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Delineating the Hybridity of Robotic Artifacts: Pathways to More Thoughtful Design in HRI

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Designing robots that people can relate to and understand requires shaping their embodiment and behavior in service of their purpose and use, without getting stuck in predominant robot stereotypes. With this work, we delineate the hybridity of robotic artifacts and discuss leveraging hybridity towards more thoughtful design. In an online study, we asked 103 participants to look at videos featuring robots being active in different contexts. After each video, participants were asked to share their impressions of the robots through questionnaires designed to evaluate four aspects: (1) ontological categorization, (2) behavioral attributions, (3) interaction considerations, and (4) perceived value. Through an interpretative analysis, the hybridity of robotic artifacts is delineated by tracing back responses of participants on the questionnaire items to its video contents through visual inspection. We discuss how the hybridity of robotic artifacts can be traced back to three distinct framings—products for use, social actors, and animate entities—that inform their perceived functional and affective value. Furthermore, we explore how these framings can merge into more complex configurations, including portrayals of robots as objects with intent, as entities that reveal a spectrum of more-than-human sociabilities, and as prompts for discussions about human–robot coexistences. We conclude by reflecting on these findings to consider how leveraging hybridity can inform more thoughtful design approaches in human–robot interaction.

CCS Concepts: • **Human-centered computing → Interaction design**; **HCI theory, concepts and models**;

Additional Key Words and Phrases: Robotic artefacts, hybridity, industrial design, thoughtfulness

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1 Introduction

The variety of robots being researched in academia and developed in the industry is expanding rapidly. Much like the branches of a phylogenetic tree, robots are diversifying into numerous paths, leading to various morphologies and behaviors. This blossoming tree mirrors the expanding contexts in which robots are now evolving, ranging from domestic settings to extreme environments. The broad range of purposes is equally impressive: alleviating loneliness, conducting search and rescue missions, welcoming customers, and mowing lawns. As a result of this diversification, the once relatively unified notion of a robot—typically seen as either an industrial machine or an android—has fragmented [5, 48]. This fragmentation becomes even more pronounced as robotic systems begin to permeate everyday landscapes and integrate into domestic settings [3, 31].

One can reasonably conclude from this development that robots do not fit neatly into a singular product category. There are as many robots as technological opportunities to invent autonomic functions, as many robots as contexts of application for the deployment of embodied agents. In addition to regrouping many different types and subtypes of systems [67], robots tend to blur traditional ontological boundaries [33, 87]. Robots are technological artifacts, but they possess interactive and morphological features that upset firm associations to the domain of machines and industrial products. Their morphology may inherit living beings' anatomical features, and their behavior may be sufficiently complex and adaptive as to evoke the behavior of animals. This perceptual ambiguity is driven partly by anthropomorphic attributions that imbue these artifacts with a human and social presence. The combination of technological, psychological, and sometimes even appealing to biological features places robots in an ambiguous ontological situation, straddling the line between living and non-living entities [47, 71, 83, 94].

Robots inherently belong to a hybrid category, seamlessly bridging the divide between the machine-like and the social. This gives them a multifaceted agency. Robots can be integrated into social routines, as extensively studied in research on embodied conversational agents [13, 75, 88] or assessed as products based on utilitarian criteria. Such objects might evoke feelings of empathy or affection. As they become part of domestic ecosystems [86], their essence is determined by their ability to assimilate into social places, such as the home or work settings and so on, and participate in daily routines (e.g., preparing breakfast, cleaning offices). When perceived as industrial products, they align with familiar categories (e.g., a lamp, a lawn mower, a vacuum cleaner), inheriting characteristics typical of those domains. The interplay of expressive behavioral cues and the psychological involvement in attributing mental capacities to objects [38, 56] can elicit potent feelings of agency [89, 90]. Moreover, robots engage in socially meaningful scenarios. Within these contexts, their agency is interpreted as the ability to perform their function and given meaning amidst a network of human and non-human entities [54] or within ritualistic social frames [98].

A focus on hybridity as the multifaceted and unstable identity and agency of robotic artifacts connects to more recent developments in the field. Drawing on Ihde's [44] account of human–technology relations, Dörrenbächer et al. [24] investigate the multifaceted ways robots can be present in everyday life through delegation, cooperation, and socializing, and use hybridity to imagine robots that "afford a broader spectrum of possible use" (p. 24), potentially fitting into new niches not previously occupied. Another relevant contribution is by Jarsve et al. [46], who offer a phenomenologically grounded exploration of what it means to be with robots and propose a framework that articulates nuances of robot–human experience along two contrasting axes: whether robots are understood as tools or as entities, and whether experiences of them are framed in technical terms or through attributed narratives, including metaphoric and emotional ascriptions.

Together, these works underscore the need to understand experiential nuances and how such understandings can inform the design and development of robotic systems. Robotic artifacts do not only blur conventional ontological boundaries but also spotlight significant design considerations. In this article, we advocate for the promotion of a design approach that embraces this inherent hybridity. Such an approach aims to expand our understanding of the morphology and experience of a diverse collection of robotic systems. It moves beyond stereotypical descriptions, such as being referred to an industrial, service, or social robot, to address the nuances of how their ambiguous nature influences perceptions and foster specific modes of interaction. Such stereotypical classifications derived from application domains are problematic because they fail to reflect the nuanced ways robots are perceived and consequently constrain their design space. In the following section, we delve deeper into the concept of hybridity, its varied expressions, and its crucial role in designing robotic artifacts more thoughtfully. This approach aims to enable a more nuanced and appropriate robot design, intended to be free from limiting conventional stereotypes.

1.1 Manifestations of Hybridity

Hybridity can be inherently integrated into the character of a computerized product. Product characters, along with their accompanying metaphors, serve as high-level descriptions of artifacts [45]. They facilitate attributive processes and help shape a product's "gestalt" guiding interpretation of its use and handling [18]. Employing hybridity as a design strategy involves tapping into these potential shifts in attributive processes to diversify the ways in which an object can be used [60]. When perceived as a machine, a product may convey attributes like efficiency and utility, emphasizing its straightforward role as a tool. In contrast, when likened to a living entity, an object might evoke empathy [42], encouraging users to engage with it both socially and emotionally. This shifts its identity toward that of an agent. Rozendaal et al. [78, 80] contend that smart objects, when viewed alternately as a machine or as a creature, can elicit changes in an object's perceived role. During exploratory interaction, the object may be perceived as oscillating between a tool used for a specific function and an agent that requires negotiation.

Integrating a social interface is crucial in the process of building robotic artifacts that are intended to communicate and interact with people. One obvious way to foster personification is by imbuing the object with appearance and behavior that have social cues and affordances, drawing parallels to living entities [11, 30]. The inclusion of a face might appear as an obvious choice to convey expressivity and intentionality, and it is indeed a direct method to promote joint attention, express attitudes via facial expressions, or transmit communicative intentions [1, 64]. Yet anthropomorphic attributions can emerge even without explicit humanoid features [68]. Objects without such explicit connotations can also achieve rich expressiveness through behavioral complexity [41, 56]. To create what Hobye and Ranten [39] term "alive connotations," one can deploy computational patterns aligned with the robot's embodiment, thereby suggesting spontaneity, environmental awareness, and agency. Interestingly, refraining from using overly obvious social affordances, as robots with humanoid embodiments often do, and instead focusing on social expressivity through behavioral aspects, may be an effective strategy for creating robotic artifacts that not only avoid feelings of uncanniness but also allow flexible shifts in how the robot is perceived—whether as a thing, a tool, or an agent.

Another important element of hybridity resides in the modes of joint activity and shared agency that define our relationship with robotic artifacts. As service robots gain autonomy (the capacity to operate without direct user intervention) and adaptivity (the ability to self-adjust in response to changing environmental conditions), interactions with them increasingly lean towards a cooperative nature [14, 53]. Cooperation fundamentally requires a shared goal, coupled with the capacity for the agents to mutually adapt in a manner that facilitates achieving this objective. The nature of a partnership varies depending on the presence of a mutual goal and the flexibility to define roles within the interaction. Consequently, the perceived agency of the robotic artifact can also oscillate. At times, the robot might be perceived as possessing its own volition, while at other times, it may be seen merely as an instrument to fulfill the user's intentions. This dynamic presents pivotal design challenges, primarily revolving around the degree of control delegated to the object and how this can be negotiated.

Last, hybridity merges different evaluation criteria. In human–computer interaction, a prevalent distinction is drawn between utilitarian values and hedonic values when assessing a product. Utilitarian values are primarily encapsulated by the Technology Acceptance Model [21, 96], whereas hedonic values, encompassing aspects like beauty, enjoyment, and fun, have become mainstream in the conceptualization and assessment of user experiences [26, 36, 93]. Although these models provide a broad perspective on interactive technologies, they haven't been specifically designed to factor in the influence of agency on the perceived value of a robotic artifact. Taking into account, agency requires an acknowledgment of characteristics like animacy and perceived intelligence [6], as well as other indicators of behavioral expressivity. Moreover, it demands an assessment of social dimensions, like the artifact's social presence [55], its sociability—reflecting how communicative and socially aware the system appears [38], and the trust the user places in the robot [23]. Intriguingly, these agency-related evaluative aspects can coexist with the more traditional values associated with product experience. When viewed as a tool, an object might elicit utilitarian assessments, but when seen as an agent, it invites evaluations linked to agency and joint agency.

When exploring the hybrid nature of robotic artifacts through the lens of industrial design and **human–robot interaction (HRI)**, a central consideration revolves around their "appropriateness." Appropriateness in design is described by Cross [19], who asserts that effective designs must align with the specific needs and constraints of their context. This includes striking a balance between technical, functional, and aesthetic considerations. Building further on these concerns, Löwgren and Stolterman [59] elaborate on how appropriateness appeals to adopting a sense of thoughtfulness into the design process. This ensures the creation of technology that not only facilitates users in their tasks but also acknowledges the broader impact of technology use on individuals and society. Consequently, crafting robotic artifacts that are appropriate for their intended purposes requires acknowledging the design attributes that are productive for generating specific user experiences. Within such a design perspective, it becomes possible to shape the particular qualities of robotic artifacts to make them suitable within a given use context.

1.2 Objectives of the Study

Hybridity emerges as an intrinsic characteristic of robotic artifacts, yet many current theoretical frameworks and evaluation methods remain ill-equipped to its multifaceted nature. While existing research has examined various aspects of HRI from usability to social presence, we lack a comprehensive understanding of how different perceptual framings combine to shape people's experiences with robots. This study aims to empirically delineate the structure of robot hybridity by examining how people interpret and make sense of robots that vary in their design features, behavioral characteristics, and contexts of use.

To achieve this goal, we developed a systematic approach combining visual analysis of video contents guided by structured evaluations through questionnaires. First, we curated a set of video recordings featuring robots that represent different points in the design space from purely functional industrial robots to socially assistive humanoids and from familiar commercial products to experimental prototypes. These videos serve as concrete instances of how hybridity can be manifested in robotic artifacts. Second, we constructed a questionnaire designed to probe multiple dimensions of robot perception. These included their ontological categories based on resemblances in appearance (e.g., machine-like, creature-like, product-like), attributions derived from movement characteristics and behavior (e.g., control, intentionality, responsiveness), interaction considerations (e.g., social engagement, instrumental use, collaborative potential), and perceptions of their value (e.g., usefulness, enjoyment, friendliness).

Through statistical analysis by means of an explorative **Principal Components Analysis (PCA)** and interpretative examination of participant responses in relation to the video contents, we seek to identify patterns in how different robot characteristics contribute to various forms of hybridity. This empirically grounded understanding offers insights for more thoughtful approaches to designing robotic artifacts that acknowledge and intentionally leverage the multiple ways robots can be interpreted and experienced. Such a design approach and sensitivity can help designers navigate key questions about robot embodiment, behavior, and interaction in relation to their design.

2 Method

To study robot hybridity systematically, we adopted a mixed-methods approach combining quantitative assessment and qualitative interpretation. Video recordings of six distinct robotic artifacts, ranging from conventional industrial and humanoid robots to more experimental designs, were presented to participants. Each video was assessed using a custom-designed questionnaire consisting of 27 items that evaluated robots on four aspects: (1) ontological categorization, (2) behavioral attributions, (3) interaction considerations, and (4) perceived value. The quantitative data underwent an explorative PCA to identify underlying dimensions of robot perception. These dimensions then served as a foundation for an interpretative analysis that traced participants' responses back to specific design features and contextual elements visible in the video contents, allowing us to delineate different forms of hybridity and their manifestations in robotic artifacts.

2.1 Participants

In total, 103 individuals participated in our study, recruited from a Dutch product evaluation panel associated with Delft University of Technology. Invitation e-mails were sent out, and from the recipients, 103 individuals completed the survey. As an incentive, participants were offered a chance to win one of twenty €10 gift certificates. The gender distribution among participants was balanced, with a slightly higher percentage of women (54) compared to men (48), and one participant chose to identify as neither male nor female. Participant ages ranged from 21 to 71, with a median age of 53. Ethical approval was gained by the TU Delft Human Research Ethics Committee (HREC), and informed consent was obtained online when logging into the system before the study started.

2.2 Selection of Robotic Artifacts

To investigate the hybrid nature of robotic artifacts, we curated a selection of robot videos freely accessible online. These videos showcased a diverse array of robots, encompassing both familiar, iconic models and more experimental, ambiguous designs. The selection also encompassed a variety of applications, ranging from robots intended for domestic use to those deployed in industrial settings, and encompassed both indoor and outdoor environments. Robots varied in terms of their embodiment, ranging from machine-like robotic arm to zoomorphic robotic artifacts. Additionally, the robots featured in the videos varied in their operational modes, with some designed for independent operation while others emphasized interaction with humans. Furthermore, the selection included utility-focused robots alongside those designed for entertainment or artistic purposes.

For more iconic robotic designs, we chose Softbank Robotics' humanoid Nao robot, known for its social applications, and an industrial robot arm, representing stereotypical examples of robots designed primarily for functional tasks and autonomous operations. Additionally, we included iRobot's Roomba robot as an example of a familiar cleaning robot, commonly found in home settings. In the realm of more experimental robotic artifacts, we've selected Blo-nut [9], a soft robot crafted as a research artifact to explore life-like behaviors that diverge from conventional robotic norms. Additionally, Bob de Graaf's robotic lamp from his "Species of Illumination" series is a hybrid creation, combining elements of a lamp with characteristics reminiscent of a bird-like creature. Furthermore, BigDog, developed by Boston Dynamics, is a prototype of a quadrupedal robot initially designed for military applications (and predecessor or the robot named Spot). It aims to replicate and explore the capabilities of animal-inspired movement across diverse landscapes. To maintain consistency in stimulus presentation, all videos were shown in grayscale and without sound, focusing on the robots' physical form and movement attributes. However, this approach eliminated potential influences from robot-generated sounds, environmental ambience, or color—factors we acknowledge and discuss as limitations in our study. That said, recent work by Esterwood et al. [29] suggests that differences in how embodiment is perceived across physical robots, screen-based depictions, or VR may not substantially affect perceptions of sociability and engagement. Table 1 provides a detailed overview of each video's content, including descriptions of the robot's morphology, context, behavior, movement, and cinematic framing. The depicted images are rendered impressions based on stills from the videos used in the study.

2.3 Questionnaire Items

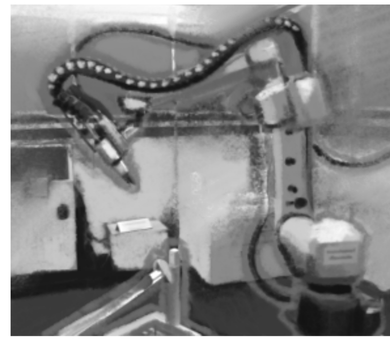
To explore the nuances of robot hybridity, we designed a set of questionnaire items aimed at capturing viewers' experiences, bringing together robots' ontological categorization, behavioral attributions, interaction considerations, and the kinds of values they elicited (Table 2). Many questionnaires already exist. The development of robotics, and especially social robotics, has been accompanied by the creation of various psychometric measures of robots' perceived characteristics (for a review, see [22, 52]). Some of these measures assess the general attitude toward robots [6, 7, 69], some focus on humanoid robots [49], some address feelings of uneasiness toward robots [70], and others explore expectations both prior and during interactions, for example with robots in the classroom [2]. However, for the aim of this study, robotic artifacts as animated machines may appeal to multiple ontological framings, catering to various interaction concerns and encompassing multiple kinds of appreciation.

We developed a set of questionnaire items through a review of existing theoretical frameworks and measurement instruments in HRI. Drawing from Dautenhahn's [20] foundational work on social robotics categorization, we developed items to capture robots' multiple categorical memberships. These were enriched by theoretical perspectives on animism [63, 78], lifelikeness [85], and human–machine ontological intersections [91]. Following Levillain and Zibetti's [56] framework for analyzing behavioral expressions, we created items measuring perceptions of control, intentionality, and responsiveness to others. These items capture how people interpret robot behavior through different interpretive frames, particularly focusing on cues that suggest agency and social awareness. Items addressing interaction concerns were crafted with insights from studies on the experience of engagement and scales on HRI covering social, functional, and collaborative elements [7, 12, 40, 101]. Items intended to capture judgments of a robot's perceived value integrate perspectives from technology acceptance research [43] and product experience [36], while also considering potential negative responses through the lens of the uncanny valley concept [66]. This allows us to explore a broad spectrum of user responses, from practical utility to emotional engagement.

2.4 Procedure and Analysis

To delineate the hybridity of our selection of robotic artifacts, we conducted an interpretative analysis by examining participants' responses to questionnaire items in relation to video content through visual inspection. This procedure involved several steps: (1) asking participants' ratings of the videos based on the questionnaire items via an online survey tool, (2) analyzing the results

Table 1. Our Selection of Six Video Clips Showcasing Different Kinds of Robotic Artifacts

Industrial Robot Arm (00:15)	
This video footage shows an industrial robot arm carrying out a construction task in a regulated industrial setting, noticeably absent of any human presence. **Robot**: A stationary robotic arm comprised of several rigid sections with a flexible conduit guiding wires from the manipulative segment down to its base. **Context**: The robot can be seen in an industrial setting without humans being present. **Behavior**: The robot uses the end of its arm to interact with a metal tube, seemingly smoothing the edges of this structure. **Movement**: The robot performs a sequence of movements in a smooth, precise, and relatively slow manner. **Cinematic framing**: The footage is shot from a handheld camera, taken from a chest-height perspective.	
Nao (00:48)	
This video footage shows the Nao robot interacting with a group of children. It is seen exchanging greetings with them and performing yoga exercises together. Additionally, one scene depicts two children walking alongside Nao, each holding one of its hands. **Robot**: An android robot approximately 60 centimeters tall, featuring multiple joints that link its distinct body parts such as the head, torso, arms, legs, hands, and feet. **Context**: The robot is seen in a casual social setting located in an area resembling an outdoor park. **Behavior:** The children are seen mimicking the robot's actions and modulating their walking pace to match the robot's tempo. **Movement**: The robot carries out intricate sequences of movements and gestures, which are performed at a slow pace and appear somewhat uneven or irregular. **Cinematic framing**: Handheld camera with varying viewpoints. The camera's presence seems ethnographic like, subtly observing and documenting the interaction.	
Roomba (00:31)	
This video clip depicts a Roomba, a cleaning robot, navigating through different sections of a living room. It maneuvers around furniture and transitions from wooden flooring to carpet. The filming perspective remains close to the Roomba throughout the sequence. **Robot**: A circular-shaped cleaning robot with a complex exterior design, featuring two rotating brushes underneath its chassis that extend outward. **Context**: The robot is seen navigating a living room environment, noticeably devoid of any human presence. **Behavior:** The robot follows direct paths at a steady pace until it encounters an obstacle, at which point it rotates to define a new random direction. **Movement:** The robot consistently moves forward, punctuated by rotations of its body. The roughness of the surface impacts the speed and fluidity of its movement. **Cinematic framing**: Numerous close-up shots to foster empathy with the robot, creating a narrative of its journey within its environment.	

(Continued)

Table 1. Continued

Robotic lamp (00:22)	
The video footage shows an animated table lamp that a person triggers by a hand wave. Following this, she directs it to a spot near her notepad, from which the lamp proceeds to illuminate that area. **Robot**: An animated table lamp, mounted on wheels, that also possesses animal-like characteristics. **Context**: The robot is situated on a desk, keeping company with an individual who is busy writing in a notepad. **Behavior**: The robot responds to the individual's hand gestures, tracking them with a minor lag. **Movement:** The robot uses its wheels to maneuver and rotate its body, although the movements are somewhat jerky. In contrast, the lampshade moves more gracefully and with greater subtlety. **Cinematic framing**: This is a well-produced film, with steady camera positioning, and carefully edited close-ups to highlight the interaction.	
Blo-nut (00:33)	
The video footage illustrates a woman delicately touching a soft robot, exploring its motion. She restricts its movements by exerting pressure with her fingers, before gradually easing off, allowing the entity to expand unhindered. **Robot**: A donut-shaped soft robotic object made of silicone that inflates when air is blown into its three air pockets, each of which can be controlled independently with varying pressure. **Context**: The robot can be seen to be held and touched by different people in an exhibition setting where other people are present as well. **Behavior:** People explore the robot with their hand and fingers while it changes shape in a continuous and dynamic manner. **Movement**: The robot's motion is smooth and seems organic, owing to its rhythmic pulsations and transformations of its overall shape. **Cinematic framing**: A combination of steady camera motion and close-up shots captures people's interactions with the Blo-nut during an exhibition.	
BigDog (00:15)	
The video showcases a four-legged, headless and tailless robot, about the size of a mule, outfitted with sacks on its back. The device is seen skillfully navigating a snowy slope and dealing with slippery, ice-laden landscapes. **Morphology**: A zoomorphic robot with four legs, carrying load on its back. **Context**: The robot is visible maneuvering through a chilly outdoor environment, descending a snow-covered incline, and stepping carefully across a frozen surface. **Behavior**: Actively maintaining equilibrium on challenging terrain, the robot demonstrates responsiveness in preventing slippage. **Movement**: The robot's leg motions, which push it forward with surprising naturalness, steadily adapt to the environmental conditions. **Cinematic framing**: The recording uses a handheld camera from a chest-level perspective to track the robot's performance.	

The depicted images are rendered impressions based on video stills.

Table 2. List of the Questionnaire Items

Ontological categorization
"To what extent does this object show similarities with...?"
[ID1] An **everyday product**
[ID2] A **creature**
[ID3] A **human**
[ID4] A **machine**
[ID5] **Something organic**
Behavioral attributions
"Select your position between two extremes?"
[BE1] **Spontaneous**—Does this object move ***by itself*** or is it being moved by an ***external force***?
[BE2] **Controlled**—Does this object move ***disorderly*** or in a ***controlled fashion***?
[BE3] **Aware of environment**—Does it appear the object is ***aware of the environment***? (***aware***, ***not aware***)
[BE4] **Intentional**—Does this object move ***randomly***, or does it appear to be ***driven by intentions/goals***?
[BE5] **Adaptive**—Can this object ***cleverly deal with changing situations***? (***does this cleverly***, ***doesn't do this cleverly***)
[BE6] **Aware of others**—Does this object ***take others into account*** in its way of conduct? (***takes others into account***, ***doesn't***....)
Interaction considerations
"To what extent do you agree with the following statement when envisioning engaging with this robot yourself?"
[IN1] **Empathic**—Interacting with this object involves my empathic sensitivity.
[IN2] **Social**—I can socially interact with this object.
[IN3] **Communicable**—I can communicate with this object.
[IN4] **Effortless**—I can interact with this object effortlessly.
[IN5] **Physical**—I can physically interact with this object.
[IN6] **Instrumental**—I can use this object for my own purposes.
[IN7] **Needs accommodation**—When interacting with this object I need to be mindful of its own intention and actions.
[IN8] **Collaborative**—I can collaborate with this object toward a common goal.
[IN9] **Me in control**—I am in control when interacting with this object.
[IN10] **Object in control**—The object is in control when interacting with it.
[IN11] **Comfortable**—I feel comfortable to interact with this object.
Perceived value
"To what extent do you agree with the following statement?"
[AP1] This object is **fun**
[AP2] This object is **useful**
[AP3] This object is **friendly**
[AP4] This object is **well-designed**
[AP5] This object is **scary**

using an exploratory PCA, and (3) conducting an interpretative analysis by comparing the robotic artifacts based on these resulting components in various combinations.

First, participants took an online survey through Qualtrics. Participants were instructed to watch six videos showcasing robots in specific contexts of use and complete a questionnaire with several questions after each video. They were free to take as much time as they needed. The questionnaire made use of a 5-point Likert scale for every item, with options ranging from 1 (strongly disagree) to 5 (strongly agree). An exception is the expressive behavior items that consisted of 5-point bipolar scales, with some of them being presented in reverse. See Table 2 for the complete list of questionnaire items. Video clips were shown to participants in a random sequence. However, for each participant and every video, the sequence of item sets remained consistent, following the order (a) ontological categorization, (b) behavioral attributions, (c) interaction considerations, and (d) perceived value. Inside each item set, the order of the questions was randomized.

Second, we conducted an exploratory PCA analysis based on these scores to examine the dimensions underlying participants' responses. The analysis utilized correlation scores of the items and employed Varimax rotation with a maximum of 25 iterations. This approach ensures that each component is chosen to be orthogonal (independent) from the other components. Our inclusion criterion for selecting a component was an "eigenvalue" equal or greater than 1.0, indicating that a

Table 3. Projected Regression Scores Based on the PCA Results of the Robot Artifacts across Components

Robot Exemplar	1. Effectiveness	2. Usability	3. Enjoyability	4. Sociability	5. Aliveness	6. Responsiveness	7. Agency
Industrial robot arm	0.82	−0.09	−0.27	−0.26	−0.65	−0.75	0.01
Roomba	0.02	1.15	−0.09	−0.53	−0.62	0.32	0.43
Robotic lamp	−0.08	0.02	0.48	0.55	−0.24	0.33	−0.83
Nao	0.31	−0.28	0.71	0.40	0.34	0.12	0.12
Blo-nut	−1.40	−0.28	0.05	−0.07	0.29	−0.28	0.07
BigDog	0.32	−0.52	−0.88	−0.10	0.88	0.25	0.20

Because these results denote projected (normalized) regression scores, all mean total scores are 0.0 with a standard deviation of 1.00.

component explains a significant proportion of the variance. For each robotic artifact, the mean regression score for each component was calculated from the PCA results and visualized in bar charts. We compared robotic artifacts on each component, wherein we carefully examined the higher and lower scoring robot videos and discussed various visual features observed while the robots performed within their contexts.

Third, we interpret these results to delineate hybridity by analyzing patterns in how components clustered together, allowing us to map different configurations of hybridity in robotic artifacts as a conceptual framework. First, hybridity was expressed through the identification of three primary interpretive frames: robots as products for use, social actors, and animate entities, each describing their functional and affective value. Second, we examined cases to explore how these configurations could coexist in hybrid forms, discussing both design opportunities and ethical tensions.

3 Results

We first present the results of the PCA analysis in relation to the videos. Figure 1 presents the results of the exploratory PCA, which identified seven components collectively accounting for 65% of the total variance. These components correspond to perceptions of robots as being associated with (1) "Effectiveness" relating to purposeful controlled behavior, (2) "Usability" capturing ease of use and familiarity, (3) "Enjoyability" reflecting hedonic and entertainment value, (4) "Sociability" indicating social interaction potential, (5) "Aliveness" represents organic and life-like qualities, (6) "Responsiveness" captures environmental and social awareness, and (7) "Agency" reflects perceived autonomy and control.

In Figure 1, the depicted component loading scores indicate the strength and direction of the relationship between each item and its respective component. We highlighted items with loadings above 0.600 or below −0.600, as these most strongly define each component. Cronbach's alpha was calculated based on these items. The values range from 0.807 (highest) to 0.581 (lowest). Although the lower values may appear modest, they can still be considered acceptable given the small number of items per component, though they should be interpreted with appropriate caution. The distribution of the videos of robotic artifacts, based on their projected scores across these components, is presented in Figure 2, and the table with the scores is provided in Table 3. We continue by describing how each component manifested across the robot videos, examining how specific design features and contextual elements contributed to participants' perceptions. For each component, we first describe its defining characteristics based on item loadings, then examine how different robot artifacts scored on this dimension.

3.1 Effectiveness

The first component captures perceptions of purposeful behavior, with strong loadings on "controlled" (0.784) and "intentional" (0.767). It also correlates with appreciations of being "well-designed" (0.698) and "useful" (0.692). The industrial robot arm exemplifies high effectiveness

	1. Effectiveness	2. Usability	3. Enjoyability	4. Sociability	5. Aliveness	6. Responsiveness	7. Agency	
[BE2] Controlled	.784	−.081	.004	−.049	.026	.133	−.096	
[BE4] Intentional	.767	.072	.109	.112	−.135	.098	−.063	
[AP4] Well-designed	.698	.300	.213	−.036	.007	.043	.119	
[AP2] Useful	.692	.490	.036	−.072	−.144	−.078	.071	.807 (4 items)
[BE5] Adaptive	.571	.133	.100	.030	.024	.545	.030	
[IN8] Collaborative	.520	.403	.098	.361	.010	.056	−.087	
[IN6] Everyday product	.128	.700	.100	−.063	−.168	−.006	.159	
[ID1] Instrumental	.424	.692	.010	.103	−.055	.067	−.149	
[IN4] Effortless	.121	.641	.365	.055	−.070	.115	−.200	
[IN11] Comfortable	.078	.636	.499	.062	−.123	.096	−.184	.782 (4 items)
[AP3] Friendly	.046	.127	.759	.292	.142	.167	.038	
[AP1] Fun	.213	.285	.693	.202	.131	.102	.053	.764 (2 items)
[AP5] Scary	−.127	−.332	−.581	.068	.431	−.074	.146	
[IN1] Empathic	−.038	−.246	−.034	.689	.105	−.061	.342	
[IN3] Communicable	.150	.153	.188	.650	.100	.356	−.142	
[IN2] Social	.030	.050	.337	.648	.171	.151	−.007	.608 (3 items)
[IN5] Physical	−.148	.391	.198	.473	.082	.195	−.031	
[ID2] Creature	.049	−.092	−.005	.240	.726	.281	.108	
[ID5] Organic	−.361	−.069	−.082	.036	.723	.071	.106	.620 (2 items)
[ID3] Human	.225	−.064	.296	.133	.598	−.009	.105	
[ID4] Machine	.504	.166	−.012	−.011	−.569	.043	−.010	
[BE3] Aware of environment	.189	.056	.095	.165	.135	.797	.085	
[BE6] Aware of others	.087	−.018	.282	.264	.062	.734	−.043	.754 (2 items)
[BE1] Spontaneous	−.161	.196	−.219	−.114	.030	.479	.446	
[IN10] Object in control	.049	−.111	.137	.015	.084	−.011	.813	
[IN7] Needs accomodation	.086	.127	−.107	.397	.128	.148	.655	.581 (2 items)
[IN9] Me in control	.291	.380	.127	.170	−.168	.008	−.584	
Eigenvalue	6.56	3.90	2.22	1.51	1.27	1.09	1.00	
Variance explained (%)	24	14	8	6	5	4	4	

Fig. 1. The PCA results. The components capture perceptions of robot: 1—Effectiveness (24%), 2—Usability (14%), 3—Enjoyability, (8%), 4—Sociability (6%), 5—Aliveness (5%), 6—Responsiveness (4%), 7—Agency (4%). Percentages in brackets describe the percentage of the variance explained for each component by the rotated solution. The total variance explained is 65%. Scores above 0.600 are highlighted. The Cronbach Alpha's of these highlighted items are shown on the right.

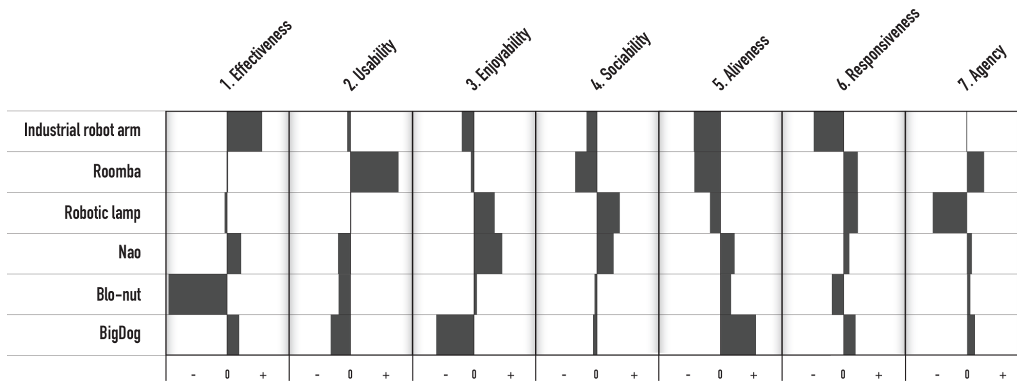


Fig. 2. Bar charts illustrating the projected regression scores for each robot video on every component.

Table 4. Overview of the Interpretations of the Component Results in a Conceptual Framework, the Robotic Exemplars That Informed Them, and the Discussion Points They Illuminate

	Prominent Robot Exemplars	**1. Effectiveness** *Functional value*	**3. Enjoyability** *Affective Value*
2. Usability *Robots as Products for Use*	Roomba, Robotic lamp	Robots that *fit* into their contexts of use	Robots that are recognized as *familiar product categories*
4. Sociability *Robots as Social Actors*	Nao, Robotic lamp	Robots that *collaborate* with people toward shared goals	Robots that evoke a sense of *companionship*
5. Aliveness *Robots as Animate entities*	Nao, BigDog, Blo-nut	Robots that make us of *bio-inspired* functions	Robots that evoke a mix of *wonder* and *anxiety*

(0.82) through its precise and smooth movements, particularly visible in its ability to trace a metal cylinder's curvature during a high-precision construction task. Its controlled motion patterns and clear task orientation strongly contribute to these perceptions. In contrast, Blo-nut scored lowest on this component (−1.40). Its behavior, characterized by the inflation and deflation of silicone air pockets, appeared more random and less controlled. The absence of clear task-oriented behavior and the unpredictability of its movements likely contributed to its lower effectiveness scores.

3.2 Usability

This component captures the familiarity with the artifact and ease of interaction, with strong loadings on and "resembling an everyday product" (0.700) and "instrumental use" (0.692). Additional correlations appear with "effortless to use" (0.641) and being "comfortable" to interact with (0.636). The Roomba robot scored the highest in usability (1.15), attributed to its familiar appearance and widely recognized use. As a commercial product frequently seen in advertisements and present in many homes, the Roomba is probably perceived as intuitive and easy to understand. In contrast, BigDog scored the lowest in usability (−0.52). Its complex embodiment, lack of familiarity, and ambiguous purpose might have made it challenging for participants to envision how they might relate to it and use it.

3.3 Enjoyability

This component reflects hedonic appreciation, showing strong loadings on "friendly" (0.759) and "fun" (0.693). Nao scored the highest in this category (0.71). The video showed its playful interactions, such as engaging children to copy its movements as part of making yoga postures. Its small stature, round face, and clumsy yet delicate movements could have evoked feelings of friendliness. BigDog, on the other hand, was positioned at the lower end of the spectrum (−0.88). BigDog may have been perceived as a more serious piece of technology but could also have elicited a sense of uncanniness (i.e., the item assessing "scary" has a considerable negative factor loading on Enjoyability of −0.581). This reaction may have stemmed from its quadrupedal, creature-like design, and life-like leg motions, which also appeared strangely human.

3.4 Sociability

This component emphasizes social interaction capabilities, with strong loadings on being perceived to be "empathic" (0.689), "communicable" (0.650), and "social" (0.648). The robotic lamp scored highest on sociability (0.55). Its zoomorphic, bird-like appearance may have provided it with cues for social interaction as it appeared to communicate by closely following human gestures shown in the video as a shared social activity. The Roomba scored lowest (−0.53). Its utilitarian, industrial design lacked such social cues and was shown in the video to operate alone, performing its cleaning function in a living room without any visible interaction with people or pets.

3.5 Aliveness

This component reflects animistic rather than machine-like qualities, with strong loadings on creature-like (0.726) and organic (0.723), and a slightly lower loading on human-likeness (0.598), just below the 0.600 threshold. BigDog scored highest in aliveness (0.88), its leg movements appearing fluid and spontaneous. Its ability to traverse rough terrain, coupled with its design blending its animalistic embodiment with human-like legs and motions, has likely contributed to its life-like appearance. The industrial robot arm scored lowest (−0.65), its machine-like embodiment and sequential, mechanical movements reinforce its machine-like identity, far removed from any organic or creature-like qualities.

3.6 Responsiveness

This component captures environmental awareness, with strong loadings on "aware of environment" (0.797) and "aware of others" (0.734). Both the Roomba and robotic lamp scored highest in responsiveness (Roomba 0.32; Robotic lamp 0.33). The Roomba demonstrated its awareness by navigating around furniture, while the robotic lamp responded dynamically to human hand gestures. The industrial robot arm scored lowest (−0.75). Its stationary position and task-specific movements within a confined space offered no indication of responsiveness to external stimuli or environmental changes.

3.7 Agency

This component reflects perceived autonomy, with strong loadings on "object in control" (0.813) and on "needs accommodation" (0.655). Additionally, just outside our set criterion, the item "me in control" loaded negatively on this component (−0.584). The Roomba scored highest in agency (0.43), which we believe can be attributed to its autonomous navigation through a living room environment. The robotic lamp scored lowest (−0.83); while following human movements closely while being on a desk, it lacked the independence exhibited by the Roomba.

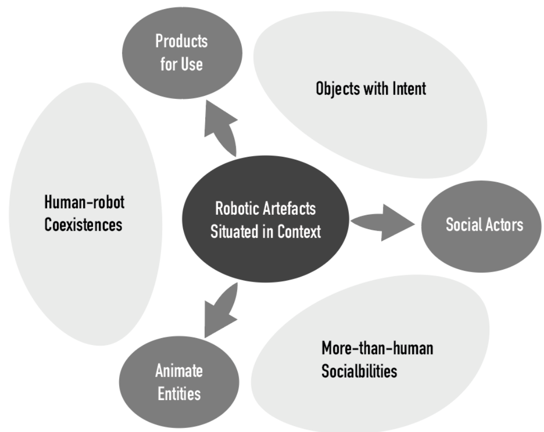


Fig. 3. Conceptual framework depicting multiple framings of robotic and their hybrid configurations.

4 Delineating Hybridity

Having identified seven distinct components through PCA that reveal how people perceive and interpret robotic artifacts, we now turn to an interpretative understanding of robot hybridity based on these results. After carefully reviewing the PCA findings by investigating trends by juxtaposing components in all different combinations, we selected three components that represent distinct interpretive frames of robots, two that reflect evaluative judgments, and another two that relate to autonomous behavior and people's responses to it. We emphasize that this has been an interpretive step in the research, in which the construction of a conceptual framework guided our interpretive decisions based on the analysis of the explorative PCA results (Table 4). We begin by discussing multiple framings and the values they address, followed by an exploration of how these framings come together in more complex configurations (Figure 3).

4.1 Multiple Framings

As a first step in our effort to delineate the hybridity of robotic artifacts, we explore how an artifact can be understood in multiple ways. To this end, we selected Components 2: Usability, 4: Sociability, and 5: Aliveness as indicative of three distinct interpretive frames of robotic artifacts that we have characterized as "products for use," "social actors," and "animate entities." Additionally, we interpret Components 1: Effectiveness and 3: Enjoyability as representing two different forms of valuing: "functional value" (how the robot serves practical purposes) and "affective value" (how the robot shapes emotional and experiential responses). We proceed by discussing these interpretive frames and forms of valuing in combination, with their prominent robot exemplars with their corresponding scores, each comparison highlighting different features of interest.

4.1.1 Products for Use. This framing of robots as "products for use" is informed from Component 2: Usability. We suggest that robots framed as products for use are understood as purposefully designed objects that operate within everyday settings using familiar modes of interaction. Among the examples, the Roomba and the robotic lamp are the only two robots that scored positively on Usability, though the robotic lamp did so at a borderline level (Roomba: 1.15; Robotic lamp: 0.02). Their functional value is interpreted to depend not only on how effectively these robots perform their behaviors but also on the extent to which they fit into their contexts. The Roomba exemplifies this through the integration of its cleaning function into a domestic environment. The affective value of robots framed as products for use appears to be tied to their intuitive use and alignment with familiar forms of interaction. While the Roomba has become an established product category in many Western countries, the robotic lamp, though still experimental, demonstrates traces of a known category by incorporating recognizable elements of a common household object (a desk lamp) into its robotic embodiment.

4.1.2 Social Actors. The framing of robots as "social actors" is derived from Component 4: Sociability. We suggest that such robots are assigned a social role across a variety of situations. This framing is exemplified by the Nao robot and the robotic lamp, which are the only two robots with distinctly positive sociability scores compared to the others (Nao: 0.40; Robotic lamp: 0.55). While Nao relies on explicit humanoid features, the robotic lamp uses more subtle, bird-like zoomorphic cues. This illustrates how sociability can operate through social affordances, shaped by the perception of robots as capable of intentional communication, social exchange, and forming relationships. In terms of functional value, robots framed as social actors can be seen as collaborative partners capable of working toward shared goals. Interpreting the video considering Nao's positive effectiveness score (0.31), we observe that facilitating joint activities, such as teaching yoga poses, relies on expressive capabilities that are instructive in nature and prompt human responses. This is less evident for the robotic lamp, which appeared somewhat simpler and clumsier in its movements (Effectiveness: −0.08). Both robots also received the highest Enjoyability scores (Nao: 0.71; Robotic lamp: 0.48), suggesting a strong link between social design elements and positive emotional responses. In the videos, this appears connected to their ability to evoke feelings of companionship through design cues that elicit social responses.

4.1.3 Animate Entities. This framing of robots as "animate entities" is informed by Component 5: Aliveness. We suggest that robots framed in this way evoke a sense of aliveness by mimicking aspects of the natural world. This interpretation is exemplified by BigDog, Nao, and Blo-nut, the only three robots that received positive scores on this component (BigDog: 0.88; Nao: 0.34; Blo-nut: 0.29). In contrast to social actors, animate entities seem to operate through animistic attribution; the ascription of life-like qualities rather than clearly articulated social capacities. The functional value of animate entities appears to stem from the effective application of biomimicry, that is, the use of design principles inspired by natural systems. For example, in the video of BigDog, the robot demonstrates its ability to traverse difficult terrain through animal-like locomotion (Effectiveness: 0.32). Similarly, Nao's movements reflect human biomechanics, supporting its functional role as a social actor, as discussed earlier. The affective value of robots perceived as alive is more complex and sometimes contradictory. Setting aside the Nao robot due to its strong Sociability score, Blo-nut's organic movements may have evoked a mild sense of enjoyment, as reflected in its slightly positive Enjoyability score (0.05). We interpret this effect as a sense of wonder elicited by its dynamic and expressive form. In contrast, BigDog's blend of life-like movement with a mechanical appearance may have triggered anxiety (Enjoyability: −0.88), as it could be perceived as disturbing. These results suggest that the affective impact of perceived aliveness depends on how bio-inspired features are implemented.

4.2 Implications of Robot Responsiveness and Agency

Components 6: Responsiveness and 7: Agency have been interpreted as experiences related to autonomous behavior and how people respond to it. We will further reflect on how these experiences may be implicated in the different interpretive framings of robots.

What stands out, and appears to be an intuitive observation, is that for robots to function as social actors, they likely need to be responsive to humans in their environment. This appears to be reflected in our results: both robots that scored positively on Sociability also scored positively on Responsiveness (Nao robot: 0.12; Robotic lamp: 0.33). In the robotic lamp video, for example, the robot appears to closely follow human hand gestures, albeit with some delay. However, in the case of the Nao robot, we suggest that a different phenomenon might be at play—an illusion of responsiveness. The robot's actions may be perceived as reactions to external cues, when in fact they follow pre-scripted behaviors. This scripting, coupled with children's anticipation of the robot's behavior, may create the appearance of responsiveness. In such cases, children might play along, reinforcing the illusion.

Regarding agency, it does not appear to align clearly with any of the three framings discussed. As described in the Results section, agency seems to manifest through the robot's level of autonomy or adherence to human commands, which is a key differentiator between the videos depicting Roomba (0.43) and the robotic lamp (−0.83). However, further insights into the perception of robot agency can be gained by analyzing the other video content. For instance, unlike stationary robots, mobile robots such as BigDog and Nao may have prompted people to consider how they would respond to the robot's movement by adjusting their own behavior, either by following it or stepping out of its way. Embodiment and materiality may also influence the perception of agency. The larger industrial robotic arm, with its hard materials and apparent power, likely demands caution, while the much smaller and softer Blo-nut encourages more direct bodily interaction. However, these observations serve to inspire further research rather than offer any conclusions.

4.3 Hybrid Configurations

A last step in the interpretative analysis is comparing these three different framings in their combination. Having established three frames, we now examine how they combine and interact as hybrid configurations (Figure 3). Figure 4 visualizes these configurations by mapping robots along paired dimensions, pointing out both productive combinations and inherent tensions. First, the Usability–Sociability plot suggests that social features can be integrated with practical functionality. The robotic lamp exemplifies this combination, achieving moderate to high scores in both dimensions. Second, the Sociability–Aliveness plot shows that some robots (like Nao) score highly on both dimensions, whereas others (like BigDog and Blo-nut) score high on aliveness but lower on sociability, providing support for the assumption that these qualities can be decoupled. This decoupling creates opportunities for different types of sociability, from explicit social engagement to more subtle forms of animacy. Third, the Usability–Aliveness plot reveals what appears to be an inverse relationship; as aliveness scores increase, usability tends to decrease. This pattern suggests a fundamental tension between these qualities. Based on these observations, we outline three key hybrid configurations.

4.3.1 Objects with Intent. Investigating the intersection of robots framed as both products for use and social actors reveals an intriguing hybrid configuration we term "Objects with Intent," following Rozendaal et al.'s suggested term [78]. The embodiment of the robotic lamp exemplifies this duality particularly well. Its design successfully integrates elements of a traditional lamp—featuring a lampshade-like component that emits light, evoking product familiarity—with a bird-like form, incorporating a body and head-like outline to create what might be described as a "lamp-creature." This duality manifests not just in form but in interaction. In the video, we observe the lamp following the person's hand gestures closely, allowing her to guide it to desired spots for illumination while carefully navigating along a path. This interaction blends both pragmatic and social qualities. It highlights the notion of shared control, where the robot's function emerges through the interaction as a form of physical dialogue between the human and the robot, while also emphasizing the social presence such hybrid objects can embody.

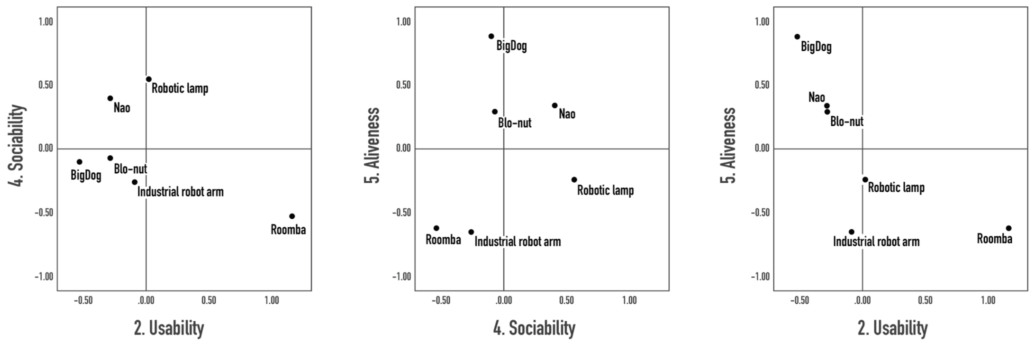


Fig. 4. Three plots illustrating hybrid configurations by mapping robots along paired dimensions. Left: Usability and Sociability ("objects with intent") Middle: Sociability and Aliveness ("more-than-human sociabilities"). Right: Usability and Aliveness ("human–robot coexistences").

4.3.2 More-than-Human Sociabilities. Our analysis reveals that while sociability and aliveness often interrelate, they represent distinct attributions, illuminating what we would like to refer to as "more-than-human sociabilities." These interactions exist on a continuum: at one end, communication occurs through artificial bodies resembling human forms using culturally established signs; at the other, communication emerges with nonhuman artificial entities, fostering novel interaction modes through empathetic human understanding. The term more-than-human is used to emphasize the expansion of nonhuman perspectives, both biological and technological [16], thereby opening up novel approaches to HRI. When reflecting on the crossovers between the "social actor" and "animate entity" framing, the Nao robot exemplifies how a humanoid form enables the simulation of human-to-human communication through culturally recognizable gestures such as bowing or waving. Conversely, the robotic lamp, although "sociable" but not particularly "alive," encourages different interaction patterns reminiscent of animal-like engagement, without relying on explicit cultural references. In contrast, BigDog and Blo-nut are perceived as "alive" but not particularly "sociable." BigDog's animal-like movements clearly convey a sense of aliveness, yet its lack of recognizable interaction cues makes social engagement challenging. Blo-nut, however, evokes aliveness through its dynamic materiality: its soft, responsive behavior invites exploratory tactile interaction, opening up possibilities for novel forms of social engagement that move beyond more established ones.

4.3.3 Human–Robot Coexistences. A particularly interesting tension emerges when examining the combination of framing robots as both "usable" and "alive." Notably, no single robot in our study fully expressed this hybridity, not even at a borderline level. This absence may suggest a fundamental tension, potentially of an ethical nature, where the utilitarian use of something perceived as alive evokes uncomfortable feelings of exploitation. This tension raises important questions about the nature of what we refer to as "human–robot coexistences": how should we relate to entities that are ambiguous in their artificiality yet display clear intents and agencies, while also considering their social–ethical implications, as addressed by Friedman [32]? Such interactions might require new forms of relating and a new vocabulary may be needed to understand and describe these entities, potentially drawing from novel frameworks in postphenomenology [97] and posthuman thinking [4].

5 Pathways to More Thoughtful Design

To summarize, we suggest three distinct ways in which people interpret robotic artifacts, guided by patterns in the empirical data. First, robots can be interpreted as products for use when they are recognized as belonging to familiar product categories and fitting into known contexts, as demonstrated by the Roomba. Second, robots can be seen as social actors, where social features support collaboration and companionship, as exemplified by Nao. Third, robots may be perceived as animate entities, drawing on bio-inspired functions that can evoke wonder, but also anxiety, as seen in Blo-nut and BigDog. Importantly, our analysis suggests that these interpretive frames are not mutually exclusive but can combine in various ways. Some combinations appear productive. For instance, robots that integrate sociability while also being recognized as familiar products, what we describe as "objects with intent," are embodied by the robotic lamp. "More-than-human sociabilities" expand the design space for sociability beyond humanoid forms, as illustrated by juxtaposing Nao and Blo-nut. However, we also perceived what appear to be tensions, particularly between usability and aliveness, that seem difficult to reconcile in robotic artifacts, prompting us to reflect on "human–robot coexistences." These findings suggest that robot hybridity, that is, the ability to evoke multiple interpretations interchangeably and simultaneously, is both an opportunity and a challenge for design. Moving from analysis to practice, we now explore how understanding these patterns can inform more thoughtful design approaches in HRI before reflecting on important study limitations.

5.1 Key Considerations for Leveraging Hybridity

The results presented here suggest pathways toward a more thoughtful design in HRI that leverages the multiple attributions to create robotic systems that move beyond dominant stereotypes. Design is gaining traction in the HRI community [15, 60, 61, 62]. Our use of thoughtfulness is inspired by "Thoughtful Interaction Design" coined by Löwgren and Stolterman [59], who state that thoughtful design involves critical reflexive mindsets that involves both ethical and esthetic judgments. A key principle guiding this process is the concept of "appropriateness," also discussed by Cross [19] to describe the suitability of a design in relation to its intended purpose and context of use. It is not uncommon for commercially available robots to be used in applications that may challenge their appropriateness, often involving stereotypical robots assigned to fixed categories based on their application. These application-domain categories (industrial, service, social, etc.) are problematic because they impose predetermined types on robotic artifacts. Our empirical findings demonstrate that such categories are inadequate for capturing how robots are perceived and experienced. Specifically, our results suggest that framings often cut across these categories, revealing how rigid classification can obscure the combination of diverse qualities that determine a robot's appropriateness for particular contexts and purposes.

We continue by discussing how thoughtful design with hybridity in mind, involves a sensitivity about how conceptualizing robot function involves the value of multiple attributions that may be synergetic or in tension with one another, and how robot movement, behavior, and embodiment can be read in multiple ways. Different combinations of these meanings may be considered more or less appropriate for specific applications. Even a robot's uncanniness could be considered appropriate in specific situations. In unpacking key considerations for more thoughtful design, we will follow Gero and Kannengiesser's framework on the anatomy of design [35], addressing points of attention related to the design of a robot's (1) Function, (2) Behavior, and (3) Structure. We use a speculative bedside nursing robot as a timely and relevant example in robotic design and HRI to demonstrate how considerations of hybridity can shape design choices and outcomes.

5.1.1 Function. A more thoughtful design approach to creating robotic artifacts that elicit specific interactions and experiences begins with an understanding of the robot's purpose and context of use. This requires a careful analysis of the identified need or problem the robot is intended to address. In design theory, the problem-solution space is understood to co-evolve [25], meaning that a design develops in dynamic interaction with the opportunities and constraints of its environment. This iterative and relational perspective encourages viewing robotic artifacts as bespoke design solutions shaped by their intended functions and context of use, from which meaningful interactions and experiences can emerge.

For example, when thinking about a robotic artifact designed to support nurses in bedside care, the image of a robotic arm, like the one referenced in our study, may intuitively come to mind. One might envision how this technology could be engineered to assist a nurse in lifting a patient, helping a patient out of bed, or supporting turning maneuvers, based on a careful analysis of nursing activities related to movement and body mechanics. A more thoughtful approach to its design extends beyond this isolated task situation and adopts a more relational perspective. For instance, how might the presence of the robot affect nurses' and patients' experiences? How will its use be socially coordinated among nurses within the team and mediating the patient–nurse relationship? How will the robot be perceived as an animate entity, make people feel comfortable in its presence? These broader considerations that inform its purpose and define its function, touch on all three interpretive frames.

Equally important is how the introduction of new technology connects to culturally established forms and practices [82] while also facilitating transformation by giving rise to new experiences and forms of activity [50]. Designing a robotic artifact to support nurses in bedside care will inevitably transform bedside practices, as previous routines may become obsolete or reconfigured, leading to new experiences, altered perceptions of work, and shifts in how bedside tasks are valued. Recognizing this parallel with the co-evolution of the problem-solution space enables designers to create robots that fit within specific contexts of use while also identifying opportunities for meaningful change. This calls for an iterative approach to how people's framing of robots take shape.

Leveraging hybridity in design, therefore, means allowing the robot's role as a mediator for change to emerge from the analysis of the problem-solution space as contextually rich, rather than oversimplifying or relying on stereotypical or benchmarked solutions *a priori*. This approach inevitably requires considering multiple and blended framings of robotic artifacts, due to the diverse relations they establish and the varied impacts they have. It also calls for sensitivity to the cultural context of the design project, as well as anticipation of how robotic artifacts may meaningfully transform the contexts in which they are situated.

5.1.2 Behavior. A more thoughtful design approach to designing robot behaviors begin by conceptualizing them as inherently expressive, since behavior inevitably carries multiple meanings through processes of human attribution [56]. A common pitfall in human–robot communication design is attempting to map one movement to one function or message, overlooking that sociability is not an add-on but a constitutive part of its behavior. In practice, the mechanical control and timing of a single movement can be read as clumsy, gentle, confident, or even as anxious. Thoughtful design therefore treats expressiveness not as a problem but as a creative resource, using ambiguity as a productive space for shaping experiences and interactions.

More-than-human sociabilities can help explore and articulate which expressive qualities might be appropriate in a given context of use. In the bedside nursing example, the design may involve creating motion qualities that feel attentive or gentle, such as initiating a robot movement gradually rather than abruptly. The effective execution of basic support functions may itself be perceived as considerate or empathetic [41]. For instance, by showing pliability during collaborative action with nurses or demonstrating sturdiness when a patient relies on it for support. Adding a communicative layer, such as a human-like voice, can draw on culturally familiar cues to clarify the robot's autonomous actions. However, this may also raise unintended expectations, inviting conversations the robot might not be equipped to handle, or causing discomfort and potential privacy concerns when an apparently intelligent entity is continuously present in a patient's personal space. See Złotowski et al. [101] for a broader discussion of the opportunities and challenges of anthropomorphism in HRI.

Performative approaches are well suited to determining which expressive qualities are contextually appropriate. Viewing robot behavior as performative means treating meaning and interaction as emerging from people's situated encounters with the robot [10, 34, 81]. From this perspective, designers may determine how a robot's expressive behaviors should take shape by at times avoiding attention, at other times explicitly prompting engagement, and at times subtly supporting collaborative actions. A performative approach calls for exploring these qualities iteratively through simulation and prototyping, from low to high fidelity, or through speculative enactments in which possible future situations are explored while remaining grounded in current realities [27].

Leveraging hybridity in design embraces expressiveness as intrinsic to robotic behavior, can draw on more-than-human sociabilities to guide what kind of expressiveness is appropriate, and employs performative approaches to determine this appropriateness in context. Leveraging hybridity in this way acknowledges the rich expressive potential of robots and supports the development of behaviors that balance their animistic, sociable, and product-like framings.

5.1.3 Structure. Last, a more thoughtful approach to HRI aligns with the classical Bauhaus adage "form follows function," echoing Gero and Kannengiesser's [35] emphasis on function, behavior, and structure as integrated wholes. For designers in Industrial Design and HRI working on the embodiment of robotic artifacts, this means balancing material choices, formal features, interaction affordances, and associative meanings so that the robot's form expresses its intended function and mode of engagement. Insights from the notion of product character [45] and form-giving practices in design [17], along with more recent work articulating computation and intelligence through form [79, 95, 99], offer valuable resources for achieving such integration.

Returning to the nursing example, the question becomes: what should a bedside nursing robot look like? The blending of framings complicates this decision, since material and morphological choices inevitably cue different interpretations. Designing the robotic artifact as a "smart medical device" may resonate more with rigid, curved surfaces (associated to a product-oriented framing), while a "friendly assistant" may involve softer materials and subtle anthropomorphic cues (associated with an animate-oriented framing), while avoiding feelings of uncanniness. A more radical stance is to focus on the bed itself as the robotic artifact, directly engaging an "objects with intent" framing. A critical design consideration is remaining aware of all these elements and skillfully integrating them to achieve the desired outcomes [84], striving for conceptual fluency and avoiding discordant associations [76].

To summarize, leveraging hybridity in design requires treating robot embodiments as integrated wholes. By drawing on human experiences and understandings of both the living and the artificial metaphors, and blending them with care, designers can harness multiple meanings productively while avoiding the tensions they may bring. Reflecting on Cross's concern with appropriateness in design [19], maintaining attention to appropriateness throughout the design process provides a powerful counter to relying on pre-existing stereotypes. Instead, it encourages thoughtfulness, aligned with Löwgren and Stolterman's [59] definition, through focusing on what is truly required when crafting bespoke robotic artifacts.

5.2 Study Limitations and Future Work

We begin our discussion of study limitations by addressing the selection of robotic exemplars, which inherently constrained our study design. In retrospect, we implicitly focused on robots as external entities rather than those that are worn or physically integrated with the human body. For instance, wearable robotic technologies, such as exoskeletons or prostheses, were not included in our sample. Zhu et al. [100] reviewed soft wearable robotics as an emerging category, highlighting their novel applications and discussing key issues around embodiment and experiential qualities, offering a valuable avenue for future exploration. Similarly, airborne robots such as drones constitute another category that was excluded from this study. Tezza and Andujar [92] provide a comprehensive review of HRI topics related to drones, while Eriksson et al. [28] creatively explore how drones enable new forms of relationality and interaction. Including these robot categories in future research could deepen our understanding of hybrid configurations, particularly as the convergence of wearable technologies and robotics challenges the traditional view of robots as entirely separate from humans. Additionally, it broadens the scope of HRI to include interactions not only with individual robots but also with distributed robotic systems.

The use of video stimuli to explore robot hybridity limits the scope of our findings, as it presents only a single interaction sequence within one context. Real-time interaction with an actual robot in a real-world setting would likely reveal additional nuances, such as how multiple framings can build up over time depending on how interactions unfold, how they may shift dynamically, and how hybrid understandings become stabilized or disrupted through ongoing engagement (see Karaosmanoglu et al. [51] for a recent study on this topic). Moreover, because participants viewed footage of only one robot in one context, we cannot draw conclusions about how different contexts shape the perception and appreciation of robots. For example, seeing a Roomba navigating around people might evoke a sense of sociability, while observing BigDog used as a practical tool for transporting goods alongside human workers might reduce feelings of alienation and instead position it as a product for use.

The sensory limitations of video introduced further constraints. Presenting grayscale, soundless video introduced several confounding factors by diminishing the richness of sensory engagement with robots. This is particularly relevant for understanding and framing robot identity. For example, Benford et al. [8] have demonstrated that the tactile dimension is a primary modality through which people make sense of the world—an increasingly important consideration in HRI (and in particular in relation to experienced safety). Sound is another essential modality [67, 72]. Pelikan et al. [74] proposed a workshop to explore sound generation in robots, evaluation methods, and theoretical perspectives. A recent special issue in this journal [77] further emphasized sound as a crucial element in robotic design and interaction. We see strong potential in incorporating sound into the study of robot hybridity, building on prior work in product experience, such as that by Özcan and van Egmond [73], who showed how auditory elements shape users' experiences and perceptions of interactive systems.

Although we developed our items based on a thorough review of existing literature, our choice of dimensions to evaluate inevitably reflects our theoretical preconceptions. This preselection carries the risk of obscuring emergent or unexpected dimensions of the hybrid robot experience. Important perceptual qualities, such as perceived temporality of movements or subtle emotional resonances, may be underrepresented or entirely absent from our evaluation framework.

Regarding our treatment of emotional dimensions, our questionnaires focused on attributes like "fun" and "friendly" but inadequately explored the full range of emotional responses that robots might elicit, such as fascination, distrust, ontological uncertainty, or attachment. These emotional nuances could play a crucial role in the formation of hybrid interpretive frames. For future research, we recommend a mixed methodological approach that integrates standardized questionnaires with rich qualitative methods. This methodological triangulation would notably allow researchers to explore how hybrid interpretations fluctuate and recombine during prolonged interactions or how cultural and personal contexts influence perceptions of hybridity.

Finally, we must consider our participant sample in light of cultural differences. Most participants were Dutch citizens affiliated with higher education, representing a specific Western European context. The three interpretive framings we articulated, products for use, social actors, and animate entities, are likely culturally situated, and the hybrid configurations we presented may be valued differently across cultural contexts. For instance, what counts as "familiar product categories" (our usability component) depends strongly on local market availability and domestic practices, and the opportunities and tensions we identified as part of hybrid framings may reflect a Western perspective, which other cultures might navigate differently. This echoes Šabanović's call, already made in 2010 [82], to include cultural and social contexts in the design, use, and evaluation of robotic systems. More recently, Lim et al. [57] reviewed cultural influences on HRI, showing how culture and cognition jointly shape how people perceive, interact with, and value robots, and similarly advocate for a culturally informed approach to HRI. Recognizing and embracing these cultural influences may shape how hybridity is conceptualized and valued, not only in terms of anthropomorphism or the perception of animism in everyday objects but also in relation to the tolerability of robot agency and expectations of socially appropriate robot behavior.

6 Conclusion

This work contributes to developing design approaches in HRI by delineating the hybridity of different types of robotic artifacts. Our findings suggest that robotic artifacts elicit multiple attributions based on their design features—such as embodiment and behavior—as perceived in specific contexts. Through this analysis, we discussed three different framings of robotic artifacts, impacting their perceived functional and affective value. Robots framed as *products for use* integrate functional capabilities in ways that make them usable in everyday settings for which their familiarity is key. Robots as *social actors* have functional value due to their collaborative abilities and affective value through the companionship they provide. Robots as *alive entities* have functional value using biomimicry to create effective behavior, and they have affective value by evoking a sense of wonder, which may also trigger feelings of anxiety.

Comparing combinations of these framings, uncovered design opportunities and tensions in HRI. For example, as a hybrid form, *objects with intent* combines a robot's framing as products for use and social actors, leading to opportunities for designing everyday things as collaborative partners. Robotic artifacts that combine social actors and alive entities brings to the surface a range of *more-than-human sociabilities*, expanding interaction possibilities that range from empathy-driven interactions to semiotic communication based on cultural signs and scripts. Last, juxtaposing alive things as products for use, sparks discussion about *human–robot coexistences*. This perspective encourages reflection on how we relate to artificial nonhumans that show signs of animism, highlighting the moral implications involved.

In conclusion, *more thoughtful HRI design* should leverage these multiple attributions to create robotic systems that move beyond dominant stereotypes, fostering more meaningful interactions while remaining mindful of potential pitfalls. We suggest that this can be achieved by embracing design approaches that treat robots as integrated, expressive wholes, where materiality, embodiment, form, and behavior are all interconnected elements shaping how robots are experienced, interacted with, and valued. Furthermore, robots are interpreted in relation to their purpose and the context in which they are used, with appropriateness serving as a key reference point. We advocate for greater visibility and broader adoption of design methodologies within HRI, as well as increased collaboration between designers and engineers—efforts we believe will strengthen and enrich the field and better equip the HRI community to address real-world challenges.

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