(T_a, I_a, F_a) = \frac{T_a + (1 - I_a) + (1 - F_a)}{3}$$

$$S(T'_a, I'_a, F'_a) = \frac{T'_a + (1 - I'_a) + (1 - F'_a)}{3} \quad (1)$$

i. If $S(T_a, I_a, F_a) \geq S(T'_a, I'_a, F'_a)$ then $SVMNT \geq SVMNT'$,

ii. If $S(T_a, I_a, F_a) \leq S(T'_a, I'_a, F'_a)$ then $SVMNT \leq SVMNT'$,

iii. And if $S(T_a, I_a, F_a) = S(T'_a, I'_a, F'_a)$ then $SVMNT = SVMNT'$, then go to the second step.

Compute the Accuracy Function (difference between the truth and falsehood) (8).

$$A(T_a, I_a, F_a) = T_a - F_a$$
$$A(T'_a, I'_a, F'_a) = T'_a - F'_a \quad (2)$$

i. If $A(T_a, I_a, F_a) \geq A(T'_a, I'_a, F'_a)$ then $SVMNT \geq SVMNT'$,
ii. If $A(T_a, I_a, F_a) \leq A(T'_a, I'_a, F'_a)$ then $SVMNT \leq SVMNT'$,
iii. And if $A(T_a, I_a, F_a) = A(T'_a, I'_a, F'_a)$ then $SVMNT = SVMNT'$, then go to the third step.

3. Compute the Certainty Function (truth) (9).

$$C(T_a, I_a, F_a) = T_a$$
$$C(T'_a, I'_a, F'_a) = T'_a \quad (3)$$

i. If $C(T_a, I_a, F_a) \geq C(T'_a, I'_a, F'_a)$ then $SVMNT \geq SVMNT'$,
ii. If $C(T_a, I_a, F_a) \leq C(T'_a, I'_a, F'_a)$ then $SVMNT \leq SVMNT'$,
iii. And if $C(T_a, I_a, F_a) = C(T'_a, I'_a, F'_a)$ then $SVMNT = SVMNT'$ are multi-neutrosophically equal, i.e. $T_a = T'_a, I_a = I'_a, F_a = F'_a$, or their corresponding truth, indeterminancy, and falsehood averages are equal.

When some sources contribute with different levels of importance, weighted averages are used, denoted as T_{wa}, I_{ua}, F_{va} and $T'_{wa}, I'_{ua}, F'_{va}$,and for the respective multi-neutrosophic tuples. Since the sources may be fully independent, partially independent, or dependent, the sum of the weights is not constrained to equal one. Therefore, the weights $w_1, w_2, \dots, w_p,\ u_1, u_2, \dots, u_p,\ v_1, v_2, \dots, v_p$are defined within the interval [0,1], and their sums may be less than, equal to, or greater than 1. The Score, Accuracy, and Certainty functions are then applied to these weighted averages to establish a more nuanced ranking of the multi-neutrosophic elements.

3. Material and Methods

This study employs Multi-Neutrosophic Sets (MNS) as a formal mechanism to represent the coexistence of diverse ethical judgments in culturally heterogeneous environments. In neutrosophic logic, any proposition—such as "This AI system improves community health"—is evaluated in terms of its truth value (T), indeterminacy (I), and falsity (F), each ranging independently from 0 to 1. The refined version allows for multiple sources or degrees of each component: $T = \{T_1, T_2, \dots, T_p\}$, $I = \{I_1, I_2, \dots, I_r\}$, and $F = \{F_1, F_2, \dots, F_s\}$, reflecting plural and possibly conflicting viewpoints.

This structure is ideal for n-alethic reasoning, which embraces the coexistence of truths, falsehoods, and uncertainties without enforcing binary resolution. Particularly in AI ethics applied to healthcare, the interplay between ancestral knowledge systems and algorithmic models generates zones of ambiguity (*nepantla*) and contradiction (*ch'ixi*), which require ethical reasoning attuned to tension, dialogue, and negotiated consensus.

This paper introduces an approach referred to as the Multi-Neutrosophic Ayni Method, which is inspired by the Andean principle of *Ayni*—a form of reciprocal and ethical co-existence that values balance,

mutual respect, and dynamic harmony—this method models the ethical interplay between diverse sources of judgment without forcing unification [12]. Rather than eliminating differences, it honors them through a formal structure that enables negotiated convergence. The name reflects both the mathematical foundation in neutrosophic logic and the intercultural epistemology it seeks to respect and operationalize.

As a novel contribution, this article introduces a Neutrosophic Consensus Measure [44] based on Euclidean distance, designed to quantify the degree of alignment—or divergence—among the various evaluations provided by multiple sources. Rather than imposing agreement, this measure preserves the integrity of plural perspectives while offering a metric to identify convergence zones in intercultural ethical deliberation. Such an approach enhances decision-making processes by foregrounding epistemic diversity as a strength rather than a limitation.

Definition 5: Euclidean Multi-Neutrosophic Consensus Measure

Let

$$\boldsymbol{x}(\boldsymbol{T_1}, \boldsymbol{T_2}, \ldots, \boldsymbol{T_p};\ \boldsymbol{I_1}, \boldsymbol{I_2}, \ldots, \boldsymbol{I_r};\ \boldsymbol{F_1}, \boldsymbol{F_2}, \ldots, \boldsymbol{F_s}) \tag{4}$$

be a Multi-Neutrosophic assessment of an element $x \in U$, where each component reflects values from distinct sources.

Let:

$$\bar{T} = \frac{1}{p}\sum_{j=1}^{p} T_j \tag{5}$$

$$\bar{I} = \frac{1}{r}\sum_{k=1}^{r} I_k \tag{6}$$

$$\bar{F} = \frac{1}{s}\sum_{l=1}^{s} F_l \tag{7}$$

Then, the Neutrosophic Consensus Measure C_x is defined as:

$$C_x = 1 - \frac{1}{3}\left(\sqrt{\frac{1}{p}\sum_{j=1}^{p}\left(T_j - \bar{T}\right)^2} + \sqrt{\sum_{k=1}^{r}\frac{1}{r}(I_k - \bar{I})^2} + \sqrt{\frac{1}{s}\sum_{l=1}^{s}(F_l - \bar{F})^2}\right) \tag{8}$$

where $\boldsymbol{p}$, $\boldsymbol{r}$, and $\boldsymbol{s}$ represent the number of truth, indeterminacy, and falsity values, respectively, and $\boldsymbol{n} = \boldsymbol{p} + \boldsymbol{r} + \boldsymbol{s}$ is the total number of neutrosophic values.

The result $\boldsymbol{C_x} \in [\boldsymbol{0}, \boldsymbol{1}]$, where:

$\boldsymbol{C_x} = \boldsymbol{1}$ indicates maximum consensus (no dispersion),

$\boldsymbol{C_x} \approx \boldsymbol{1}$ indicates minimum consensus (maximum dispersion).

This measure reflects the degree of alignment among diverse sources, without requiring exact agreement, making it especially suited for ethical evaluations in intercultural and plural settings.

To operationalize plural ethical evaluation in culturally diverse contexts, this study proposes the Multi-Neutrosophic Ayni Method—a stepwise approach that integrates ancestral relational ethics (*Ayni*) with neutrosophic logic to assess the acceptability of socio-technical systems. The method proceeds as follows (Figure 4):

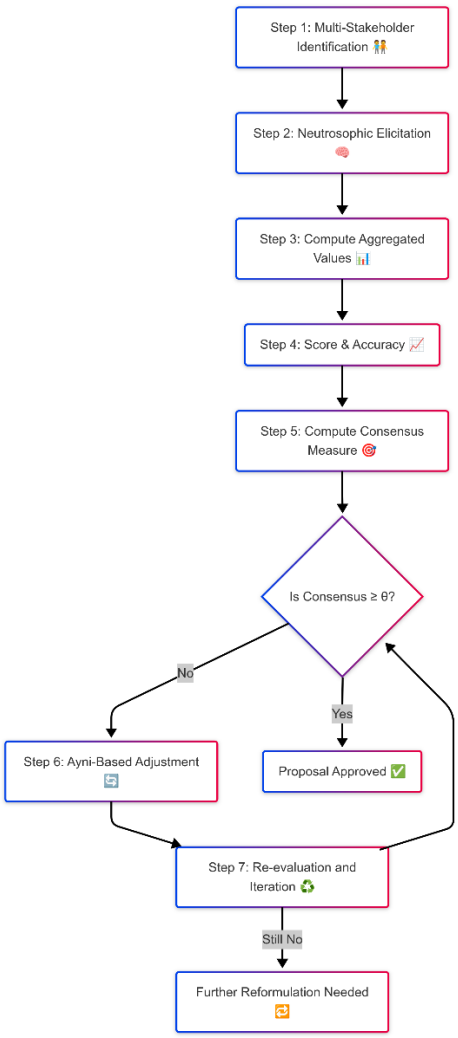

Figure 4. Multi-Neutrosophic Ayni Method

Step 1: Multi-Stakeholder Identification

Identify a diverse set of stakeholders involved in or affected by the proposed intervention. These may include technical experts, community elders, traditional knowledge holders, public officials, and other

relevant actors. Define a consensus threshold (θ), where θ ∈ [0, 1], as a predefined value that depends on the context.

Step 2: Neutrosophic Elicitation

Each stakeholder evaluates a given ethical proposition (e.g., "This AI system is beneficial and ethically appropriate") in terms of:

- Truth (T) – perceived ethical and practical validity.
- Indeterminacy (I) – uncertainty or unresolved concerns.
- Falsehood (F) – perceived ethical harm or inappropriateness.

Each component can be expressed as a set of degrees $T = \{T_1, \dots, T_p\}$, $I = \{I_1, \dots, I_r\}$, $F = \{F_1, \dots, F_s\}$, forming a Multi-Neutrosophic Tuple.

Step 3: Compute Aggregated Values

Calculate the average of each component:

$$\bar{T} = \frac{1}{p}\sum_{j=1}^{p} T_j,\ \bar{I} = \frac{1}{r}\sum_{k=1}^{r} I_k,\ \bar{F} = \frac{1}{s}\sum_{l=1}^{s} F_l \quad (9)$$

Step 4: Calculate Neutrosophic Score and Accuracy

Use the score function:

$$S = \frac{1}{3}\left(\bar{T} + (1 - \bar{I}) + (1 - \bar{F})\right) \quad (10)$$

and the accuracy function:

$$A = \bar{T} - \bar{F} \quad (11)$$

These values provide a quantitative reflection of collective ethical alignment and divergence.

Step 5: Compute the Euclidean Multi-Neutrosophic Consensus Measure

To assess the level of convergence among stakeholders, calculate C_x (8).

Consensus Threshold Rule: If $C_x < \theta$, a new deliberative round is initiated to address dissent and refine the proposal.

Step 6: Ayni-Based Adjustment

If the consensus threshold is not met, a culturally grounded process of *Ayni* is activated:

- Stakeholders openly express concerns and expectations.
- Proposals are ethically renegotiated through community logic, rituals, or symbolic mediation.
- Adjustments are made to the technological design or implementation strategy.

Step 7: Re-evaluation and Iteration

A second (or subsequent) neutrosophic evaluation is conducted with updated values. If the consensus threshold is now exceeded, the proposal moves forward with intercultural legitimacy. Otherwise, further dialogue and reformulation may be required.

This method acknowledges plural truths, dynamic uncertainties, and situated falsehoods, without forcing premature resolution. It promotes ethical alignment not through top-down authority, but through dialogical convergence rooted in both formal logic and ancestral reciprocity. As such, the Multi-Neutrosophic Ayni Method constitutes a replicable, flexible, and culturally sensitive approach to ethical decision-making in AI-driven health systems and beyond.

4. Illustrative Case – Evaluating an AI Health Diagnostic System in an Indigenous Territory

A regional health authority proposes implementing an AI-powered diagnostic system trained on biomedical data to assist in early disease detection within an Indigenous community. The system uses symptom pattern recognition and predictive modeling to suggest potential diagnoses.

However, the community has a longstanding tradition of ancestral medicine, based on holistic principles involving herbal treatments, spiritual diagnosis, and community rituals. The proposed system, while technically promising, raises epistemic tensions with local healers and elders.

To evaluate the ethical acceptability of the project, a community assembly is convened. Participants include:

- **Medical AI developer**: values the diagnostic precision and scalability of the AI system.
- **Traditional healer (yachak)**: emphasizes the risk of spiritual imbalance and cultural erosion.
- **Community leader**: seeks integration but is uncertain about long-term implications.
- **Public health representatives** highlight potential public health benefits.
- **Young community members**: express openness but with questions about trust and respect.

Each participant offers a **multi-neutrosophic evaluation** of the proposition:

"The AI system will be beneficial and ethically appropriate for our community health practices."

Situation: The community assembly analyzes the AI project using the Multi-Neutrosophic Ayni Method method.

1. **Sources of truth (T):**
   - *p = 3 evaluators* (AI developer, public health officer, youth representative)
   - Assigned values:

     $$T = \{0.90, 0.40, 0.30\}$$

     These values reflect a wide range of perceptions—from strong optimism to skepticism—regarding the system's technical capabilities and alignment with public health goals.
2. **Sources of indeterminacy (I):**
   - *r = 2 evaluators* (community leader, youth representative)
   - Assigned values:

     $$I = \{0.80, 0.20\}$$

     This reflects divergent views about cultural compatibility, governance, and trust in AI technologies
3. **Sources of falsity (F):**
   - *s = 2 evaluators* (traditional healer, elder community member)
   - Assigned values:

     $$F = \{\, 0.85, 0.25\}$$

     Concerns range from a strong sense of epistemic and spiritual conflict to a more moderate skepticism regarding the erosion of ancestral medical practices.

Final Multi-Neutrosophic Tuple:

$\text{AIHealthProject}(0.90, 0.40, 0.30\}, \{0.80, 0.20\}, \{0.85, 0.25\})$

Averaged Components:

- Truth (T) ≈ (0.90 + 0.40 + 0.30)/3 = 0.533
- Indeterminacy ($\bar{I}$) ≈ (0.80 + 0.20)/2 = 0.50
- Falsity (F) ≈ (0.85 + 0.25)/2 = 0.55

Neutrosophic Score Function:

$$S = \frac{\bar{T} + (1 - \bar{I}) + (1 - \bar{F})}{3} = \frac{0.533 + 0.50 + 0.45}{3} \approx 0.494$$

Accuracy:

$A = \bar{T} - \bar{F} = 0.533 - 0.55 = -0.17$

Consensus Measure (C_x):

$C_x \approx 0.57$

Interpretation:

Therefore, the Neutrosophic Consensus Measure for the AIHealthProject is approximately 0.57, indicating a moderate level of consensus among the different evaluations. This is closer to agreement (1) than complete disagreement (0). Importantly, the Euclidean Multi-Neutrosophic Consensus Measure ($C_x \approx 0.57$) falls below the pre-established threshold of 0.9, signaling a lack of sufficient convergence among stakeholder perspectives

Collective Action and Ayni-Based Adjustment:

In response to the unmet consensus threshold, the community assembly activated a participatory process grounded in Ayni—the Andean principle of reciprocity and relational balance:

- Traditional healers requested formal inclusion of ancestral diagnostic knowledge in the proposed system.
- Youth representatives called for mechanisms to ensure transparency and ongoing participatory monitoring of the AI's performance.
- A decision was made to pilot the system in parallel with existing traditional practices, rather than replacing them.
- The community reached agreement on data governance guided by customary law and collective consent protocols.
- This dialogical and culturally grounded refinement process led to a second neutrosophic evaluation with increased consensus and improved alignment between technical innovation and cultural integrity.

Second Evaluation (after adjustments):

- **New values:**

$$T = \{0.85, 0.85, 0.75\}, I = \{0.30, 0.25\}, F = \{0.40, 0.30\}$$

AIHealthProject({0.85,0.85,0.75},{0.30,0.25},{0.40,0.30})

- **New averages:**

$$T_a = 0.82,\ I_a = 0.275, F_a = 0.35$$

- **New Score:**

$$S = \frac{0.82 + 0.275 + 0.65}{3} \approx 0.73$$

- **New Accuracy:**

$$A = 0.82 - 0.35 = 0.47$$

- **Consensus Measure:**
- $C_x \approx 0.94$

The second evaluation shows a notable improvement in both the score (S ≈ 0.73) and accuracy (A = 0.47), indicating stronger ethical support and clearer differentiation between perceived benefits and harms. Crucially, the consensus measure C_x reached 0.94, which is well above the pre-established threshold of 0.9, signifying high alignment among stakeholders.

This outcome reflects the success of the Multi-Neutrosophic Ayni Method in facilitating intercultural negotiation without suppressing dissent. Through transparent dialogue and culturally sensitive adjustments, the community was able to refine the project and co-construct an ethical pathway forward. The method thus served as both a quantitative decision-making tool and a relational, epistemically plural mechanism—offering a replicable model for inclusive AI adoption in diverse health systems.

5. Conclusions

This work introduces an innovative framework for evaluating the ethics of artificial intelligence and sustainability by integrating n-alectic reasoning with Latin American Indigenous philosophical principles. By incorporating *Buen Vivir*, *yanantin*, *ch'ixi*, In Lak'ech, and *nepantla*, it demonstrates that Indigenous worldviews inherently reflect dynamic, complementary, and non-binary logic structures. These can be rigorously formalized through Refined and Multi-Neutrosophic Sets, enabling the representation of multiple truths, uncertainties, and contextual ethical values. This approach offers a powerful ethical lens for assessing AI technologies in intercultural and ecologically sensitive contexts, as illustrated by the case study on Indigenous health.

Beyond logical modeling, the article contributes the Multi-Neutrosophic Ayni Method—a culturally rooted decision-making process that blends neutrosophic consensus with ancestral ethics of reciprocity. The inclusion of the Euclidean Multi-Neutrosophic Consensus Measure offers a practical tool to assess ethical alignment without suppressing diversity, reinforcing the importance of pluralistic deliberation in technology governance. Future directions include exploring weighted consensus metrics that reflect epistemic authority or community trust, and applying the framework in areas like climate adaptation, educational technologies, and Indigenous land-use planning. Ultimately, this work invites scholars and practitioners to engage in intercultural dialogue, co-design technologies with communities, and embrace plural logics that nurture life, diversity, and planetary care.

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