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RESEARCH

Robots with us, not like us: designing robotic otherness through scent in ScentDia

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Abstract
This article addresses the diffusion of social robots not merely as technological innovation, but as an emerging transformation that may reshape human social environments, interactional patterns, and modes of coordination. To orient this transformation towards social sustainability, we propose a twofold contribution grounded in difference and complementarity rather than imitation and substitution. First, we advance a transdisciplinary paradigm for social robotics, termed "robots with us, not like us," articulated through three interconnected components: *peri-human design*, which proposes an alternative to anthropomorphic design based on compatible difference; *perceptual identity markers*, understood as design operators that make robotic otherness perceptually and socially legible while stabilising identity across interactions; and *futuring social robotics*, a synthetic methodology for exploring emerging forms of human–robot sociality. Second, we materialise this paradigm in ScentDia, an artistic social robot that uses scent as a perceptual identity marker to investigate olfaction as a medium of social presence. As it encounters humans, ScentDia modulates specific (non-biological, non-human) olfactory stimuli to signal its robotic identity and establish a clear form of compatible otherness, leveraging olfaction as a channel for recognition, orientation, and affective attunement. Together, the paradigm and its material instantiation introduce *olfactory social robotics* as a programmatic research direction, exploring how a socially sustainable human–robot world may be shaped through the valorisation of difference.

Keywords Social sustainability · Peri-human design · Perceptual identity markers · Futuring social robotics · Olfactory social robotics · Synthetic anthropology · Synthetic ethics

1 Framing a sustainability-oriented inquiry on social robots

1.1 Social robots and the social sustainability challenge

Recent discussions in AI suggest that further progress depends on systems capable of learning through perception, action, and interaction with the physical world (e.g., LeCun 2025). If this trajectory unfolds, it points towards a growing deployment of robots in everyday human environments, including social robots. This development raises still underexplored questions concerning the participation of such agents in human social environments, and what this implies for the sustainability of human social bonds. Within this context, the present article introduces a transdisciplinary, design-oriented paradigm, its first implementation, and a related programmatic research direction aimed at

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promoting socially sustainable forms of human–robot interaction grounded in difference and complementarity.

The most distinctive trait of social robots is that they engage humans through social signals compatible with human modes of social interaction—including gaze, gesture, posture, facial expressions, proxemics, and language (e.g., Fong et al. 2003; Breazeal 2003; Lehmann and Rossi 2020). Increasingly present in domains such as education, therapeutic mediation, care, and companionship, these artefacts are now being empowered by advances in generative AI, which reinforce their capacities for social interaction in real-world settings (e.g., Zhang et al. 2023). On these grounds, their diffusion cannot be reduced to a technological innovation; it may be more appropriately approached as an emergent transformation in socio-technical evolution. As these "social machines" participate in human relational systems, they contribute to the reshaping of interactional modes, forms of coordination, and self-understanding (e.g., Lamola 2022; Šabanović, 2010; Seibt 2018; Seibt and Hakli 2026; Volpe et al. 2020). Under these conditions, the question is not simply how these systems operate within human environments but also who they are to us—and, in turn, who we are becoming through our interactions with them. This introduces a key and still underdeveloped dimension of responsibility in the age of robotics: *social sustainability*, broadly understood as the capacity to preserve and support human social bonds.

The social dimension of sustainability is attracting growing attention in AI research, often linked to ethical design, social inclusion, and fair access to resources in line with the Sustainable Development Goals (e.g., Redko 2023). However, its specific development within the field of social robotics remains limited, despite growing awareness that AI systems are embedded in and can reshape social environments (Sætra 2021). Given the potential implications that social robots may have for human sociality (e.g., Seibt and Hakli 2026), we propose to address their social sustainability through a focused approach. Rather than concentrating primarily on harm reduction or safeguards, the scientific community should also aim to actively preserve and support human social bonds and relational capacities, by enabling forms of robotic presence that participate in, rather than displace, human social dynamics.

The ambition of our work is to address this challenge by advancing four interrelated levels of inquiry in social robotics—philosophical, methodological, implementational and artistic—that collectively articulate a programmatic, hypothesis-generating research direction, which we refer to as the paradigm "robots with us, not like us".

These levels are not conceived as discrete layers or as a progression from abstract theory to applied example. The present contribution proceeds from an epistemological stance grounded in cybernetics and synthetic modelling, as well as in constructivist and enactive epistemologies. Conceptual principles do not precede implementation as external blueprints, but take form through material realisation, and artefacts operate as epistemic probes that refine and transform the theoretical horizon from which they emerge (e.g., Craik 1943; McCulloch 1965; Piaget 1967; Maturana and Varela 1987; Pfeifer and Scheier 2001; Cordeschi 2002; Damiano and Stano 2023; Damiano and Fleres 2026). In line with this stance, philosophical exploration, methodological inquiry, technological construction, and artistic practice operate here as mutually informing dimensions of a single research process, and building *robots with us*, *not like us* is treated as a single epistemic operation articulated across these complementary levels of inquiry.

Where questions of social sustainability are concerned, it is particularly important that philosophical commitments are explicitly embedded in design decisions rather than left implicit or added retrospectively. Presenting them together not only makes this integration visible but also clarifies how these commitments shape the robot's construction and how the constructed robot renders them tangible and available for assessment.

1.2 Levels of the inquiry

At the *philosophical level* (Sects. 2 and 8), we propose a systemic, relational, and pluralist epistemology and ethics of social robotics—the paradigm *robots with us, not like us*. Based on previous work (e.g., Damiano and Dumouchel 2020), we argue that social robots should be conceived as new social actors: agents capable of participating in social coordination dynamics with humans through mechanisms that are different from ours. This view implies a reorientation of social robotics, away from anthropomorphic design, understood here as a design orientation that seeks to render robots socially intelligible primarily through human likeness in appearance, behaviour, or expression. We propose instead what we call "peri-human design," construed as an approach in which robots operate within the same perceptual domains of human social interaction, but shift the guiding principle of design from minimising difference through resemblance to maximising compatible difference as a basis for interactional intelligibility. From this perspective, the future of human–robot sociality lies not in the simulation of human sociality, but in the construction of new forms of social dynamics. This reorientation carries ethical implications. Social robots do not replace human actors, but act as relational partners—distinct agents capable of supporting our capacity for social engagement.

To operationalise the philosophical principles of peri-human design, we introduce the concept of a "perceptual identity marker." This notion refers to a sensory signal that simultaneously manifests the robot's distinct artificial

identity and invites social engagement by leveraging evolved mechanisms of human social cognition. It embodies the epistemological and ethical commitment to difference as a resource: enabling relational compatibility while preserving clear distinctiveness. A perceptual identity marker thus stabilises difference as a condition for coordination rather than imitation.

At the *methodological level* (Sect. 3), we introduce "futuring social robotics" as a transdisciplinary research practice in which robotic, philosophical, and artistic exploration converge to anticipate and prototype forms of cohabitation with artificial agents that still have to come. This approach does not impose normative or pedagogical models, nor prescribe desired outcomes. It creates a context in which people can encounter new robotic social agents through lived interaction: a space that makes future forms of human–robot coexistence both imaginable and experienceable. In this way, futuring social robotics does not build robots to solve predefined problems, but introduces them as generative prototypes that enable participants to experiment with human–robot sociality and position themselves critically and autonomously—not by instruction, but through direct engagement with emerging relational possibilities. Futuring social robotics thereby establishes a situated mode of inquiry through which novel forms of human–robot sociality can be explored in relation to their implications for social sustainability.

At the *implementational level* (Sects. 4–7), our approach is embodied in the robot ScentDia, presented not as a post hoc validation of a prior philosophical thesis, but as a first synthetic construction through which the theoretical commitments of the framework are materially explored. As the first exemplar of peri-human design, ScentDia explores one possible configuration of perceptual identity markers: olfactory stimuli as a medium for robotic social presence, thereby introducing what we term "olfactory social robotics."

The adoption of olfaction is theoretically grounded. We do not treat scent as a privileged or exclusive sensory modality; rather, our approach opens to a plurality of perceptual identity markers that can be articulated and combined. We focus on olfaction as an initial revealing instance of perceptual identity markers, chosen because its structural features make it particularly suited to bring into view the epistemological and ethical commitments of the peri-human framework. First, olfaction operates through distributed persistence: scent extends beyond discrete interactional episodes and configures shared environments over time, allowing a form of identity continuity that does not rely on performative simulation. Second, it is non-iconic: olfactory signals do not depend on morphological resemblance or expressive mimicry to function as identity cues. Third, across biological systems—and crucially across species—olfactory signalling supports recognition and relational orientation without imitation, enabling identification without likeness. Together, these properties allow scent to manifest artificial distinctiveness while simultaneously inviting social engagement, thereby supporting both the perceptual identity marker framework and our account of social sustainability as the preservation and reinforcement of human relational bonds in human–robot ecologies. Accordingly, ScentDia does not simulate human or biological odour signatures. It generates an olfactory presence specific to its artificial identity, thereby expressing difference without imitation and investigating how robotic agents may participate in shared social environments by foregrounding alterity rather than resemblance.

Our exploration of olfaction follows an established trajectory in social robotics. Gaze, gesture, posture, and expressive behaviours were introduced by drawing on models of human and cross-species social signalling (e.g., Breazeal 2003, 2004; Fong et al. 2003; Dautenhahn 2007). These modalities were initially advanced as theoretically grounded design hypotheses and only subsequently subjected to systematic empirical investigation within human–robot interaction research. Olfaction is positioned here within the same epistemic sequence: conceptual grounding, design implementation, and later empirical validation.

At the *artistic level* (Sects. 4–7), our approach is materialised in ScentDia as both a social robot and an installation. Realised through collaboration between robotic art (e.g., Velonaki and Rye 2016), olfactory artistic creation (Gerakinis 2025), and philosophical-ethical design (e.g., Damiano 2021), this robot embodies an aesthetic-epistemological operation: to create a sensory portal into future human–robot social relations. As an art installation, ScentDia is not merely shown, but experienced, offering a space in which humans can encounter and reflect on the social actors of the future. Artistic creation becomes, here, a form of future world-making grounded in experience, interaction, and the material realisation of human–robot social contexts to come.

1.3 Scope and positioning

This article should be read as a pre-HRI, hypothesis-generating and framework-setting contribution. It does not aim to isolate causal effects of olfaction, nor to provide experimental validation of specific interaction outcomes. It articulates a transdisciplinary design and research framework whose purpose is to open and structure a field of inquiry that may subsequently be addressed through controlled and systematic HRI studies. Accordingly, the observations reported from ScentDia's première exhibition are not presented as empirical evidence, but as situated, qualitative, and exploratory material, intended to indicate emerging forms of interaction and research directions rather than to support or test theoretical claims. In this sense, the contribution is positioned as complementary to experimental HRI approaches, as part of an earlier exploratory phase of inquiry.

2 Robots with us, not like us

2.1 Social robots in relational terms

Social robotics has developed as a field at the intersection of embodied approaches to social cognition and the engineering domain of Human–Robot Interaction (HRI). This convergence produced two key traits of the field.

First, social robotics redefines human–robot interaction, shifting from the classical operator–machine model of HRI towards forms of human–robot collaboration grounded in socially meaningful signals (e.g., gaze, gesture, posture). On this basis, social robots are evaluated in terms of "social presence," understood as their capacity to elicit in users the sense of "being with another" (Heerink et al. 2008).

Second, social robotics is structured around two distinct approaches to the design of social robots. The embodied cognitive science tradition, through the cybernetic principle of "understanding by building" (e.g., Cordeschi 2002), supports the construction of robots as artificial models of human social cognition, that is, artefacts that enact and test scientific hypotheses about the mechanisms underlying human social processes. By contrast, the HRI tradition promotes the design of robots capable of engaging humans through socially intelligible behaviours, without reproducing those underlying mechanisms. Following John Searle's terminology, these can be described as the "strong" and the "weak" approaches to social robotics (e.g., Damiano and Dumouchel 2020, 2024), since the former aims to construct genuinely social agents by transferring or modelling human social cognition in artificial systems, while the latter focuses on simulating socially effective behaviours, equipping robots with non-human mechanisms to participate in social interaction.

A central tension in social robotics is that, while the strong approach remains largely an unrealised scientific ambition, the weak approach has proven more effective in practice, shaping the actual diffusion of social robots in real-world settings. This inversion raises a key question about how sociality should be understood and modelled in this field.

Numerous studies have shown that robots developed within the weak approach are often recognised by human users as "social partners." They are perceived neither as human nor animal social beings, nor as mere objects, but as occupying an *in-between zone* defying traditional classifications (e.g., Kahn et al. 2002; Melson et al. 2009; Severson and Carlson 2010; Xiao et al. 2021; Jung and Hahn 2023; Toparlak 2023).

An early and paradigmatic example is Bartok Jr. (Hegel et al. 2006), which mirrors users' emotions not by replicating human physiology, but via a speech-based system that infers affective states and expresses them through facial animation. The success of this and similar robots lies in their ability to participate in human social coordination—such as emotional mirroring—without reproducing the biological bases of human sociality. These examples invite us to rethink how we define and evaluate social agency in robotics, exposing structural tensions between the strong and the weak approaches. As argued elsewhere (e.g., Damiano and Dumouchel 2024), the inversion between the two can be interpreted in different ways. One might explain the practical success of weak robotics as the result of lower technical demands. Yet a more compelling interpretation points to a central epistemological insight: the need to move beyond an individualistic conception of sociality.

Indeed, the current strong/weak distinction assumes sociality to be a set of individual properties that could, in principle, be transferred to artificial systems. In contrast, a systemic perspective conceives sociality not as something an agent possesses, but as a relational phenomenon that emerges through dynamic interaction (e.g., Bateson 1972; Varela 1995; Dumouchel 1995; Gallese 2009). If we adopt this view, sociality is redefined as an agent's ability to participate in circuits of social signalling—based on gaze, posture, timing, and expression—which coordinate the interactors by aligning or opposing their actions (e.g., Damiano and Dumouchel 2026). From this perspective, the success of the weak approach becomes theoretically significant. The strong approach, still tied to an individualistic paradigm, appears conceptually limited in addressing the relational complexity of social life. In contrast, the weak approach—though originally intended as merely functional—emerges as *stronger than the strong*, in two relevant ways. First, it can be interpreted not only as a technological endeavour but also as a scientific one: an implicit application of the *understanding-by-building* method, not at the level of individual cognition, but at the level of interindividual coordination. As we have shown in previous work on the epistemology of synthetic modelling (Damiano and Dumouchel 2020), weak social robots function as scientific models of social interaction dynamics—not of their biological substrates. They embody hypotheses about how social coordination works, typically tested through empirical studies of human–robot interaction. Second, building on this insight, the weak approach succeeds where the strong approach does not. That is, it produces artificial social actors. From a systemic and relational standpoint, weak social robots can be recognised as novel and distinct kinds of social agents: artificial agents capable of participating in coordination dynamics with humans via mechanisms that differ from those of human or animal interactors (e.g., Damiano and Dumouchel 2020, 2024).

This reconceptualisation suggests that defining social robots cannot be a priori or absolute, but must be situated and empirical—shaped by context, users, and interactions. Whether or not a robot is social depends on the

circumstances, not on a fixed set of internal features. Accordingly, the criteria for evaluating social robots must also shift. From a systemic-relational perspective, what matters is not whether a robot possesses human-like social capacities, but whether it contributes to the formation of social dynamics through signalling and coordination. In this view, the question is not whether a robot *is* social in itself, but whether it *does* sociality in context.

We believe this approach better reflects how humans relate to robots and effectively supports their integration into our evolving social landscapes. It introduces diversity and, more precisely, a form of pluralism into the taxonomy of social agents. This pluralism is not to be understood in terms of user diversity or variability of interaction contexts, as often addressed in HRI research (Esterwood et al. 2021; Søraa et al. 2023). We construe it as a plurality of forms of social agency and coordination grounded in the coexistence of heterogeneous—human and robotic—agents, and in the non-equivalent mechanisms and modes through which they participate in social interaction. Within this perspective, social robots *need not*—and, as we argue, *should not*—reproduce human sociality to engage with humans meaningfully. This view enables a critical ethical framework moving beyond the merely prohibitive logic that too often dominates ethical discourse on social robots.

2.2 Synthetic anthropology and ethics

Seen from a relational perspective, weak social robotics—the approach currently driving the diffusion of robots in real-world settings—reveals a different picture of our future with social robots. The diffusion that may lie ahead can be interpreted not only as a socially impactful wave of technological innovation, but also as an *understanding-by-building* process unfolding at scale, in which hypotheses about social coordination are effectively tested in real-world conditions. Each social robot deployed in private or public contexts embodies assumptions about social coordination, turning its integration into a potential exploration of those assumptions in situated contexts.

From this angle, implementational social robotics is not just a branch of engineering but an *understanding-by-building science*—a "synthetic anthropology." That is, an experimental practice that studies us, humans, and our forms of sociality by constructing robotic agents capable of interacting with us (e.g., Damiano and Dumouchel 2018). Crucially, this anthropology is not only epistemic but also transformative. It concerns not only who we are as social beings, but also who we are becoming—and who we may wish to become—through the creation, deployment, and integration of robotic social agents. This process of self-transformation can be more appropriately construed not merely at the individual level but also at cultural and systemic levels, reshaping societal boundaries (e.g., Lamola 2022; Fleres and Damiano 2025). In this sense, weak social robotics becomes a means of self-knowledge through a dynamic of self-transformation.

As robotic agents enter our interactional spaces, they tend to affect how we perceive ourselves, how we relate to others, and how we shape our shared social world (e.g., Seibt and Hakli 2026). This transformation leads us towards a future that, far from merely extending the present (Morton 2018), is *deep future*, in the sense of an open-ended, co-constructed, and uncertain horizon. Indeed, we cannot fully predict or grasp the unfolding of the changes produced by social robots, because the very process through which we come to better understand ourselves is also the process through which we transform ourselves by creating, deploying, and engaging with them.

The key question, then, is whether this dynamic can be steered towards social sustainability. We propose that it can be. It is possible to generate virtuous loops between what we learn about ourselves through social robots and how we evolve through our engagement with these machines. And we believe this potential extends directly to the ethical domain.

The first lesson of *synthetic anthropology* is that robots can become social actors by participating in relational coordination through alternative, non-human mechanisms. This insight breaks the anthropocentric monopoly on social agency and enables a shift from purely negative ethical framings to a constructive paradigm.

These dominant framings—which we have described elsewhere as purely negative ethics (e.g., Damiano and Dumouchel 2018) —are typically articulated around risks of substitution and deception (e.g., Danaher 2019; Torras 2024). While often motivated by legitimate concerns, such critiques express predominantly precautionary approaches. They are formulated after robots have been developed, yet offer little capacity to influence their design in meaningful or generative ways. Worse, their purely prohibitive logic and lack of constructive engagement risk leaving social robotics without dedicated ethical guidance, thereby opening the field to market-driven dynamics or ad hoc value systems.

This calls for a "synthetic ethics." Building on the epistemological shift from individualistic to relational models of sociality, *synthetic ethics* extends the *understanding-by-building* paradigm into the ethical domain (e.g., Dumouchel and Damiano 2017; Damiano and Dumouchel 2024, 2026). It emerges as a transdisciplinary and proactive engagement—to be integrated in the practice of social robotics—aimed at transforming encounters between humans and under-construction robotic agents into an opportunity for empirical inquiry. These encounters become experimental situations through which we can better understand how we behave, feel, and co-orient in the presence of artificial social

others—and, simultaneously, refine the ethical dimension of robot design in response to those situated dynamics. Synthetic ethics, in this sense, is not a normative stance based on predefined principles, but a methodological framework: a way to construct ethical meaning and relevance in context, through interaction. It transforms the uncertainty surrounding emerging human–robot relations not into a problem to be solved once and for all, but into a generative space of reflection, orientation, and co-evolution.

The core ethical principle that synthetic ethics inherits from synthetic anthropology is this: if robots are recognised as different kinds of social actors, then they *cannot and should not* be conceived as substitutes for humans, not merely as simulators, but as participants in our evolving social landscapes. This principle, far from being rhetorical, provides a concrete criterion for evaluating the social sustainability of robotics, as defined earlier in this article: a robot is socially sustainable when it contributes to the preservation and strengthening of human social bonds and relational capacities. This emphasises the ethical importance of *differentiation* between humans and artificial agents. Because social robots operate through different mechanisms and give rise to different forms of interaction, they should not aim at mimicry, but at compatible alterity—forms of difference that can sustain relational engagement without confusion. *Designing for difference, not imitation*, avoids risks of negative ethical framings: illusion of human presence, erosion of authentic relations, and role replacement. It is also what enables robots to engage us meaningfully, while contributing to the diversity, intelligibility, and resilience of the social world.

2.3 Towards implementation: peri-human design and perceptual markers

To move concretely beyond mimicry, we translate the philosophical framework described above into two epistemological and ethical notions for the design of social robots.

The first concept is *peri-human design*, defining a domain in which robots engage with humans not by reproducing human features, as in anthropomorphic design, but by activating relational dynamics through distinct modalities of presence grounded in compatible difference. The prefix *peri-* (from the Greek *perí*, meaning "around" or "near") indicates a space that approaches the human without coinciding with it: a liminal zone in which social interaction can be sustained through compatible difference rather than resemblance. Importantly, this does not imply moving outside the perceptual domains through which human social interaction is ordinarily organised, but reconfiguring how these domains are mobilised in design. Peri-human design operates within those same domains as fields of compatibility, while shifting the guiding principle of design from minimising difference through resemblance to maximising compatible difference as the basis for interactional intelligibility. Within this space, difference becomes a design resource, enabling robots to participate in social coordination without relying on anthropomorphic simulation. This corresponds to the deliberate use of non-human forms of presence as a positive design constraint guiding interaction beyond resemblance.

The second concept is *perceptual identity marker*, defined as a deliberately designed sensory signal that manifests the robot's artificial identity while anchoring interaction in evolved mechanisms of human social cognition. Crucially, a perceptual identity marker does not correspond to any sensory feature as such, but to the relational function a signal performs: sustaining a recognisable and coherent interactional identity across encounters. Such markers render a robot's alterity intelligible and socially readable, not by approximating human morphology or expression, but by stabilising distinctive perceptual regularities within shared domains of interaction, without inducing illusion or confusion about its nature as an artificial agent. Potential instantiations of perceptual identity markers include non-biological tactile feedback, thermal or auditory signals, rhythmic micro-movements, and—as in the present work—olfactory cues. On these grounds, peri-human design is not simply an alternative to anthropomorphic design, but a complementary one. It does not seek to replace anthropomorphic design altogether, but to complement it by combining perceptual identity markers that foreground artificial identity through difference with any anthropomorphic cues.

At this stage, peri-human design and perceptual identity markers should be understood as heuristic rather than operational. A useful parallel can be drawn with Masahiro Mori's original formulation of the uncanny valley (Mori 1970), which did not introduce measurable design criteria, but articulated a robust relational phenomenon. Mori identified a breakdown of familiarity arising when an artefact elicits strong social expectations that it cannot coherently sustain across modalities and over time—an effect he explicitly shows to be intensified by movement. As Mori emphasised, the issue is not human likeness per se, but the instability of social affinity produced when perceptual, behavioural, and temporal cues fail to align (Mori 1970).

Reframed in relational terms, this insight suggests that familiarity is not a function of resemblance, but of whether an encountered agent remains socially interpretable within coordination dynamics (e.g., Damiano and Dumouchel 2024, 2026). In this sense, uncanny responses can be interpreted as disruptions of social coordination rather than as reactions to difference as such. The peri-human design and perceptual identity markers are introduced in this same epistemic spirit: not as prescriptions or metrics, but as orienting principles that redirect design away from mimicry and towards compatible difference—forms of recognisably non-human presence

capable of stabilising interaction without generating the perturbing ambiguities typically associated with near-human simulation.

This perspective differs from anthropomorphisation-based accounts of human–robot engagement (e.g., Epley et al. 2007), which frame social attribution primarily as a projection of human traits (Damiano and Dumouchel 2018). In contrast, the peri-human design proposed here treats sociality as emerging from coordination grounded in difference rather than similarity, without relying on the attribution of human-like properties to the robot.

Together, the notions of peri-human design and perceptual identity marker support differentiated interaction and help address the key risks often emphasised by critical ethical framings—namely, deception and substitution—not through exclusion, but through design. By fostering perceivable and intelligible difference, these concepts contribute to socially sustainable forms of human–robot coexistence, grounded in pluralism rather than imitation.

A systematic theoretical and applicative development of the relations between peri-human design, perceptual identity markers, pluralist models of social coordination, and the uncanny valley—that is, of the broader paradigm *robots with us, not like us*—lies beyond the scope of the present article and constitutes the focus of ongoing work (e.g., Damiano 2026; Damiano et al. 2026). Here, we concentrate on articulating and exploring these notions within an explicitly exploratory and synthetic research framework, using ScentDia as a situated case through which such principles can be enacted and examined.

3 A synthetic research framework: futuring social robotics

3.1 Social robotics as a synthetic research laboratory

Building on the philosophical grounding defined above, our work approaches social robotics as a synthetic research laboratory, that is, as a domain in which robotic artefacts function as instruments for probing and reflecting on human sociality, intersubjectivity, and cohabitation. Within this perspective, the robot is not conceived as a solution to a pregiven problem, but as a generative perturbation: a novel form of social presence that brings into view fundamental and open questions, such as what counts as a social being and what forms social coexistence may take. These questions cannot be exhaustively specified in advance, nor fully addressed through predefined hypotheses, fixed validation protocols, or standard performance metrics alone. They require an initial phase of situated, exploratory inquiry, focused on lived experiences of relational (affective, aesthetic, cognitive) engagement.

This exploratory phase is not positioned in opposition to experimental Human–Robot Interaction (HRI), but as complementary and prior to it. Its role is to articulate interactional variables, conceptual distinctions, and design questions that can later be investigated through controlled and systematic empirical studies. In this sense, the present contribution is intentionally *pre-metric* rather than *anti-metric*: it precedes and informs experimental HRI research by opening a space in which forms of interaction are first made perceptible and available for analysis.

Traditional HRI research typically operates within experimental paradigms aimed at evaluating performance, acceptance, and efficacy. While essential for applied development, such paradigms are limited when it comes to exploring radical conceptual shifts and reconfigurations of sociality. When social robotics is approached from a relational and pluralist perspective, interaction cannot only be tested; it must also be invented. This requires epistemic conditions in which meaning is not only measured but also allowed to emerge through open-ended encounters, making it possible to explore novel configurations of human–robot cohabitation and their implications for social sustainability.

3.2 Futuring social robotics as a synthetic approach

Within this epistemic orientation, we articulate a transdisciplinary methodology that we term *futuring social robotics*. This approach builds on the synthetic approach, as well as on the notions of synthetic anthropology and synthetic ethics introduced in Sect. 2.

Rooted in the principle of *understanding-by-building*, the synthetic approach has developed across multiple domains—from early cybernetics to embodied AI, Artificial Life, and synthetic biology—as a methodology that investigates complex phenomena by constructing material systems that enact theoretical hypotheses under specific constraints (Langton 1989; Damiano and Stano 2023). Rather than reproducing natural systems in their entirety, it generates operational models through which the mechanisms of life, cognition, and sociality can be explored as they are and as they could be.

Futuring social robotics extends this logic to the domain of social interaction to come. It does not aim at simulating human sociality, but at instantiating possible forms of human–robot social interaction, in which new configurations of presence, coordination, and experiential engagement can be explored. In this framework, robotic, artistic, and philosophical inquiries converge in a mode of investigation that uses robotic artefacts as epistemic operators: material systems through which hypotheses about sociality are enacted and made experientially accessible.

While sharing with speculative and critical design an interest in opening alternative futures (Dunne and Raby 2013), futuring social robotics is distinguished by its explicit commitment to material prototyping and situated interaction. The futures it explores are not only imagined but also enacted, through concrete configurations in which humans and robots enter shared perceptual and relational environments. In this sense, the robot functions as an epistemic artefact—a "revealing machine" in Pickering's sense (2010)—whose value lies not primarily in functional performance, but in its capacity to disclose new experiential, conceptual, and applicative trajectories for human–robot sociality.

This orientation resonates with ongoing initiatives at the intersection of art, technology, and research—including S + T + ARTS (European Commission 2016), Making Futures (2024), the Manifesto of Artistic Research (Henke et al. 2020), SymbioticA (Morisson 2018), and Art-Based Research (Leavy 2020), among others. However, futuring social robotics departs from these trajectories in a crucial respect. It treats artistic and philosophical inquiry not only as modes of reflection or critique but also as constitutive components of a synthetic methodology, in which robotic artefacts are developed as operational models of social interaction. In doing so, it foregrounds the epistemological and ethical stakes of social robotics, positioning design as a site for prototyping socially sustainable human–robot ecologies.

3.3 Research questions and orientation

As an expression of the theoretical and methodological framework outlined above, our work is guided by a set of open-ended questions rather than fixed hypotheses.

> How can a robot become socially legible within a peri-human design space, through compatible difference rather than anthropomorphic mimicry as the primary ground of interaction?
> Can olfaction operate as a perceptual identity marker that supports social coordination?
> What forms of presence, engagement, and interpretation emerge in encounters with an olfactorily expressive peri-human robot?
> What directions for socially sustainable HRI can be generated from this exploratory setup?

Together, these questions define the direction of the current exploratory stage of the ScentDia project, in which the robot is construed as the concrete locus of this inquiry: an artefact through which peri-human design and perceptual identity markers are not treated as abstract notions, but are explored through their material configuration, multisensory expression, and situated exhibition.

The following sections articulate how this direction is specified in practice, by detailing the design, implementation, and deployment choices through which olfactory social presence is constructed and made available for investigation.

4 ScentDia: the Diamandini series at an olfactory turn

4.1 The Diamandini series

The Diamandini series (2011–2025), initiated by Mari Velonaki, represents a long-term artistic and epistemological exploration of robotic presence, affect, and intercorporeality. Since its inception, it has investigated the forms of embodied relation possible between humans and robots, employing materiality, ambiguity, and slowness as relational strategies.

The first Diamandini robot (2011), developed with the support of the Australian Council for the Arts and the Australian Research Council at the Australian Centre for Field Robotics (University of Sydney), was conceived as an interactive installation exploring implicit modes of communication through movement (Fig. 1). Its sculptural figure, with a porcelain-like finish, diverged from stereotypical humanoid robots while echoing the human form (Silvera-Tawil et al. 2015; Velonaki and Rye 2016). A patented omnidirectional motion base enabled smooth, gliding movement across changes in direction and velocity. Through subtle, non-verbal gestures, material ambiguity, and slow motion, the robot produced an unsettling yet compelling presence, resisting anthropomorphic mimicry while sustaining social tension and curiosity. It was conceived not as a tool, but as an embodiment of otherness—an early exploration of what we now describe as peri-human design, where difference becomes a resource for relational engagement.

Over time, the series evolved from direct physical proximity to ambient and distributed presence. The second iteration, *Diamandini Revisited: In Conversation…* (2024), was commissioned for the opening of the new National Communications Museum in Melbourne and developed at the Creative Robotics Lab (National Facility for Human–Robot Interaction Research, University of New South Wales, UNSW, Sydney). This version introduced sonic presence through a distributed sound system, enabling a dialogic exchange with George the Australian Speaking Clock (1954) within a shared museum environment (Fig. 2). This marked an early instance of a robotic body generating a distributed soundscape, where movement and sound were intertwined in real time (Robinson et al. 2022).

This configuration shifted the focus from embodied expressivity to perceptual coupling, introducing an early form of *peri-presence*: a mode of robotic presence grounded in co-sensing, resonance, and multisensory engagement.

Fig. 1 *Diamandini* (2011), the inaugural piece of the *Diamandini series*

Fig. 2 *Diamandini Revisited: In Conversation…* (2024), extending the series into distributed sonic presence within a museum environment

4.2 ScentDia: Diamandini's olfactory turn

Developed in 2025 as part of the Diamandini series, ScentDia marks an explicit materialisation of the paradigm *robots with us, not like us*, introducing olfactory stimuli as a medium for crafting robotic presence within a multisensory constellation of movement, sound, and scent.

The choice of olfaction aligns with a broader trajectory of olfactory experimentation across art, technology, and robotics. Within the artistic domain, Hiroshi Koyama's olfactory sculptures evoke memory and affect through static scent compositions (Jaquet 2022; Olfactory Research Network 2022). In contrast, ScentDia mobilises scent dynamically: it becomes a moving, performative element inscribed in spatial and social interaction. A similar cultural turn appears in immersive media, where scent is used to enhance environmental realism (Rogers 2025). However, while such applications treat olfaction as perceptual augmentation, ScentDia adopts a generative stance, using scent to create relational dynamics rather than simulate existing environments. In parallel, robotics has explored olfactory sensing, for instance through insect-inspired electroantennogram systems (Martínez et al. 2014). Unlike these perceptual approaches, ScentDia actively emits scent as a form of social presence, structuring interaction through a distributed olfactory field.

What distinguishes olfaction in ScentDia is that scent is treated not as decoration, but as a perceptual identity marker: a non-iconic and environmentally diffused signal that invites interaction while maintaining robotic otherness.

5 Towards olfactory social robotics: scent and sociality

5.1 Olfaction as a cross-species infrastructure for social signaling

Olfaction is not an arbitrary channel for exploring robotic social presence. Across biological systems, it already functions as a medium through which organisms signal identity, state, orientation, and relational relevance. For this reason, it offers a plausible basis for social signalling

that does not depend on morphological resemblance or symbolic communication.

This role is evident across multiple domains. In plants, volatile organic compounds enable forms of chemical signalling related to threats, resources, and pollination, supporting coordination without nervous systems (Pierik et al. 2012; Conchou et al. 2019). In animals, olfactory cues convey identity, kinship, reproductive status, and affective states, shaping behaviours such as mating, cooperation, parental care, and social recognition (Brennan and Kendrick 2006; Ferguson et al. 2001; Almeida-Santos et al. 2019). In humans, olfaction remains deeply integrated with memory, emotion, and decision-making, contributing to attraction, kin recognition, and affective attunement (Cann and Ross 1989; Shepherd 2004; Olsson et al. 2006). Importantly, olfactory signalling also operates in cross-species contexts, including interspecific recognition, predator–prey dynamics, and ecological coordination networks (Jones et al. 2016; Naves-Alegre et al. 2022).

What matters here is that olfaction supports socially relevant differentiation across heterogeneous agents. It enables recognition and orientation through cues that are non-iconic, environmentally distributed, and often effective beyond the boundaries of a single species. In this respect, olfaction differs from channels such as facial expression, gaze, or speech, which are more tightly bound to species-specific morphologies and expressive repertoires. This continuity is summarised in Table 1.

Together, these elements make olfaction a strong candidate for robotic social signalling. Its relevance lies not in any claim of sensory privilege, but in the fact that it already operates as a durable and socially meaningful infrastructure for recognition, differentiation, and orientation across diverse forms of life.

5.2 Olfaction as scaffolding for difference in human–robot sociality

In ScentDia, olfaction is introduced not to function as a symbolic message or as a representation of inner states. Its role is to provide the robot with a consistent perceptual signature through which its presence can be sensed, remembered, and anticipated. What is stabilised in this way is not a human-like actor, but a distinct relational profile. In this sense, while scent is introduced in ScentDia as a perceptual identity marker, its distributed and persistent character also enables it to function as an atmospheric condition of co-presence. These two dimensions are complementary rather than alternative: the perceptual identity marker supports the robot's recognisability across encounters, while atmospheric diffusion shapes the shared relational environment in which coordination unfolds.

This dual function is particularly well supported by olfactory presence, since it is not confined to the robot's body or to a single interactional instant. By diffusing in space and lingering over time, scent contributes to the formation of a shared perceptual environment in which the robot can become recognisable in its otherness through recurrence. In ScentDia, this olfactory dimension is coordinated with movement, sound, and spatial positioning, so that presence emerges through a multisensory configuration (O'Callaghan 2016). Moreover, olfactory cues operate not only as immediate signals but also as atmospheric conditions capable of modulating affect, attention, and social alignment over time (Kiyokawa et al. 2012; Croijmans et al. 2022).

Under these conditions, olfaction scaffolds continuity, difference, and social legibility. It allows the robot's presence to persist beyond discrete episodes of contact, making this agent perceptually trackable and relationally intelligible based on the establishment of an explicitly artificial identity.

In this sense, olfaction does not add an expressive layer to an otherwise complete interaction, but operates as a structuring condition for presence within the peri-human

Table 1 Olfaction as a cross-species social signalling infrastructure

Domain	Main social function of olfaction	Type of signalling	Relevance for olfactory social robotics
Plants	Signalling threats, resources, pollination conditions	Chemical coordination without nervous systems	Indicates that coordination can emerge without representation or shared morphology
Non-Human Animals	Conveying identity, kinship, reproductive status, affect	Recognition, differentiation, behavioural coupling	Supports identity-based coordination through non-iconic and non-morphological cues
Humans	Shaping attraction, memory, affective attunement, kin recognition	Implicit, affective, socially modulating cues	Grounds social perception in non-verbal and distributed perceptual signals
Cross-species contexts	Mediating interspecific recognition and ecological interaction	Predator–prey, scavenging, interspecific orientation	Suggests that olfactory signalling can sustain coordination across heterogeneous agents

design space. In ScentDia, it functions as a way of organising how a distinct robotic presence persists, spreads, and becomes perceptually available in a shared human–robot environment. As a first realisation of the *robots with us, not like us* paradigm, ScentDia introduces olfactory social robotics as a programmatic research direction.

6 ScentDia's olfactory identity, presence and interaction dynamics

6.1 Olfactory identity

ScentDia's olfactory identity was developed through a dedicated design process led by olfactory designer Manos Gerakinis, founder of Manos Gerakinis Parfums, together with the perfume team of Vioryl (Gane et al. 2013). The aim was to create a scent capable of functioning as a perceptual identity marker—in this case, an olfactory identity marker—deliberately diverging from familiar human and cosmetic fragrances. Introducing scent was therefore not merely a matter of assigning the robot its olfactory identity, but also of recognising that robotic embodiment is never perceptually neutral.

In the absence of an established tradition of olfactory design in robotics, the scent was conceived as a symbolic and genealogical marker of presence, drawing on material, aesthetic, cultural, and historical references. It reflects ScentDia's dual lineage: its robotic form, conceived in Australia, and its olfactory identity, shaped in Greece. The composition blends cypriol and sandalwood with oakmoss and citrus, linking the robot's Australian origin with the context in which its scent was crafted. It also draws on a symbolic reconstruction of Greek automata mythology—from Hephaestus and his golden maidens to the archaic *kore* figure that informed the robot's aesthetics. These references informed the design process, but were not intended as interactional cues or as a basis for attributing human-like meaning during the exhibition.

The resulting scent emits a subtle metallic aura—both earthy and synthetic—designed not for conventional pleasantness, but as a distributed atmospheric presence that marks the robot's passage through the perceptual field without relying on visual or linguistic cues. In this sense, the fragrance functions not as an accessory, but as relational scaffolding, anchoring the robot's presence in the social world while remaining open to interpretation. In this way, scent materially supports distinction, recognition, and continuity of presence across encounters.

6.2 Olfactory presence and diffusion

ScentDia's scent system was conceived as a material experiment in *peri-presence*: a distributed, multisensory mode of presence that lingers in space and time, resonates with human perception, and asserts the robot's otherness—even when it has physically moved on. The system was designed not simply to add an olfactory element but also to create an *atmospheric landscape*: an asymmetric, temporal, transitory trace that extends the robot's presence beyond its body and inscribes it into the sensory ecology of the environment.

Designing such a presence meant overcoming significant constraints. Conventional delivery mechanisms—relying on alcohol, water, or heat—were excluded because they risked damaging electronics and flooding the space with an overpowering, uniform scent. To address these challenges, the Creative Robotics Lab developed a custom device that releases subtle, synchronised trails of scent aligned with the robot's movements and interaction cues. The emitter was deliberately positioned at the rear of the robot, enabling it to leave an olfactory trail as it moved through the environment. This decision ensured that the scent unfolded as a trace rather than a cloud, marking the robot's passage without saturating the space—and enhancing the asymmetry of its presence.

This rear-positioned, trailing emission reflects a deeper design logic. It materialises the idea of a robot that engages relationally without confronting directly, asserting its distinct identity through a presence that is felt rather than imposed. The design draws on biological paradigms of scent-marking and social signalling, where individuals leave traces that communicate identity, territory, and emotion beyond immediate contact. At the same time, it resonates with cultural practices such as the *sillage* of perfume—a crafted olfactory trail that evokes intimacy, memory, and difference. The scent system thus bridges biological, anthropological, technological, and artistic dimensions, inhabiting a peri-human space where natural and cultural registers intersect to create a novel form of social presence.

The resulting scent-scape transforms key aspects of biological and cultural olfactory presence—persistence, diffusion, and emotional resonance—into a uniquely robotic modality. As in previous iterations of the Diamandini series, where sound extended the robot's presence through distributed resonance, scent here unfolds atmospherically and temporally, engaging humans through a distributed social signal that is unfamiliar yet legible. In doing so, the system enacts the principles of perceptual identity marker and peri-human design: it performs difference as a condition for connection, inscribing the robot's path in the interactional field and anchoring its presence within a multisensory social ecology. This perspective also opens a line of inquiry into shared *olfactory ecologies*, in which multiple human and

Table 2 Olfactory interaction principles in ScentDia

Principle	Operational dimension	Interactional effect	Relevance for peri-human design
Temporal relational proximity	Emission probability increases with dwell time near the robot	Duration becomes a criterion for engagement rather than explicit signalling	Interaction grounded in temporal co-presence as a basis for coordination, rather than discrete command-based exchange
Movement quality sensitivity	Variations in visitors' movement (smooth vs abrupt) influence emission and robot trajectory	Visitors' behaviour modulates the rhythm of interaction	Coordination emerging through mutual adjustment within a shared perceptual field, rather than recognition of predefined signals
Initiation of contact	Emission after periods without nearby interaction	The robot signals presence and invites attention without direct address	Engagement initiated through an olfactory perceptual identity marker, without reliance on direct addressing or representational cues
Departure cue	Emission during pivot-and-leave manoeuvres	Withdrawal becomes perceptually legible and structured	Disengagement structured as part of ongoing coordination dynamics, rather than interruption of interaction
Environmental regulation	Emission frequency adjusted to visitor density and spatial distribution	Maintains atmospheric legibility and prevents saturation	Interaction distributed across a shared environment, enabling non-dyadic and ecologically situated coordination

robotic olfactory presences may dynamically co-configure a common perceptual environment.

More than a signal of identity, the scent system contributes to the emergence of a novel kind of social actor: a robotic participant in the multispecies ecology of interaction. By harnessing olfaction's cross-species power to evoke recognition, memory, and affect, the robot situates itself as a distinct yet compatible partner in human social life. This extension of olfaction into human–robot social interaction exemplifies the ambition of the paradigm *robots with us, not like us*: creating robotic partners that are different yet attuned, capable of co-shaping shared social worlds through perceptual and affective resonance. In this sense, scent becomes not merely a medium of presence but a sensory passage into a more plural human–robot sociality.

6.3 Olfactory interaction design

In ScentDia, interaction is organised around spatial–temporal relations that structure how the robot becomes perceptible in the shared environment. Distance and duration function as primary variables of engagement, rather than gesture, expression, and other anthropomorphic cues.

Operationally, the scent module is integrated into the same control architecture that governs ScentDia's omnidirectional motion and sound. The system does not modulate the quantity of fragrance released, but regulates emission frequency in relation to social parameters detected in the environment (visitor density, proximity, and dwell time). To avoid saturation, the robot maintains a short-term memory of recent emissions and combines it with data from external cameras that estimate the number and spatial distribution of people in the exhibition space. Because olfactory interaction is spatially distributed and cumulative, regulating emission frequency requires a global estimate of occupancy and flow to avoid plume build-up. Four external cameras provided stable full-field coverage of the exhibition area independently of the robot's self-motion, enabling consistent scheduling of short pulses and helping maintain a trailing *sillage*. External cameras were preferred over integrated vision because they ensured reliable coverage of the exhibition space, reduced the technical load on the robot, and privileged olfactory presence as the central medium of interaction, allowing scent emission to remain the primary channel through which social engagement was structured.

In line with this design, ScentDia's responsivity does not rely on recognising gestures, faces, or verbal input. Instead, its interaction is modulated by spatial–temporal parameters—such as proximity, dwell time, and occupancy patterns—which regulate how movement and olfactory emission are coordinated in the shared space. Accordingly, ScentDia's interactional dynamics unfold through the principles given in Table 2.

These principles do not define fixed interaction rules, but describe a relational logic through which olfactory presence, movement, and environmental conditions co-structure social engagement in the peri-human design space.

7 Staging co-presence: a synthetic ecosystem

7.1 The première setting and olfactory proxemics

The première of ScentDia took place on February 21 2025 at the National Museum of Science and Technology "Leonardo da Vinci" in Milan. The robot was exhibited for ten days in the Polene Hall, a large gallery dedicated to the carved figureheads of historical ships, whose spatial and atmospheric qualities contributed to shaping the perceptual conditions

of the installation (Fig. 3). The public introduction was held in the Count Biancamano Hall, aboard the reconstructed bridge of a 1920s ocean liner, a setting that aligned with the project's broader concern with orientation, trajectory, and distributed presence.

The première was staged as a synthetic ecosystem: an open interactional environment in which human and robotic agents shared a perceptual space without predefined interaction scripts or task-oriented protocols. The robot operated within a delimited interaction zone, while an external vision system tracked visitor trajectories, enabling autonomous movement based on proximity and orientation. Olfactory stimuli were released intermittently, synchronised with movement and ambient conditions, generating distributed and ephemeral markers of presence across the shared environment.

Within this configuration, interaction did not unfold as a sequence of discrete exchanges, but as continuous modulation of a shared perceptual field. Scent emissions reconfigured the environment over time, prompting visitors to adjust distance, orientation, and duration of co-presence. Engagement emerged through micro-adjustments rather than explicit signalling, with coordination distributed across space and time rather than localised in face-to-face interaction.

We interpret these dynamics as an instance of *olfactory proxemics*: the structuring of distance, alignment, and passage through temporally coordinated olfactory cues. Extending proxemic theories traditionally grounded in visual, postural, and linguistic signals (Mumm and Mutlu 2011), olfactory proxemics operates through distributed and lingering markers that shape interaction at the level of shared atmosphere rather than discrete communicative acts.

In this register, the robot does not mirror human expressions or rely on symbolic exchange. Instead, it modulates a perceptual trace unfolding in time, to which humans respond through adjustments in posture, pacing, and spatial positioning. This interactional asymmetry—grounded in different modalities of perception and expression—opens a relational field in which coordination does not depend on equivalence or simulation, but on compatible difference.

These dynamics suggest that social coordination can emerge from non-representational forms of signalling distributed across a shared, affectively modulated environment. In this sense, ScentDia's olfactory social presence may be understood as activating minimal forms of relational attunement, consistent with what we have elsewhere described as artificial empathy (e.g., Damiano et al. 2015; Dumouchel and Damiano 2017), without relying on mimicry or internal state attribution.

Fig. 3 *ScentDia (2025)*, introducing olfactory presence in social robotics as a perceptual identity marker

7.2 Olfactory interaction in situ: field notes and open questions

In line with the methodological approach outlined in Sect. 3.3, we collected exploratory, non-systematic observational field notes during the première and the subsequent ten-day exhibition. The aim was not to produce controlled or generalisable evidence, but to document how ScentDia's olfactory presence was engaged with in a situated, open-ended environment.

Observations were guided by heuristic behavioural dimensions derived from the olfactory interaction design (Sect. 6.3), including approach and yielding behaviour, spatial positioning, duration of proximity, and responses to scent emission and trajectory changes.

The material is presented in three steps: (A) recurrent interactional configurations, (B) illustrative episodes, and (C) prospective lines of inquiry for future HRI studies.

7.2.1 Interactional configurations noted across the exhibition

The configurations reported below are used as descriptive labels to organise recurrent observations. They are not intended as formal categories or measured behavioural patterns, but as heuristic ways of making situated interactional dynamics legible within the framework introduced above.

Across the exhibition, these configurations were not isolated events but unfolded through small, recurrent adjustments in visitor behaviour—including brief verbal attributions, pauses within the robot's wake, side-by-side pacing, and spatial yielding during trajectory changes (Table 3).

7.2.2 Illustrative episodes

The following episodes are presented as illustrative examples drawn from field notes, without claims of representativeness or frequency.

Close inspection by children. During a primary-school visit (~ 15–20 children), several approached the robot from behind (where the emission module is located), inhaled during a short pulse, lingered, and repeatedly referred to "the robot's smell," showing sustained engagement.

Playful interaction. A visitor kneeled and staged a mock proposal to the robot after commenting on its scent, suggesting role attribution and addressability without reliance on facial or linguistic cues.

Interspecies curiosity. Across multiple days, the resident museum cat repeatedly followed segments of the robot's recent path and paused in areas where scent had just been released (as reported by museum staff).

7.2.3 From observations towards HRI: emerging questions

Coherently with our methodological approach, the material collected during the première and the ten-day exhibition should be understood as exploratory and preliminary. These observational field notes provide situated insights into how visitors engaged with ScentDia's olfactory presence, but they do not constitute systematic HRI data and are not intended as empirical validation.

Their role is instead to articulate an initial exploratory layer within a futuring stage of research, in which relational dynamics are made observable and rendered available for further investigation. In this sense, the exhibition contributes by making interactional dynamics traceable, identifying variables that can inform the design of subsequent controlled HRI studies, and providing a situated basis for considering how such interactional configurations may relate to questions of social sustainability. Accordingly, the prospective research directions summarised in Table 4 translate these recurrent interactional configurations into candidate variables for future HRI investigation.

The lines of inquiry outlined here are intentionally conceptual and are meant to inform subsequent experimental work. Accordingly, operational parameters (e.g. timing, distance, occupancy, and dwell time) will be specified in dedicated HRI studies.

8 Robotic presence from perceptual identity to co-regulation

8.1 Scent from identity to co-regulation

In ScentDia, scent has been established as a stable perceptual identity that renders the robot's presence recognisable

Table 3 Interactional configurations observed during ScentDia's exhibition

Configuration	What was observed	Relevance for HRI
Transition-coupled attribution	Scent linked to the robot during approach and especially withdrawal	Identity legibility emerging at interactional transitions through an olfactory perceptual identity marker
Wake tracking (sillage windows)	Visitors paused or repositioned within the robot's olfactory trail	Spatial memory and distributed tracking of the robot's identity within the shared environment
Parallel co-presence	Side-by-side pacing with alignment in speed and orientation	Coordination through non-verbal and non-representational dynamics of co-presence
Temporal engagement patterns	Repeated or prolonged proximity preceding approach behaviour	Temporal coupling as a basis for interactional coordination
Disengagement as cue	Emission during pivot-and-leave associated with yielding and space reopening	Turn-taking and coordination structured through olfactory signalling
Ambient diffusion under crowding	Scent becoming diffuse background at peak density	Environmental constraints and saturation effects in olfactory interaction
Boundary cases	No visible reaction in some passes	Detection thresholds and environmental masking of olfactory signals

Table 4 Prospective lines of inquiry for future HRI studies

Research focus	Question	Relevance for HRI
Legibility at transitions	Compare attribution of scent when emissions are aligned with approach/withdrawal versus non-aligned conditions	Transitions as privileged moments for identity legibility through an olfactory perceptual identity marker
Co-presence structuring	Assess whether emission timing correlates with dwell time and spatial alignment	Olfactory cues as scaffolding mechanisms for side-by-side coordination and sustained co-presence
Withdrawal as coordination	Test whether emission during pivot-and-leave facilitates yielding and reopening of space	Turn-taking and coordination dynamics mediated by olfactory signalling
Ecological bounds under crowding	Examine how density affects salience and ambient diffusion of scent	Environmental constraints and scalability limits of olfactory interaction in real-world settings

across time and space. From this point, it operates not only as a marker of presence but also as a factor shaping how interaction unfolds through variations in intensity, rhythm, and spatial diffusion, giving rise to processes of modulation and co-regulation.

Variations in emission can sustain a background presence, mark transitions, or signal shifts in proximity. These variations do not represent internal states or convey discrete messages; rather, they modulate how the robot becomes perceptually available within the shared environment. In this sense, such variations contribute to structuring the temporal and affective dynamics of interaction, influencing how agents orient, remain, or disengage within a shared space.

In this way, olfactory expression extends perceptual identity into a distributed and temporally unfolding layer of interaction, in which presence is not simply recognised but also continuously shaped and adjusted.

Such dynamics may become particularly relevant in contexts where visual or verbal channels are less effective. In assistive settings, for instance, olfactory expression may support temporal orientation and interaction flow for visually impaired users. In care environments involving dementia, differentiated olfactory cues may contribute to routine recognition, emotional stabilisation, or the modulation of agitation. More broadly, olfactory presence may shape interaction by evoking memory and affect, contributing to shared atmospheres that sustain engagement.

These dynamics are not limited to human–robot interaction. Because olfaction operates across species, olfactory cues may also support forms of interaction involving non-human agents. Companion animals, whose perceptual world is strongly structured by smell, may engage with robots through olfactory signals, potentially fostering familiarity, reducing stress, or enabling forms of interspecies coordination.

Together, these dynamics suggest that olfactory expression can extend perceptual identity into a mechanism of relational regulation, contributing to the emergence of shared, distributed, and multispecies interactional ecologies.

8.2 Multisensory markers and compatible otherness

The conceptual and functional role of scent in ScentDia provides a generative model for the design of other perceptual identity markers. Rather than being tied to a specific sensory modality, perceptual markers can be understood as operating across a range of perceptual domains through which social coordination is structured.

Within this perspective, modalities such as tactile, thermal, visual, or rhythmic signals are not introduced as auxiliary features, but as potential design dimensions through which robotic presence can be constructed and stabilised across interactions. What matters is not the modality itself, but the capacity of these signals to generate recognisable and consistent perceptual patterns that support orientation, anticipation, and coordination in shared environments.

Tactile cues, for instance, may take the form of rhythmic vibration or variations in surface tension accompanying proximity or contact. Thermal modulation—intentionally differentiated from human or animal body temperature while remaining perceptually accessible—may signal activation, rest, or invitation without relying on biological mimicry. Visual or luminous patterns, as well as movement rhythms, can provide alternatives to gaze and gesture, establishing forms of presence that are clearly distinct from human expressive repertoires while remaining interactionally legible.

Such an approach is particularly relevant in contexts of sensory or cognitive fragility, where conventional interaction channels may be less effective or even disruptive. However, its relevance is not limited to specific user groups. More broadly, it supports the design of robotic agents whose social presence is grounded in compatible otherness: forms of perceptual distinction that remain intelligible within human coordination dynamics without reproducing human likeness.

From this perspective, perceptual identity markers constitute a transferable design–research framework. They enable the systematic exploration and comparison of different

modalities of robotic social presence, each defined by the stabilisation of distinct perceptual patterns within shared environments. Rather than converging towards anthropomorphic resemblance, this framework opens a multidimensional design space in which diverse forms of robotic presence can be developed, combined, and evaluated in terms of their capacity to sustain socially meaningful interaction.

Designing for difference, in this sense, functions as a constructive principle, contributing to plural and socially sustainable forms of human–robot coexistence.

8.3 Perceptual markers and experimental responsibility

The introduction of perceptual identity markers shifts ethical questions from what robots are or represent to how interaction is materially structured and experienced. What is at stake is not only what a robot does but also how its presence becomes perceptually available, how it orients others, and how it participates in shaping shared relational environments.

In this perspective, the dynamics described above—variations in emission, distributed presence, and co-regulation—are not neutral interactional features, but the very conditions through which relational configurations emerge and stabilise. The question is not simply whether a given signal is recognisable or effective but also how it structures rhythms of engagement, patterns of coordination, and forms of social intelligibility within a shared environment.

What kind of interaction is made possible when presence is structured through distributed, non-symbolic perceptual cues? What forms of coordination, expectation, or asymmetry emerge when signals do not represent states but modulate conditions of engagement?

This reorientation is particularly relevant in exploratory settings such as the one presented in this work, where interaction is not predefined but unfolds through situated encounters. Rather than applying external criteria, ethical reflection operates here within the configuration of perceptual conditions themselves, as these shape how agents orient, respond, and co-exist.

In this sense, experimental responsibility does not consist in evaluating outcomes after the fact, but in attending to how interaction is made possible in the first place. Designing perceptual identity markers means configuring how presence is distributed in space and time, how difference is made perceptually intelligible, and how coordination can emerge without relying on equivalence or simulation.

From this perspective, synthetic ethics does not prescribe norms in advance, but operates within the construction of relational environments, as an ongoing practice of orientation within emerging forms of human–robot coexistence.

9 Conclusion

This article has argued that the future of social robotics should not be oriented towards increasingly persuasive versions of human likeness, but towards forms of robotic presence grounded in difference, legibility, and relational compatibility. Against substitutional and mimetic models, we have proposed the paradigm *robots with us, not like us*, articulated through peri-human design, perceptual identity markers, and futuring social robotics.

ScentDia has materialised this orientation by exploring scent as a medium of robotic social presence. Rather than functioning as a validation device, it operates as a synthetic artefact through which a different design trajectory becomes perceptible and available for inquiry. What emerges from this work is not a closed solution, but an opening: olfactory social robotics as an initial programmatic direction within a broader, plural field of exploration. Within the peri-human design space, multiple perceptual identity markers and modalities of presence can be developed to explore how artificial agents may participate in shared social environments without reproducing human sociality, instead giving rise to a variety of distinct and generative forms of human–robot social coordination.

The central issue is not whether robots can become more like us, but whether we can learn to design socially sustainable forms of coexistence with agents that remain recognisably other. This valorisation of difference, we suggest, is one of the central questions for the future of social robotics.

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Author contributions L.D. developed the theoretical framework and conceptualisation. M.V. conceived ScentDia and directed its design and development. M.G. directed the design and development of ScentDia's olfactory signature. R.M. contributed to the theoretical grounding and research development. L.D. wrote the main manuscript text. All authors contributed to the integration of the work and reviewed the manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest The authors declare no competing interests.

Use of AI-assisted tools The authors used AI-assisted language tools solely for minor editing purposes (grammar and language refinement). All conceptual content, arguments, structure, and references were developed entirely by the authors.

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