

Aesthetics as a core design dimension for human-centred robotic systems

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Barriers to the widespread adoption of robots often stem less from limitations in technical capability than from the social, cultural and interpretive contexts in which these systems are encountered. We therefore argue that aesthetics should be treated as a core design dimension, alongside functionality and safety, to support meaningful and situated human–robot interactions.

Robotics have advanced in precision and autonomy. However, their integration into everyday environments remains constrained by factors that extend beyond technical capability. Concerns around safety and public-space norms often shape deployment more decisively than engineering performance alone, as illustrated by the 2025 Los Angeles incident involving a delivery robot navigating a pedestrian-dense area¹.

Treating devices as purely instrumental does not remove their experiential dimension: engagement is embodied, contextual and social, shaped by aesthetic qualities and lived experience². Work on robotic companionship and ‘dressing’ technological bodies shows that materiality and motion influence recognition, inclusion and marginalization in real settings³. Therefore, aesthetics should be considered as a core design dimension in (soft) robotics, moving beyond just function⁴.

Form, emotion and meaning

Work on aesthetics in robotics has remained largely disconnected from work on technical innovation and tends to concentrate on anthropomorphic robotic systems⁵. This narrow emphasis overlooks the extent to which users’ encounters with robotic systems are shaped by more foundational experiential determinants, which we frame across three dimensions: form, emotion and meaning (Fig. 1).

Form. Form refers to the perceivable organization of a device; that is, its geometry and the spatiotemporal structure of its motion and behaviour. In robotics, form is therefore not only static shape but also multisensory form: the approach trajectory, speed profile and responsiveness that constitute an aesthetic of behaviour in interaction⁶. Smooth motions can signal approachability⁷, whereas looming paths and computerized reactions can be read as threats – interpretations that might persist regardless of surface treatments, such as colour and texture.

Emotion. Emotion refers to affective responses that arise within a responsive human–robot loop, in which each adapts to the other’s actions. These include embodied, pre-representational affect and reflective responses, as well as context-dependent appraisals, that align with appraisal theories and empirical models of situated (non-universal) aesthetic experience⁸. While form dictates designable cues, emotion captures how these cues are experienced (for example, comfort, trust and/or anxiety) in a given social and cultural context. These outcomes can be measured (for example, by comfort ratings) and optimized as design objectives⁹. In human–robot interactions and haptics, such design objectives serve as key evaluation metrics. However, they should also drive initial, iterative co-design of form and responsiveness.

Meaning. Meaning relates to the cultural, social and ethical interpretations that accumulate around a device; that is, what it represents beyond the immediate interaction. Meaning emerges through usage, media and cultural references; for example, a robot may be perceived as being caring or surveillant, or it may carry stigma, depending on who uses it and where it is used. This perspective is rooted in the humanities and arts, which treat artefacts as sites of interpretation and anthropological meaning-making beyond their creators’ intentions¹⁰. For robotics, this concept highlights transdisciplinary collaboration with various stakeholders to surface diverse interpretations and anticipate unintended meanings prior to deployment.

This form–emotion–meaning lens (Fig. 1) builds on established design and human–robot interaction accounts of experience as an interplay of sensory qualities, affect and interpretation over time (for example, visceral–behavioural–reflective levels)¹⁰. Rather than proposing a new taxonomy, we operationalize these frameworks for embodied robotics, with materials, compliance and interaction dynamics as primary design variables. The dimensions are coupled: morphology, materials and control (form) shape affective responses (emotion), as well as perceived role and contextual fit (meaning), whereas role and context requirements constrain form and modulate emotion. These considerations are situated and vary across users, cultures and settings.

Physical intelligence as enabler for robot aesthetics

Aesthetics vary across robotic domains but are particularly important in soft robotics, because compliance is not only a prerequisite for function but also a perceptual and affective cue. Deformation can make adaptability visible, soften hesitation about touch, and shape how an interaction feels.

Psychophysical studies of touch suggest why compliance can matter aesthetically. For example, research on material perception

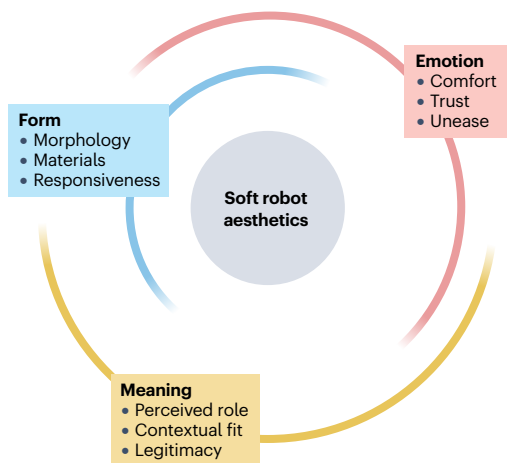


Fig. 1 | A layered lens for soft robot aesthetics. Soft robot aesthetics can be framed within three coupled dimensions: form, emotion and meaning. Experiences emerge through interaction and are embedded in social and cultural contexts.

distinguishes sensory dimensions from affective dimensions and links perceived softness to pleasantness during active exploration¹¹. Interestingly, sensory and affective descriptors co-vary across touched materials, offering a vocabulary for separating sensed properties from felt experience¹². In soft robotics, contact and actuation can appear as continuous deformation, externalizing interaction states both visually and haptically. Moreover, soft devices are often applied at the body–device interface; thus, wearability and social appropriateness become central design constraints and opportunities.

In addition to visual and tactile properties, motion responsiveness is central to aesthetic form. The motion of soft systems with physical intelligence¹³, which move by following their underlying physics (that is, through compliance and dynamics), seems natural and life-like, in contrast to that of systems with rigid, computerized actuation, and thereby potentially promotes interaction.

Nevertheless, intrusive sensing, unexpected material response or misleading cues of safety can compromise positive perception. Material and morphological choices should therefore be tied to intended use and should be evaluated with relevant user groups using ethics-reviewed protocols.

Therefore, design choices should be informed not only by a device's technical affordances but also by its experiential and meaning-making potentials. Accounting for these dimensions enables forms of compliance that expand the range of interactions that users perceive as desirable, appropriate and compatible with their identities.

Implementing aesthetics in human-centred design

Robot aesthetics can be integrated into designs as a set of experiential requirements, alongside mechanics, control and safety. Importantly, here we consider 'aesthetic' in a human-centred design sense (as a deliberate variable that shapes perception, behaviour and adoption) by extending established approaches (such as design thinking and material-led design) to embodied robotic systems, for which interaction is physical and material.

Specify. Specify situated experiential and meaning goals alongside functional and safety criteria, with early input from aesthetic practitioners and stakeholders.

Translate. Translate goals into designable levers, without privileging form as the sole starting point. Translation of aesthetic considerations

into functional designs can proceed from any dimension: meaning goals may motivate re-framing of the task; emotion goals may motivate interaction dynamics; and form goals may constrain or enable both.

Experiment. Experiment with experience, not just with technical metrics. In human–robot interactions, perceptual outcomes are often the performance targets themselves; therefore, whether meaning goals are being achieved should be evaluated through the use of structured user studies, rating scales and real-world observations. Experiments should include diverse users, cultures and levels of technological familiarity, and they should be treated as feedback to jointly adjust form, emotion and meaning, rather than as late-stage validation.

Practise. Practise through early transdisciplinary collaboration and shared resources. Programs such as artist- or designer-in-residence, shared prototyping spaces and small exploratory grants can support high-variance ideas. In addition, transparent documentation and datasets, as well as reproducible protocols, can make robot aesthetics community practice.

From technical performance to embodied experience

Robot aesthetics should be viewed as a key research agenda to avoid translational failure of technically capable systems. For example, a life-supporting artificial heart may meet clinical targets but may not achieve clinical translation if it negatively affects quality of life. Similarly, a domestic assistive robot may function well but feel intrusive, signalling surveillance rather than care. Performance is necessary but insufficient – experience and interpretation determine sustained adoption.

Treating aesthetics as a key design dimension that integrates form, emotion and meaning offers a route to the development of devices that users can accommodate and might even identify with. For example, in soft robotics, compliant materials could be applied that shape interaction qualities compatible with diverse identities, bodies and cultural settings.

Embedding this perspective requires shifts in training, evaluation and incentives. Engineers should be equipped to collaborate with design and humanities experts, and experiential outcomes should be evaluated as performance targets, alongside force, accuracy and robustness. Funding, publication and review criteria should reward transdisciplinary prototypes and in-context, longitudinal evidence.

However, robot aesthetics also carries risks. The very cues that provide reassurance may inadvertently elicit unwarranted trust in systems with ethically problematic functions (for example, surveillance technologies that are deliberately designed to appear friendly). Treating aesthetics as a central design consideration therefore carries ethical obligations, including ensuring alignment between a device's communicated intentions and its actual operations, maintaining transparency on data use, and upholding accountability to the communities affected by its deployments.

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Author contributions

All authors made a substantial contribution to discussion of the content. N.P. and A.C. wrote the manuscript. All authors reviewed and/or edited the manuscript before submission.

Competing interests

The authors declare no competing interests.