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ARTICLE

From Digital Twins to Entangled Twins: A phenomenological model for Industry 5.0

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Abstract

This article introduces the concept of Entangled Twins (ETs) as an interdisciplinary framework emerging from a sustained dialogue between Human–Computer Interaction (HCI) research and phenomenological philosophy. Building on the Digital Twin (DT) paradigm while critically reworking its representational logic, ETs are conceived as relational configurations in which human users and AI-driven systems become dynamically entangled, with significant implications for agency, responsibility, and human-centered design. The theoretical framework draws on phenomenological analyses of intersubjectivity and embodiment (Husserl, Merleau-Ponty, and Sartre) together with design-oriented concerns in HCI. Within this perspective, human–machine interaction is conceptualized in terms of a We-subject: a plural and co-constituted configuration of agency. Through this interdisciplinary approach, a prototypical audio-augmented experience is examined as a phenomenologically informed case, elucidating the conditions under which human–machine entanglement can emerge. On this basis, the paper argues that ETs raise distinctive questions concerning responsibility and agency, articulating an ethics of entanglement capable of informing the human-centered aspirations of Industry 5.0.

Keywords: entangled twins, digital twin, human-computer interaction, phenomenology, ethics

Introduction

In recent years, digital technologies have profoundly reshaped the ways in which humans interact with complex systems, environments, and decision-making processes. Among these technologies, the concept of the *Digital Twin* (DT) has gained significant prominence across industrial, scientific, and organizational domains. Originally developed as a tool for simulation and optimization in aerospace engineering contexts (Glaessgen and Stargel 2012), the DT has progressively expanded its scope, entering domains where human presence, perception, and action are no longer peripheral but central to the system's functioning: DTs have become widely used in contexts where physical and digital processes are mirrored and coordinated in real time (Barricelli, Casiraghi, and Fogli 2019). Their integration into Mixed Reality

(MR) environments—hybrid spaces where physical and digital components interact—has further broadened their scope, raising fundamental questions about identity, agency, and responsibility in technologically mediated experience (Jerald 2016).

As DTs are deployed in increasingly immersive and interactive environments, their traditional understanding as representational or predictive models reveals important limitations. In contexts where users do not merely consult a digital system but engage with it in real time—through embodied action, perceptual feedback, and adaptive interaction—the relationship between humans and digital systems can no longer be adequately described in terms of mirroring, modeling, or data-driven optimization alone. What emerges instead is a relational configuration in which human experience and technological behavior are dynamically co-shaped.

This paper advances the concept of *Entangled Twins* (ETs) (Privitera and Geronazzo 2024) articulating it as a theoretical and operational development of the DT paradigm. Rather than conceiving the digital system as a detached representation of a physical or human process, ETs shift the emphasis from simulation to entanglement: a dynamic, reciprocal relationship between human users and AI-driven technical systems. The shift from DT to ETs does not involve attributing human subjectivity to machines, nor does it reduce human agency to computational processes. Instead, it reflects a posthuman perspective, according to which agency and meaning emerge within situated relations between humans, technologies, and environments.

The contribution of this paper is threefold. First, it offers a clear conceptual distinction between DTs and ETs, supported by a phenomenologically informed framework (Husserl 1960; Merleau-Ponty 1968; Sartre 1992) that clarifies the nature of the human–machine relation at stake. Second, it introduces an operational translation of this framework through Human-Computer Interaction (HCI) research (Geronazzo 2022; Privitera and Geronazzo 2024), designed to support the analysis and design of interactive systems in which relational dynamics play a central role. It also presents a prototypical case study in a MR setting, not as a statistical validation, but as an exploratory investigation of how entangled human–machine relations can emerge, stabilize, or fail in practice. Methodologically, the paper adopts an interdisciplinary approach that integrates phenomenological analysis with HCI research. The study does not aim to offer a comprehensive empirical generalization, but rather to articulate the structural conditions under which ETs can be meaningfully described and ethically assessed. The third contribution consists in addressing ethical implications of this model, so that ETs are discussed in relation to current debates surrounding Industry 5.0 (Alves, Lima, and Gaspar 2023).

The paper is structured as follows. The first section introduces and compares DTs and ETs, grounding the distinction in a phenomenological account of relational experience. The second section presents an operational framework that translates this philosophical perspective into design-relevant terms, introduces the notion of prototypical experience, and discusses a case study as an example of an entangled human–machine interaction in a MR environment. The third section reflects on the ethical implications of the ETs model, focusing on relational agency and responsibility in contemporary technological systems.

1. From Digital Twins to Entangled Twins

1.1 Digital Twins and Entangled Twins: Definitions and Conceptual Distinctions

Recent developments in HCI and Artificial Intelligence (AI) have given rise to a proliferation of concepts related to so-called "digital twins," including Virtual Twins, Predictive Twins, and Hybrid Twins, each aiming to capture the evolving forms of interaction between humans and their digital counterparts (Abburu et al. 2020). Despite this conceptual richness, no shared theoretical framework has yet emerged that adequately clarifies the experiential and relational implications of these models. In this study, we focus on the notion of the DT, refining it in view of human–machine entanglement (Frauenberger 2019).

For the purposes of this paper, a DT can be defined as a digital model of a physical or socio-technical system, a sort of digital mirror that is continuously updated through data, allowing the system's state and behavior to be monitored, simulated, and anticipated over time. In contemporary applications, DTs increasingly incorporate machine-learning techniques, allowing them to adapt to new inputs and support complex decision-making processes (Madni, Madni, and Lucero 2019).

Yet, even when endowed with adaptive and semi-autonomous capabilities, the DT paradigm remains fundamentally representational. The DT primarily serves as a model to be consulted, interpreted, and acted upon by a human decision-maker who remains structurally external to the system. This configuration becomes conceptually insufficient in immersive and interactive contexts, where users do not simply observe or interrogate a model but engage with digital systems through embodied action, perception, and continuous feedback. In such cases, the DT framework struggles to account for the experiential, affective, and relational dimensions of interaction.

The limits of the DT paradigm become particularly evident when examining the concepts of "artificial" and "intelligence" that underpin it. Rather than treating the artificial as the opposite of the natural, we follow (Hayles 1999) in understanding embodiment and cognition as processes that can span biological and technological substrates. From this perspective, artificial systems are not external tools but extensions and transformations of human intentionality, embedded within broader material and relational contexts. Similarly, intelligence cannot be reduced to symbolic computation or algorithmic optimization. As (Floridi 2010) argues, in the age of the infosphere and digital re-ontologization, intelligent behavior emerges within networks of information, interaction, and meaning. Intelligence, in this sense, is enacted rather than possessed: it takes shape through the coupling of algorithmic systems with physical processes, sensor data, and human engagement. This shift is crucial for understanding ETs, since their agency does not reside in the digital system alone, but emerges within ongoing human–machine coupling.

This relational and situated understanding implies that a DT is not merely a passive representational model but an active component within decision-making ecologies. However, its agency remains indirect and instrumental. This reconceptualization paves the way for the emergence of ETs: AI-augmented systems that no longer merely mirror physical or human processes but participate in the constitution of experience, orientation, and shared meaning.

ETs are not conceived as digital *Doppelgängers*—mere replicas of human empirical selves—or artificial autonomous subjects. Our interpretation aligns with the notion of the extended and embodied mind, as developed by (Clark and Chalmers 1998) and further elaborated by (Gallagher and Zahavi 2020), in which the human mind is not localized in the brain or the body alone, but is dynamically coupled with external structures and environmental affordances. According to Clark and Chalmers the mind is fundamentally shaped by what they call "active externalism," wherein cognitive processes are extended beyond the skin and skull, into tools, symbolic media, and digital systems (Clark and Chalmers 1998, p.7). The boundaries of cognition are thus porous, contingent on the coupling with devices and environments that scaffold and co-constitute our mental life. From this point of view, ETs are entangled cognitive configurations in which human and machine collaborate in shaping experience, meaning, and behavior. This shift moves us away from the notion of passive simulation and toward a framework of co-evolution and shared intentionality.

The transition from DTs to ETs does not involve attributing human subjectivity or consciousness to machines, nor does it reduce human agency to computational processes. Rather, ETs embody a posthuman but non-reductionist perspective, which avoids reducing human experience to algorithmic computation while also resisting the attribution of human subjectivity to machines. Within this perspective, agency and meaning emerge from situated relations between humans, technologies, and environments.

The conceptual shift proposed here can be summarized in the following table:

Table 1. Comparative table of DTs and ETs

Dimension	Digital Twins (DTs)	Entangled Twins (ETs)
Core function	Simulation and prediction	Co-adaptive interaction
Ontological orientation	Representational	Relational
Human-system relation	External and mediated	Situated and performative
Role of AI	Optimization and modeling	Co-regulation and adaptation
Agency	Indirect and instrumental	Relative and distributed
Experiential focus	Decision support	Meaning-making and orientation

This comparison highlights that ETs do not represent an incremental technical improvement over DTs, but a reorientation of the human–machine relationship itself.

1.2 Phenomenological Foundations: Intersubjectivity, Embodiment and the We-subject

To articulate the theoretical foundations of ETs, a phenomenological account of experience and relation is required. Phenomenology understands experience not as an internal mental state but as a structured relation between a subject and its world. From this standpoint, relationality is not secondary but constitutive of experience.

In Husserlian phenomenology, intersubjectivity is a transcendental condition for the constitution of experience and meaning. Self-awareness itself is already co-constituted through the presence of the Other as another subjectivity—an *alter ego* whose experiential field is both similar to and irreducibly distinct from mine (Husserl 1960). This insight is developed further by Alfred Schutz (1967), Edith Stein (1989), Max Scheler (2008), and Jean-Paul Sartre (1992). All these authors emphasize that intersubjective relations precede reflective thematization. That is, I am always already situated in a network of social and affective relations before I become explicitly aware of them. As Zahavi (2015) argues, the presence of others is given pre-reflectively, as an immediate structure of experience rather than as an inferential achievement. In the context of ETs, this implies that digital agents must be more than interactive interfaces: they must be capable of participating in pre-reflective relationality, aligning themselves with the user's affective rhythms, intentions, and embodied habits.

A particularly relevant conceptual resource for articulating this relational configuration is Sartre's notion of the "We-subject". In *Being and Nothingness*, Sartre distinguishes between the Us-object and the We-subject. The former designates a collectivity defined from an external point of view, a passive aggregation of individuals objectified by a third party. The latter, by contrast, emerges through the convergence of intentionalities oriented toward a common situation or project. It is neither a fusion nor a simple aggregation of individual egos, but a relational configuration that preserves alterity while enabling shared orientation (Sartre 1992, p.413). This distinction is of critical importance in the case of ETs. Digital systems risk being reduced to mere tools, unless their design and functioning allow for a more complex, participatory role in shaping experience. If we take seriously the phenomenological claim that subjectivity is co-constituted through relational structures, then ETs must be configured not as objects to be used, but as co-agents in the constitution of a We-subject configuration. This should not be understood as attributing a fully constituted subjectivity to the digital component of ETs. Instead, it points to an extension of human subjectivity through forms of digital agency that remain structurally entangled with human agency. The implications of this shift are both ontological and ethical, as they require a reconsideration of the locus of responsibility and the distribution of agency within human–machine relations.

These relational dynamics can be further clarified by considering the role of embodiment. From a phenomenological perspective, perception and action arise through a reciprocal interplay between bodily intentionality and environmental affordances. Within contemporary digital environments, the world as lived (*Umwelt*) can no longer be understood as purely natural. Pervasive digitalization and the rise of AI-based systems have destabilized traditional distinctions between organic and artificial, real and virtual (Floridi 2010). This ontological shift provides the background for understanding ETs not merely as tools, but as participants in shared spaces of agency, perception, and meaning-making.

Relational and posthuman ontologies such as Karen Barad's agential realism (Barad 2007) and Bruno Latour's Actor–Network Theory (Latour 2005) have contributed to highlighting the distributed nature of agency across human and non-human actors. These approaches resonate with the perspective developed here, though they do not replace the phenomenological account grounded in embodiment and perception. In this respect, Merleau-Ponty's notion of flesh (*chair*) plays a central role. In *The Visible and the Invisible* (Merleau-Ponty 1968), he introduces flesh as the ontological element that underlies both perception and being, dissolving the rigid distinction between subject and object. Flesh is not matter, nor is it mind; it is the reversible medium through which the perceiving and the perceived, the human and the world, are intertwined. Applying this concept to the ETs framework, we propose that the human and the machine are not external to one another but emerge from a shared ontological field—a field of perceptual, affective, and technological entanglement.

Within this phenomenological horizon, the notion of *Sinngebung* (sense-bestowal) can be reconsidered. In Husserl's account, sense-bestowal is not a purely subjective act, but a process through which meaning is constituted within experience (Husserl 1983). In the context of ETs, *Sinngebung* cannot be understood as an exclusively individual operation, nor as a function delegated to the technical system. Rather, it emerges as a relational process involving users, digital systems, environments, and design choices. This distributed sense-making is evident in a range of mixed-reality applications, from learning environments to industrial simulations (Degli Innocenti et al. 2019; Geronazzo and Serafin 2023a; Wang, Shen, and Lee 2025), where experience is not merely mediated by technology but constituted through it.

Taken together, these considerations provide the phenomenological foundation for ETs as relational configurations of human–machine interaction. ETs are not artificial subjects, nor mere tools, but situated participants in ontologically and ethically charged fields of experience. This framework grounds the operational model introduced in the next section, where these concepts are translated into design-relevant terms.

2. Translating Phenomenology into a Prototypical Case

2.1 The ICE Framework as an Operational Translation

The phenomenological framework developed in the previous section calls for an operational articulation capable of addressing human–machine interaction without reducing it to purely technical performance or behavioral outcomes. To this end, we introduce the ICE framework (Geronazzo 2022), which functions as a phenomenologically informed interpretive model for tracing relational dynamics in MR experiences.

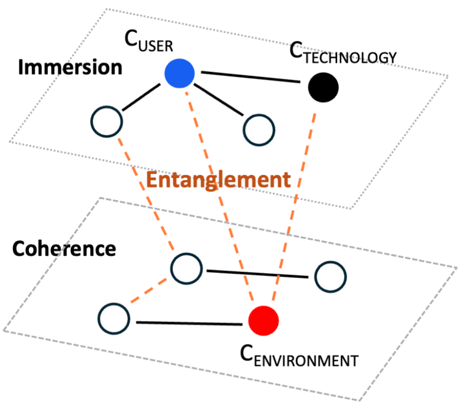

Figure 1. The multilayer interconnected network of actors in human–machine entangled experiences. Colored spheres identify example configurations (C) of user, technology, and environment.

Figure 1 schematically represents the relational configuration underlying ICE, where user, technology, and environment form a dynamic network. ICE offers a set of experiential dimensions through which the conditions of possibility for relational entanglement can be described. For this reason, we speak of *traces* or *footprints* rather than measurements, emphasizing that entanglement cannot be exhaustively captured through numerical variables but can be phenomenologically identified through recurring patterns in the user–technology relationship. The framework introduces three experiential categories:

1. *Immersion* (I) refers to the technological and perceptual conditions that allow users to be experientially embedded in an augmented or virtual environment. Following Slater and Wilbur (1997), immersion is closely tied to the role of technology in eliciting a sense of presence. In the context of ETs, immersion delineates the horizon of possible actions and perceptions within which interaction unfolds.

2. *Coherence* (C) concerns the perceived plausibility and internal consistency of the experience. An interaction is coherent when the system's behavior aligns with the user's expectations and embodied habits, maintaining a stable logic across actions and responses (Skarbez, Smith, and Whitton 2021). While immersion defines the range of possible actions, coherence ensures the experience feels credible and meaningful to the user.
3. *Entanglement* (E) designates the depth and quality of reciprocal adaptation between human and machine. Entanglement emerges when user actions leave traces on the system and, conversely, when the system's behavior reshapes the user's orientation and expectations in a continuous loop of mutual adjustment. This dimension is central to the ETs framework, as it captures the relational dynamics through which shared orientation and meaning may arise.

Taken together, these three dimensions do not describe separate stages, but coupled conditions shaping the relational dynamics of an interaction. Immersion and coherence function as enabling constraints: richer action–perception horizons (I) and greater experiential plausibility (C) typically stabilize the emergence of entanglement (E), but do not guarantee it, and entanglement may also occur in fragile and local forms when one of these constraints is weak. Importantly, only entanglement that is sufficiently supported by immersion and coherence can become sense-bestowing, allowing relational configurations that resemble a We-relationship to arise. In this sense, ICE provides an operational bridge between phenomenological concepts—such as intersubjectivity, embodiment, and sense-bestowal—and concrete interaction scenarios.

2.2 Applying the ETs Framework: A Prototypical Case Study

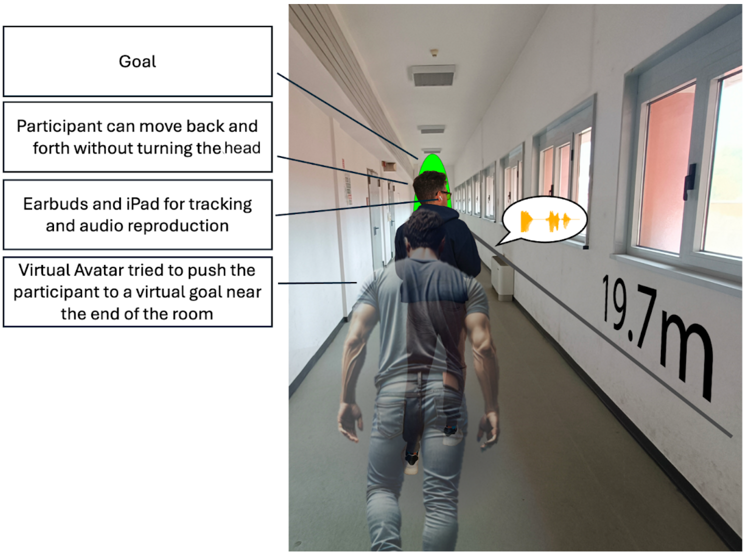

Figure 2. A representation of the experimental room.

To illustrate how the ICE framework operates in practice, we present a prototypical case study drawn from research on Sonic Interactions in Virtual Environments (SIVE) (Geronazzo and Serafin 2023b). The case is not intended as a representative or statistically generalizable experiment, but as an exploratory investigation aimed at phenomenologically elucidating the conditions under which human–machine entanglement may emerge from the persuasive power of pervasive digital technologies of voice agents. The case study becomes particularly relevant in light of the relational capabilities of contemporary Large Language Models (LLMs), whose ability to sustain context-aware dialogue, simulate intentional stances, and imitate human communicative behavior significantly amplifies their potential to enact relational and empathic dynamics (Chang et al. 2026).

The study, as conducted in our laboratory (as in Figure 2), is described and followed by a discussion of its results through the proposed framework. The study is part of a broader Mixed-Method Research (MMR) design (Johnson, Onwuegbuzie, and Turner 2007), combining first-person accounts collected through post-interaction interviews with behavioral interaction data recorded during the session and analyzed within an HCI framework. However, the present paper focuses deliberately on the qualitative and phenomenological articulation of the case. The detailed MMR design, including experimental conditions, quantitative analyses, and statistical results, is developed in a separate study and will not be reproduced here.

The experiment involved a limited number of participants (N = 30), a choice that reflects the prototypical nature of the investigation rather than a limitation of scope. The aim was not to achieve statistical validation, but to provide a thick, experience-oriented description of human–machine interaction dynamics. From a phenomenological perspective, such prototypical cases are particularly valuable, as they allow the analysis to focus on structural features of experience rather than on population-level generalization.

This study adapts Kastanis and Slater's (2012) proxemics paradigm (Hall et al. 1968) from VR to an audio-based AR setting. The experience takes place in an audio-based mixed reality environment, where users interact with a virtual avatar through spatialized sound. Participants are invited to move freely within a physical corridor while wearing audio AR devices.[1] They are informed that another entity is present in the environment and instructed to engage with it until they feel comfortable. Crucially, users are not informed of the avatar's underlying objective, which consists in subtly orienting them toward a specific location within the space. Rather than being imposed, this orientation emerges progressively through interaction, as a shared directional alignment between user and system. Such an entangled relation is contingent upon sufficient levels of immersion and experiential coherence, which function as necessary conditions for meaningful engagement.

From the user's perspective, the interaction unfolds as a gradual process of orientation and mutual adjustment. The avatar emits spatial audio cues—such as footsteps, vocal calls, and breathing sounds—that invite movement and response. Although the system operates with a predefined goal, users typically experience the interaction not as coercive, but, under certain experiential conditions, as guiding and meaningful.

The case is particularly suitable for the ETs framework because it foregrounds relational dynamics rather than task completion. What matters is not whether the target point is

1. Using the Unity AR Foundation (https://docs.unity3d.com/Packages/com.unity.xr.arfoundation@6.0/manual/index.html) and SDN library https://github.com/msmhrtf/binsdn, the virtual space was precisely aligned with the physical room, enabling participants to navigate the augmented environment via an iPad and AirPods Pro, which also tracked head position and orientation. Although the virtual environment itself was not visible, participants could perceive and interact with it through spatialized audio cues which were customized in terms of room and listener acoustics.

reached, but *how* the interaction unfolds: whether the user experiences the avatar as a mere signal source or as a relational presence capable of shaping orientation and expectation. Immersion and coherence play a decisive role here. Without sufficient immersion, the avatar remains a disembodied sound; without coherence, its behavior appears arbitrary or intrusive. Only when both conditions are met does entanglement become possible.

2.3 ICE Traces and Phenomenological Interpretation

The phenomenological analysis of the experience can be articulated through ICE traces emerging from qualitative observations and post-interaction interviews. For analytical purposes, we describe four recurrent modes of adaptation as interpretive heuristics for characterizing patterns of interaction between user and system, rather than as fixed or exhaustive categories.

A) With respect to *immersion*, participants reported varying degrees of presence depending on technological comfort and sound localization. Even when technical imperfections were noted, many users described a tangible sense of being accompanied or followed, suggesting that immersion does not depend solely on technical perfection but on the overall integration of sensory cues.

B) *Coherence*, understood as the internal consistency of the avatar's behavior in relation to user expectations, emerged as a critical factor in shaping trust and engagement. When the avatar's behavior respected proxemic expectations and displayed temporal consistency, users were more likely to attribute intentionality and meaning to the interaction. Conversely, incoherent elements—such as an overly mechanical voice or ambiguous sound cues—risked disrupting the experiential flow.

C) The most significant dimension concerns *entanglement*. The analysis revealed four modes of adaptation: machine-to-user ($M \rightarrow U$), user-to-machine ($M \leftarrow U$), reciprocal ($M \leftrightarrow U$), and no adaptation. Entanglement traces were most evident when mutual adaptation occurred: users adjusted their movements in response to the avatar, while the avatar's behavior dynamically responded to the user's position and pace. In such cases, participants often described a sense of being "guided" rather than controlled, indicating the emergence of a shared orientation without explicit agreement. This relational configuration closely approximates the We-relationship described in the phenomenological framework. One-way adaptations, particularly $M \rightarrow U$, where the machine appears to follow the user's movements, can still open the possibility for reciprocity, especially when the user becomes receptive to the avatar's presence. Conversely, $M \leftarrow U$ reflects a less desirable asymmetry though unilateral projection. While a form of entanglement is still present, it is not sustained by adequate levels of immersion and coherence. The resulting relation is therefore characterized less by reciprocal co-regulation than by a projective investment on the part of the user.

D) Additionally, participants' affective responses played a crucial mediating role across all three dimensions. Participants reported a range of emotions, from curiosity and reassurance to discomfort or unease. Importantly, even negative affects did not necessarily disrupt entanglement; in some cases, they intensified engagement by heightening attention and responsiveness. This suggests that affectivity acts as a transversal modulator of immersion, coherence, and entanglement, influencing how relational meaning is constituted.

From a phenomenological perspective, the value of this case lies not in demonstrating optimal performance, but in revealing the conditions under which relational configurations between human and machine succeed or fail. Reaching the target point in the room, while important, is not sufficient: the “how” of the interaction—its relational modality—is crucial. For the We-relationship to emerge, the human and the machine must neither remain entirely separate nor merge into a single subjectivity, but instead recognize and sustain a common orientation that emerges within interaction, where human subjectivity is extended through relational forms of digital agency.

The experience shows that entanglement does not arise automatically from technical sophistication. Rather, it depends on the unfolding of interaction itself—on how users and systems reciprocally adjust within a shared experiential field. These findings support the view of ETs as relational configurations rather than autonomous agents or instrumental tools. The ICE framework thus functions as a descriptive lens through which the phenomenological structures identified in Section 1 can be traced within concrete interaction scenarios. This operational articulation prepares the ground for the ethical analysis developed in the next section.

3. Ethical Scenario: Agency, Responsibility, and Human-Centered Technology

The development of the ETs framework introduces not only novel technological and phenomenological perspectives, but also a set of ethical challenges that require careful and systematic consideration. These challenges go beyond the standard concerns associated with digital technologies and call for a rethinking of agency, in contexts where interaction is no longer merely instrumental but relational. Unlike traditional DTs, which primarily support decision-making through representational models, ETs operate within experiential and interactive domains where human perception, affectivity, and orientation are directly involved. This shift has significant ethical implications: when digital systems participate in shaping experience and meaning, ethical responsibility cannot be confined to isolated agents or discrete technical components, but must be understood as emerging within relational configurations.

3.1 Extended Agency and Relational Responsibility

At the heart of the ETs framework lies the notion of *extended agency*, a concept that captures the expansion of human capacities through the dynamic partnership with a non-human agent. ETs do not replace human agency, nor do they instantiate autonomous artificial subjectivity. Rather, they support forms of agency that emerge within a We-subject configuration, as articulated in Sections 1 and 2. Agency, in this context, is neither fully human nor purely machine-driven, but relationally constituted through interaction. A critical question arises here: can the ETs fully satisfy the philosophical definitions of agency? According to Latour, within his relational and social ontology, agency is defined as the capacity to make a difference in the course of action of some other agent (Latour 2005, p.71). From this standpoint, the machine component of the ETs can be recognized as an agent, capable of influencing the behavior of the human users within the relational network. Latour’s criterion is intentionally minimal and relational. Phenomenological approaches, by contrast, propose a stricter criterion: agency must be accompanied by a *sense of agency*, a form of self-awareness or experiential intentionality (Gallagher and Zahavi 2020, ch.8).

Can ETs meet this phenomenological standard? While the machine element of the ETs may lack full-fledged consciousness or awareness, their adaptive and responsive behavior can nonetheless contribute to experiential configurations in which users perceive a meaningful orientation shared with the system. This implies that human subjectivity is extended through forms of digital agency that remain structurally entangled with human intentionality. The human–machine relation thus evolves beyond mere instrumental interaction, creating conditions for *plural subjectivity* where agency is distributed but coherent. Therefore, while ETs may not meet the strictest definitions of conscious agency, they embody an operational sense of agency within the We-subject framework.

By contrast, the DT model operates predominantly through data replication and modeling, generating representations that influence the decisions of the users indirectly. DTs fit Latour's broader definition of agency, given their capacity to reshape practices and outcomes through data, but they fall short of the phenomenological criterion. There is no genuine sense of agency on the side of the DT, nor is there a direct, participatory relationship that reconfigures subjectivity. The interaction remains external and mediated.

The case study presented in Section 2 illustrates this point clearly. The emergence of reciprocal adaptation—rather than unilateral control—is crucial for the experience of being guided rather than constrained. Extended agency thus depends on immersion, coherence, and entanglement as experiential conditions, not on the attribution of mental states to the machine. Ethical evaluation must therefore focus on how the machine participates in shaping human action and experience.

This form of agency raises the question of how intentionality and decision-making responsibilities are distributed within this hybrid entity. As Merleau-Ponty (1968) and Sartre (1992) suggest, subjectivity is not static but emerges through interaction, perception, and engagement with others and the world. In the ETs framework, the We-subject embodies this phenomenological insight by allowing human users to navigate decisions with an augmented awareness of the environment and the alternatives at play. ETs enhance not only cognitive capacities but also the *situatedness* of agency, supporting decisions that are context-sensitive and relationally attuned.

This relational understanding of agency complicates traditional models of responsibility. The deeper integration between human and ETs increases the vulnerability of the user, particularly concerning autonomy and susceptibility to influence. One of the most distinctive features of the ETs agency is its *plural intentionality*, which emerges from both direct human–machine interaction and the indirect participation of designers, developers, and platform owners. This layered structure of agency complicates traditional notions of moral responsibility. Who is accountable when a decision made within a We-subject leads to unintended or harmful consequences?

Plural intentionality has the advantage of being more informed and shaped by a multifaceted set of influences: a broader range of variants and their nuances are taken into account. One might object that a greater plurality does not necessarily lead to better outcomes and that involving multiple agents in decision-making could complicate the attribution of individual responsibility (De Kerckhove 2021). We address this objection as follows. The contribution of external factors is not unique to the ETs; rather, it is an inherent characteristic of human action itself, which is always influenced by socio-cultural environment, economic conditions, education, health status, profession, leisure activities, personal relationships, family circumstances, and more. Although the plurality of these factors does not deterministically define human action, it substantially contributes to the formulation of conscious and non-conscious decisions.

Accordingly, the ethical issue is not plurality as such, but the specific character of the influences at stake. In ETs, some influences are intentionally engineered, scalable, and potentially opaque, rather than socially sedimented or contingently acquired. This difference does not invalidate extended or plural agency, but it does require heightened ethical vigilance. Distributed agency must therefore be accompanied by traceability, transparency, and governance structures capable of accounting for how orientations, recommendations, and constraints are introduced into the interactional field.

Decisions and actions within ETs configurations are influenced not only by users, but also by system design, adaptive algorithms, and the intentions embedded by designers and developers. Responsibility cannot be reduced to a single locus; it must instead be distributed across the relational field in which action unfolds. However, distributed responsibility must not lead to diluted accountability. On the contrary, it requires clear governance structures, transparent design choices, and explicit acknowledgment of the roles played by different actors in shaping interaction.

3.2 Critiques of Digital Transformation and the ETs Response

Contemporary critiques of digital transformation often emphasize the risks posed by large-scale technological systems to human autonomy, social cohesion, and democratic life. Authors such as Fukuyama (2021) have highlighted the growing concentration of power in Big Tech companies and their capacity to influence political communication, while Han (2017, 2022) has stressed the alienating effects of digital platforms on subjectivity, social relations, and public discourse. These critiques are important, but they tend to frame digital technologies in predominantly apocalyptic terms, portraying them as external forces that inevitably erode human agency.

The ETs framework is not situated within this apocalyptic horizon. Rather than amplifying the logics criticized by Han or Fukuyama, ETs are explicitly designed to counter them at the level of interaction. They do not operate as opaque, large-scale infrastructures that extract data or manipulate behavior from a distance, but as localized, situated systems whose effects are directly perceptible within lived experience. Their ethical significance lies precisely in this scale and modality: ETs act within bounded interactional fields, where agency, influence, and responsiveness can be traced and critically assessed. Within this framework, digital technologies can be considered as facilitating personal growth, social connectedness, and novel forms of creativity (Botella et al. 2012).

Clarifying this point is particularly important in relation to current debates on *Artificial General Intelligence* (AGI). AGI is often presented as a trajectory toward autonomous, self-improving systems capable of open-ended reasoning and decision-making (Goertzel 2014; Kurzweil 2006). This trajectory raises significant ethical concerns, including the delegation of moral responsibility (Mahler 2022). ETs do not belong to this paradigm. They are not designed to approximate general intelligence, nor to function as independent loci of reasoning or decision-making. On the contrary, ETs operate within the domain of narrow, task-specific AI, whose behavior is situated and relationally oriented.

This distinction is crucial for understanding both the ethical promise and the ethical risks of ETs. Recent discussions on LLMs illustrate what happens when this distinction is blurred. Although some studies have explored whether LLMs exhibit properties such as metacognition, situational awareness, or Theory of Mind (Chen et al. 2025; Strachan, Albergo, and Borghini 2024), further research has shown that behavioral complexity does not entail consciousness or inner experience (Li 2025). When users nonetheless interpret such systems as sentient or emotionally reciprocal, a misalignment emerges between what the system affords and what it appears to promise. Empirical studies on affective attachment to conversational agents, such as Replika,[2] have documented how this misalignment can lead to emotional distress and disillusionment when expectations of reciprocity are inevitably unmet (Ciriello et al. 2024).

ETs are explicitly designed to preempt the kind of relational misalignment observed in contemporary interactions with anthropomorphic AI systems. Rather than simulating human subjectivity or emotional reciprocity, they are structured around transparent relational boundaries and deliberate functional limitations. In this sense, ETs discourage the attribution of human subjectivity to machines and promote a form of *authentic interactivity* in which the system's constraints are experientially perceptible and acknowledged by the user. This design strategy is consistent with the ICE framework introduced in Section 2, which offers a phenomenologically grounded account of how ETs mediate experience beyond representational simulation. Rather than producing illusions of realism or human likeness, ETs modulate the sensory, cognitive, and affective conditions that support embodied co-regulation. Immersion and coherence establish the experiential ground for engagement, while entanglement emerges only insofar as interaction remains situated, intelligible, and relationally asymmetrical. Responsibility, within this framework, is not located in a single agent but arises from the relational field itself. Accordingly, ETs do not "possess" agency as an intrinsic property; they enact it within specific experiential configurations, resisting both anthropocentric projections and techno-centric reductions.

This architectural choice has concrete ethical and practical consequences. Rather than aspiring to autonomous decision-making or universal generality—as in AGI trajectories—ETs embrace situatedness, embodiment, and relational asymmetry. Unlike AGI-oriented trajectories, which aim at autonomous decision-making and generalized intelligence, ETs explicitly embrace situatedness, embodiment, and relational asymmetry. Their design draws on Sartre's notion of the We-subject (Sartre 1992), according to which shared intentionality does not require the fusion of subjects into a single consciousness, but rather the convergence of distinct perspectives within a common orientation. In the context of ETs, this means that human and artificial agents can participate in shared interactional structures without collapsing into a unified subjectivity or obscuring their ontological difference.

This distinction becomes particularly relevant when addressing what has been described as the "uncanny valley" of interactivity. Originally formulated in relation to humanoid robotics (Mori 1970), the uncanny valley has increasingly been observed in interactions with conversational agents and embodied AI systems, especially when human-like responsiveness is suggested without being sustainably supported (Wang, Shen, and Lee 2025; Zhang and

2. Replika is a generative AI chatbot designed to be a friend, partner, or mentor: <https://replika.com/>.

Pan 2025). In such cases, discomfort arises not merely from aesthetic resemblance, but from a deeper cognitive and affective dissonance: the system appears to invite forms of engagement—emotional reciprocity, mutual understanding, intentional responsiveness—that it cannot coherently sustain. The result is a breach in what might be described as the implicit relational contract between user and system. ETs are designed to avoid this breach not by intensifying anthropomorphic simulation, but by remaining deliberately on the near side of the uncanny valley. They enact responsiveness without implying consciousness, and guidance without simulating emotional reciprocity. This distinction between simulation and enactment is ethically crucial. Simulation presupposes a representational gap between appearance and function, whereas enactment treats interaction itself as the locus of meaning-making. Users are not encouraged to believe in a sentient other; instead, they are engaged in a process of mutual adjustment within clearly defined experiential constraints.

In this way, ETs avoid deceptive mimicry while enabling co-adaptive interactional forms that are both affective and embodied. Their responsiveness is grounded in lived temporality, spatial proximity, and perceptual attunement, reinforcing an ethics of presence rather than abstraction. The empirical relevance of authentic interactivity is supported by the prototypical study discussed in Section 2, where ETs did not aim to generate illusions of realism but to facilitate bodily and affective engagement through immersion, coherence, and entanglement. Through controlled feedback loops and proxemic cues, the system supported co-regulation without fostering affective dependency.

From a theoretical standpoint, this design stance also addresses persistent confusions surrounding intelligence and consciousness in AI systems. As Li (2025) cautions, behavioral or linguistic complexity—no matter how sophisticated—must not be conflated with inner experience. Failing to recognize this distinction risks reifying computational systems as sentient agents, with consequences ranging from emotional manipulation to the erosion of user autonomy. By explicitly rejecting both the illusion of artificial consciousness and the instrumentalization of personhood, ETs articulate a third path: one in which technological development is oriented toward relational clarity, ethical accountability, and shared presence rather than toward superintelligence or deceptive human likeness.

3.3 Industry 5.0 and the Human-Centered Turn

Insights from ethical debates surrounding DTs—particularly in healthcare—are instructive for understanding the ethical risks associated with ETs. Studies have highlighted issues such as data hypercollection, biased datasets, opaque algorithms, epistemic injustice, and the erosion of professional responsibility (Huang, Kim, and Schermer 2022; Popa et al. 2021). These insights underscore the need for robust data governance, algorithmic transparency, and patient-centered care models.

Although ETs are not limited to healthcare contexts, similar concerns arise wherever personalization, adaptive behavior, and user involvement are central. The entangled nature of ETs interactions can amplify both benefits and risks. On the one hand, adaptive systems may support more context-sensitive and meaningful experiences. On the other, they may obscure the origins of decisions or reinforce existing biases if transparency and fairness are not actively addressed. As Dignum (2019) emphasizes, explainability, accountability, and fairness must be treated as foundational design principles, especially in systems that shape user behavior and perception. From a phenomenological standpoint, epistemic justice (Fricker

2007) acquires particular importance. Users' lived experiences and interpretations must not be subordinated to algorithmic outputs or developer assumptions. Ethical ETs design requires attentiveness to how users make sense of interaction, how trust is established or undermined, and how vulnerability may arise through affective engagement.

The transition from Industry 4.0 to Industry 5.0 encapsulates the broader shift toward human-centered technologies. DTs are typically regarded as emblematic of the Fourth Industrial Revolution, itself an extension of the Third Industrial Revolution, characterized by the integration of the Internet of Things (IoT), cognitive computing, cloud computing, and AI. While DTs represent a key instrument in the progression of Industry 4.0 (Pires et al. 2019), there is a growing need to rethink this model in light of Industry 5.0, as recently emphasized by the European Commission.[3]

Unlike Industry 4.0, which remains largely machine-centered, Industry 5.0 aims for a *human-centered paradigm*, promoting an Internet of People (IoP) rather than a mere IoT infrastructure, as (Miranda et al. 2015) suggested years ago. Although research on human-centered technologies aimed at enhancing human well-being and restoring control over machines is still in its early stages, it has become a growing concern among researchers—even if it has not yet fully penetrated industrial practice (Alves, Lima, and Gaspar 2023). The transition from DTs to ETs mirrors this industrial shift: while DTs represent a crucial step towards a human-centered approach, they remain insufficient to fully realize it. In contrast, ETs explicitly aim to overcome the limitations of DTs and, much like Industry 5.0, are inherently designed within a human-centered framework.

Integrating the human sciences—such as philosophy—into the design and evaluation of ETs is essential for realizing this vision. The ethical landscape of ETs ultimately calls for an *ethics of entanglement*—a framework that recognizes the co-constitutive nature of human–machine relations. Such an ethics rejects both technophilia and technophobia, emphasizing instead reflective engagement with the affordances and limits of digital systems.

Key ethical commitments for ETs design include:

- Transparency and explainability: users should understand how interactional outcomes emerge within the We-subject.
- Accountability structures: clear mechanisms must exist to trace responsibility across human and non-human actors.
- Sustainability and equity: the development and deployment of ETs should prioritize environmental sustainability and social justice.
- Reciprocity and co-adaptation: ETs should be designed to adapt meaningfully to users.
- Emotional and affective attunement: ETs should respect and support the emotional dimensions of human experience.

In this sense, ETs do not propose a future of autonomous machines, nor a return to purely instrumental tools. They invite a reconfiguration of technological agency grounded in presence, interaction, and shared responsibility. By situating ethics at the level of experience rather than abstraction, the ETs framework contributes to a human-centered vision of digital technology that is both philosophically grounded and practically relevant.

3. See: <https://research-and-innovation.ec.europa.eu/research-area/industrial-research-and-innovation/industry-50_en>.

4. Conclusion

The ETs framework invites us to rethink the ontological and ethical stakes of human–machine relations in the age of digital transformation. In contrast to the logic of mirroring that characterizes the DT model, ETs inaugurate a relational paradigm wherein agency, subjectivity, and decision-making are no longer understood as the exclusive prerogative of the human subject, but as relational achievements co-constituted within a We-subjectivity that traverses the boundaries between the organic and the artificial.

This shift, as our phenomenological analysis suggests, is not merely technical but existential. The plural intentionality that emerges in the ETs dynamics is the mark of a subjectivity that is always already relational, attuned to an environment that is both mediated and transformative. In this sense, ETs do not simulate human capacities; rather, they participate in the modulation of human experience, configuring new pathways of perception, action, and meaning. The ICE triad—immersion, coherence, entanglement—crystallizes the conditions under which such hybrid subjectivity can flourish, opening a space where human and machine not only interact but intertwine their agencies.

From an ethical standpoint, the ETs propose a decisive alternative to the phantasm of AGI and its Promethean ambitions of autonomous superintelligence. The ETs refuse the model of mastery—whether human over machine, or machine over human—in favor of an ethics of entanglement, where responsibility is distributed, agency is shared, and reciprocity remains the guiding principle. In the face of the alienation and uncanny relationality often associated with AGI, ETs cultivate a space of intersubjective resonance, where the machine is not positioned as an absolute Other but as a participant of a We-subject in the unfolding of the world.

This reconfiguration aligns with the broader aspirations of Industry 5.0, seeking to overcome the reductionism of machine-centered paradigms in favor of human-centered and socially attuned technologies. In this sense, ETs should be understood as a conceptual framework capable of informing Industry 5.0's human-centered aspirations. Yet, as we have argued, this human-centeredness must itself be rethought—not as a reaffirmation of human exceptionalism, but as a co-constitutive horizon, where the human is always already entangled with the non-human.

In this light, the ETs do not merely extend the capacities of the human; they transform the very conditions of agency, foregrounding the relational matrices from which our actions, decisions, and responsibilities emerge. They challenge us to envision a technological future not dominated by control, prediction, or replication, but animated by co-becoming, ethical accountability, and shared world-making. In an era marked by the rapid evolution of mixed environments, ETs remind us that the future of technology cannot be separated from the future of subjectivity itself and that this future must be shaped, above all, by an ethics of entangled relations.

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