Applied speculations in the baggage hall: Transdisciplinary thinking around robotic work futures

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Robotic technologies are often proposed to relieve dull, dirty, or dangerous work, but may cause work to instead be experienced as boring, or dehumanized. Understanding the impact of robotics on the workfloor is complicated by the entanglement between emerging robotic capabilities, social dynamics, and organizational issues – which we call Worker-Robot Relations. Consequently, the impact of robotics on work is often studied in hindsight. Speculative design methodologies can facilitate alignment of robotic developments with a meaningful future of work, by creating boundary objects for communicating about current and future work practices. Making use of an unfolding artistic collaboration, we propose an experiential approach for speculating about future Worker-Robot Relations. We enabled speculative encounters between participants and robotic creatures that embody seven meta-behaviors. We abstracted these from observed behaviors in a current work context in baggage handling. We present the findings from focus groups responding to these encounters, including implications for HRI and speculative design.

CCS Concepts: • **Computer systems organization → Robotics**; • **Human-centered computing → Human computer interaction (HCI)**; • **Applied computing → Media arts**; **Industry and manufacturing**.

Additional Key Words and Phrases: Human-Robot Interaction, Applied speculations, Research through Design, Industrial robotics, Meta-behaviors

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1 Introduction

Robotization—the strategic design of robotic innovation processes—is a specific type of technological intervention that can support work at the physical, psychological, social, and organizational levels [93]. Robotization of work processes has typically been driven by the practical thinking that tasks should be automated and taken over by robots when "dull, dirty or dangerous" – the '3 Ds' of robotization. However, this framing is insufficient to provide guidance when introducing robotic technologies in organizations and workfloors [90] as they do not account for the full range of motivations driving robotization, including organizational and political factors [30]. This has led to the addition of other Ds to the list, such as dear [67], and delicate [95]. In addition, approaching robotization only through the perspective of its practical advantages leads to overlooking the complex social and ethical effects that come into play when robots enter the work environment, especially around questions of whether robotic capabilities are seen as collaborative extensions to humans or replacements for their labor.

This tension leads to a widening between what robotics experts believe to be possible, what managers believe to be productive, and what workers think is preferable [69]. The challenge of developing preferable futures with emerging technology is not unique to HRI. Many disciplines have investigated ways to rethink and re-imagine possible pathways and relations, often emphasizing the crucial role of metaphors, symbols, myths, stories, and legends for nurturing social imagination [39, 70]. Among these, alternative design methodologies, such as design fiction and material speculations [77] and speculative enactments [36, 91] have been suggested as powerful ways to stimulate social imagination around possible technological futures [10, 37, 92]. In particular, fictional, counterfactual, and provocative artifacts are used in these practices as boundary objects [87, 94]. Boundary objects are artifacts that are "plastic enough to adapt to local needs... yet robust enough to maintain a common identity across sites" [87, p. 393]. In other words, they have both sufficient coherence to give precision to debate, but open enough to allow diverse audiences and disciplines to engage in conversations about social and political consequences of technological innovation [99, 105]. While HRI has engaged with many of these possibilities [e.g. [4, 7, 31, 48, 56, 57, 62, 81, 103], the specific field of work robotization still lacks examples of creative, critical, speculative processes that support the design of preferable futures, and questions remain regarding whether such an approach would be helpful in a context strongly characterized by hierarchical structures, practical objectives, and values of progress and efficiency. We see a challenge for researchers to bring diverse stakeholders together and balance the ambition of encouraging free roaming of ideas and novel or lateral thinking while also preventing a drift towards fantasticating or falling into the well-trodden pathways of utopias and dystopias.

This paper asks what kind of artifacts and practices can support dialogue and collective social imagination among different stakeholders about the possibilities of work robotization while also providing anchors to connect back to the particularities and requirements of an industrial work environment. The work is carried out as part of a transdisciplinary project that centers around a case study carried out in collaboration with the baggage handling hall of Schiphol airport, stemming from a research partnership with TU Delft. Transdisciplinarity is a complex topic, and here we follow van der Bijl Brouwer's description [96] of interweaving complex processes that aim at i) integrating multi-level knowledge towards a common purpose within different academic disciplines; ii) establishing participative collaborations between the real world knowledge of non-academic stakeholders, and researchers from several academic disciplines, in order to re-frame societal and technological problems; iii) tackling complex challenges in order to guide the system or the context towards a desired direction, relying on processes of social learning. The work here is a small part of this process, aimed at enabling integration of knowledge (i) and supporting connection between stakeholders (ii). While this early-stage work incorporates direct insights from workers, gathered through the project, its primary focus was on exploring and refining knowledge within the project itself. It operates within the framing questions defined by the broader context.

The work is developed with a view to transdisciplinary practices that can engage with social quality-of-life questions as well as technological ones [51]. We draw on experiential methods as well as speculative practices to investigate future possibilities for the robotization of parts of the baggage handling process. We start by developing a notion of 'meta- behaviors': a new approach to capturing physical, cognitive, inter-relational, and interactive performances occurring in a specific workfloor and abstracting them to such a degree that they maintain a link to the source context while also being able to refer to others. The meta-behaviors were identified through observations conducted on the workfloor, and translated into 'robotic creatures' by a group of students supported by international artistic practitioners. We decided to use the term robotic creature to differentiate them from real-world research and commercial robots, stressing their provocative and reflective nature over their applicable functionalities.

The results of this materialization were instantiated in an immersive exhibition and experience. Visitors were asked to engage with the robotic creatures and speculate on their relations to the meta-behaviors, the work context, and the future of robotics. After this exploration, we used focus group sessions to both i) understand visitors' experiences and ii) connect these to speculations about the future of work in the Schiphol baggage hall.

As a whole, the paper contributes:

- The concept of meta-behaviors as boundary objects that support discussion around future work robotization, bringing knowledge from an industrial context into connection with a creative, speculative process.
- Demonstration of the possibilities afforded by experiential creative methods for work robotization.
- Qualitative findings from the focus groups that show how the experiential translations of meta-behaviors can foster rich and grounded discussion about human-robot futures, yet their craft and use are non-trivial. We ask:
  - RQ1: *Were the creative embodiments of meta-behaviors as immersive experiences comprehensible to participants and relatable to industrial robotic capabilities?*
  - RQ2: *Were the meta-behaviors and robotic creatures effective in fostering visitors' critical thinking concerning robotic work futures?*
- Reflections on boundary objects and intermediate-level knowledge as key enablers for a relational, design-driven approach to HRI.

The remainder of the paper is organized as follows. First, we provide background on related work, addressing developments in HRI, design as a space for social imagination, and HRI designed speculations. Next, we detail the broader research context, how we identified the meta-behaviors, and the design process that led the students to creating the robotic creatures and the exhibition. In Section 4 we describe our research methods, procedures, and materials. In Section 5 and 6 we respectively delve into our results and discuss them in relation to transdisciplinarity, intermediate-level knowledge, and boundary objects. We conclude the paper pointing out possible trajectories for future developments.

2 Background

The core background for this work is in design rather than HRI, as we are interested in the design techniques that fill a research gap in that space. In particular, it is motivated by calls for a designerly approach to research and knowledge in HRI [60, 61, 74], as well as questions of how we can carry out HRI knowledge work using intermediate-level knowledge [27, 49]. We are further interested in a question of what pragmatic approaches support transdisciplinary work with industrial stakeholders.

2.1 Developments in Human-Robot Interaction

In the last decades, industrial robotics has reoriented towards the development of collaborative robots (cobots) intended for "direct physical interaction with a human user within a shared workspace" [28]. These robots are designed to avoid the need for physical barriers and cages, by working with lower speeds and forces and being responsive to conditions around them [21]. This paradigmatic shift towards worker-robot collaboration has led to a flourishing in HRI research that extensively engages with matters of mutual understanding. This includes developing the concept of shared mental models [43, 72, 73, 83]; exploring ways to enable effective turn-taking [18, 44]; providing workers with opportunities for programming robots themselves [14, 75]; shared control [1] and enabling robots to navigate work environments in a socially acceptable manner [66, 85].

Alongside technical aspects of direct interaction between robots and workers, researchers have been paying increasing attention to the effects of robotization at the social, organizational, and political levels [8, 13, 21]. Robots were observed to positively affect work motivation when successfully contributing to employees' positive development and fostering the basic psychological needs of perceived autonomy, relatedness, and competence [93]. Robots were also found to have significant effects on work dynamics, from altering roles and relations to triggering jurisdictional disputes [8] and raising ethical concerns [97], such as human deskilling [8] and job loss [98]. In this regard, scholars have started to call for more holistic and responsible approaches to work robotization, arguing for the need to understand not just the perspectives of diverse stakeholders [22] but also their potentially contrasting values: for instance, tensions between efficiency and profit versus quality of working life and personal growth [13]. It has become evident that the design of robotization processes needs to start from mapping out the 'what, how, and why' of bringing robots into the design of work, identifying and shaping how relations between robots and human workers will develop [107].

The HRI community has engaged with these areas of concern, in particular through welcoming diverse epistemologies such as feminist theories [103] and the social construct of mutual shaping of technology and society [82], as well as moves towards transdisciplinary practices [5]. However, challenges remain that the repercussions that robots might have on the work environment are both serious, yet hard to foresee and prevent.

The design of robots, and HRI, is particularly fraught, as these artifacts come embedded into a rich imaginary of super-human entities [15] and non-human superpowers [71]. Even more so than other technologies, the marvelous capabilities of robots stimulate fantastications about how current practices can change, while also inhibiting social imagination about how people might fit in these imagined futures [69]. This adds up to a contemporary societal inability to imagine alternative futures, especially better ones, a problem commonly described as a crisis of imagination [3, 69]. The challenge, then, is how to imagine plausible, achievable, and socially desirable robotic work futures.

2.2 Design as a space for social imagination

The design discipline, especially in its alternative and critical declinations, is regularly engaged with finding ways of nurturing our social imagination around technological innovation. Design looks at how technologies, when situated in existing contexts, have the capacity to redefine these and create new contexts too [31], and operating under the acknowledgment that not only do we shape technology, but that technology shapes us back [65]. The material or mediating experience of design artifacts creates 'possibilities to reason upon' and blurs the boundaries between what is actual and what is possible [99]. Material Speculations — as Wakkary et al. [99] call these practices — are powerful not only because of their capacity to offer alternatives in the form of artifacts, but more importantly because these invite reflections on what would be the necessary conditions for these artifacts to exist. More generally, experiential work can help to make technical concepts visible and available for critical engagement [47], such as to speculative enactments [36, 91] where participants act out potential futures as a route to critical engagement.

These embodiments can take many forms. Steering wheels become a vehicle for imagining alternative futures around driving automation [58]; hairdryers become symbolic representations of alternative autonomous energy futures, offering different performances to support deliberation [79]; a digital camera becomes an object to articulate how abstract interaction principles such as inhibition can be translated into material forms [78], or to explore particular characteristics of technology [11].

When employed in participatory processes, design fiction and speculation can facilitate diverse stakeholders navigating the unfamiliar and uncharted territories opened up by novel technologies, in a fashion that is often deeply engaging yet humorous [54]. The very counterfactual nature of these explorations encourages the public to gain a meaningful understanding of technology and its societal embedding, and to imagine possible alternatives [38].

Speculative artifacts are increasingly employed in design research as boundary objects [40, 86, 87, 94] whose plasticity enables the transfer of knowledge and mobilization of design activity between diverse, interdisciplinary groups. This facilitates debate between strategic stakeholders who might have contrasting values and interests, for example, cognitive robotics engineers, innovation managers, civil servants, and road safety experts developing futures for driving automation [58].

2.3 HRI design speculations

Speculative and critical practices are gaining popularity in HRI research, especially as it looks to develop public and social applications of robotic technologies. There is an emerging realisation that research into robotic technologies needs to take into account the socio-material complexities of the situations into which they are deployed [33, 34, 76], coupled with a history of using speculation around robots that goes back to the beginnings of speculative design practices [7], as a way to open up alternative modes of thought about what the technologies are and do. We identify four key strands in this space, that we situate our work relative to: speculation for conceptual development; speculation to understand values and their tensions; speculative robots to experientially engage publics; and co-speculation as a design tactic for complex situations.

Conceptual speculative approaches work at a high level, leveraging creative techniques to critically engage with preconceived ideas about what robots are, should do, and for which ultimate purpose should be deployed [7, 60, 85]. As an early example, Auger [7] uses speculative design methodologies to emphasize the importance of understanding robots not only in utilitarian, instrumental, terms, but also from a socio-relational perspective where domestication, a principle radically opposed to efficiency and autonomy, can become a meaningful concept to think about how to design robots that are supposed to live with us. Alves-Oliveira et al. [4] explored the use of visual and conceptual metaphors to help re-conceptualize robots and break free from dominant assumptions and norms around morphology, utility, and relationships. Hoggenmueller et al. [[50] extend this approach by using text-to-image generative AI tools to let researchers' imagination room free and far away from existing and familiar configurations, while Cho takes this into posthuman speculation [25] and ways to think about relations with things that have minds [24]. Finally, Chen et. al use a speculative framework to re-imagine the relations between robots and ecology, through participatory design processes [20], and Winkle uses sociotechnical fiction to interrogate far futures and support meaningful discussion in the HRI community [102].

Dropping down from the far future, value-oriented speculative works provide the community with visual and semantic approaches that not only help us imagine robots otherwise, but first and foremost invite us to understand, reflect upon, and question the assumptions we hold, and the values we carry in our HRI design work. Cheon and Su [23], for instance, asked 23 roboticists to write fictional autobiographies and to articulate what facts and steps would have led to these imagined futures, as a way to elicit individual views, values and aspirations, and reflect upon how these related to HRI work. With a similar ambition to emphasize the importance of understanding personal values and how these affect HRI design, Luria et al. [62] engage with the concepts of destruction, catharsis, and emotional release in stark contrast to values of efficiency and strength. By illustrating how these concepts could translate in robot designs, the authors discuss and exemplify how the HRI community could account for robots' non-utilitarian values.

Experiential techniques are used to engage publics and stakeholders with speculative robots. Hoggenmueller et al. [48] developed a robot able to draw with chalk on the street as an experiential manifestation that triggers debate about robots' role in public placemaking; Lee and Jung [56] explored the potential value of a ludic approach to re-imagine the role and value of robots, materialized through a bubble-blowing robot. Beyond purely ludic approaches, speculative enactment [36] has been used as a tool to look into the expressive movements of robots in service roles [55], and theatre practices give a way to speculate about embodied meaning making [41].

When working into complex environments, co-speculation – the crafting of speculative possibilities in collaboration with publics – can be a tool to help users, workers, bystanders and so on to bring their knowledge into the process of shaping robotic technologies. Chen et. al [19] use a card game to create speculative scenarios to understand the affective ecologies of domestic robots, and help non-experts take a combinatorial approach to designing robotic technologies. This approach can be seen in related technologies such as hybrid working environments [17], smart homes [26], human-thing interactions [26, 100], transhuman communication [42] or other digital infrastructures [80, 91], but is under-explored in HRI. Co-speculation can take many forms: Brunnmayr and Weiss use roleplaying games to create narratives of future robotics [16], enactments of various forms give a substrate to speculate from [26], while Ahmed et al. [2] generate a design space that can be leveraged by designers and researchers in creating companion robots.

Overall, speculative HRI design work then pushes the community to extend its thinking and sense of responsibility not only to the present, but also to the future, asking for an explicit commitment to delineating desirable robotic imaginaries as a way to drive change towards positive human-robot futures [106]. In this vein, Lupetti et al. [57] explore the concept of citizenship to focus on matters of relationality and interdependency when robots operate in public and are entangled in networks of human and non-human relations. Collyer-Hoar et al. use speculation to explore the hopes and fears that children have around social robots [29]. Outside of robotics, speculative methods help to understand workers' imaginaries of their futures, in support of designing the jobs they might want to move towards [64].

2.4 Synthesis

These examples show a growing range of speculative practices in HRI; however, despite some recent examples, most speculative work in HRI is concerned with either the domestic sphere or the public realm. The domain of work robotization tends to lack research leveraging creative and imaginative approaches to address future worker-robot relations. This may be due to the early adoption of industrial robots, leading to a conception that their configurations, roles, and values are strongly determined; it may also be that it lacks the frontier 'what-if' feeling of other robotic developments. However, it is precisely here where practices and configurations have crystallized that there is an extreme need for social imagination. The complex intertwining of economic, social, political, and technological factors playing a role in work robotization points to a tremendous need for imagining and designing alternatives, and for supporting discussion on how these alternatives could come to be. Speculative design has a complex history; while it is often seen as creative and critical, it also has a corporate history, as a tool for developing technological innovation where the social conditions of technology are as important as its function [104].

Hence, we are investigating what we call *applied speculation* within an industrial context as a relevant means to identify viable alternatives of fruitful relationships between humans and technology [84] and to challenge dominant views and practices [104]. The rest of the paper reports on an exploration of speculative and imaginative approaches for redefining robotic work futures together with a wide array of stakeholders, and we engage with the term *applied speculation* in Section 6.1.

3 A speculative exploration of robotic work futures

To explore the idea of speculations for robotic work future we relied on the concept of meta-behaviors: behavioral primitives that do not define any specific course of action but point to behavioral patterns that are observable in a range of situations, like asserting control over a system. Echoing a shift from thinking about 'robots' to thinking in terms of 'robotic capabilities' [45], meta-behaviors were used by the research team as an abstraction of physical, cognitive, interactive, and inter-relational performances and repeating patterns that employees usually execute during their activities. These were intended to engage with the distinct nature of robotic creatures, such as the capability to exhibit autonomy and cognition, and their physicality [85], while avoiding getting stuck in current configurations of industrial robotics. Within the context of larger research project (Section 3.1), we carried out a process of Figure1:

- Identifying meta-behaviors by leveraging ongoing ethnographic design research [9] in the baggage hall (Section 3.2).
- Crafting the speculation by creating an immersive experience with a cohort of students exploring interactive environments on the Interactive Environments Minor course and the Living Architecture Systems Group (LASG) who provided a form language and robotic technologies (Section 3.3).
- Guiding visitors to experience the speculation through a structured exploration of this experience (Section 4).
- Co-speculating in focus groups, in order to assess whether the meta-behaviors and experience were comprehensible and sparked discussion about HRI and robotic work futures (results in Section 5).

3.1 Research context

This research is part of a larger collaboration between three parties: i) a transdisciplinary research and innovation center, ii) a major European airport, and iii) its major baggage handler organization. It is constructed following a three horizon-strategy to: i) solve day-to-day challenges that affect the workflow and the organization, ii) investigate opportunities for incremental transformations with positive impacts in the short future, and iii) envision long-term future possibilities with a high potential of disruption at multiple organizational levels.

To that end, the collaboration with the airport has been established, which started in the autumn of 2023 with a pilot project phase lasting 8 months. The intended outcome of the pilot project is paving the way for establishing a long-term partnership that aims to shape the future of baggage handling work, with and for baggage handling workers., The project brings together researchers from engineering, design, and social sciences, innovators, and baggage-handling experts in the involved organizations, trying to establish a transdisciplinary project environment.

The larger collaboration unites two directions of inquiry, aligning it with the horizon 1 and 3's goals: i) dealing with urgent current issues around the physical strain faced by baggage handling workers in the current baggage halls and ii) addressing long-term issues around the future of work when introducing robotic assistance, and other long-term infrastructural and organizational changes.

Both directions of inquiry are driven by a strong desire to ensure both healthy and meaningful work for employees, with opportunities for professional growth and agency over the work process. The stakeholders start with understanding that addressing the issues requires 'buy-in' from the workers, otherwise there will be low takeup. Therefore, the collaboration explores how current and future workplace attractiveness would be impacted by e.g., emerging technologies, changing work processes, issues of overload and underload – both physical and cognitive – social dynamics on the workfloor, innovation and implementation challenges, and inter-organizational dynamics that facilitate or hinder bottom-up innovation.

Within the pilot project, five early-career researchers are appointed to work full-time (hereafter called the transdisciplinary taskforce, or TD Taskforce). The TD Taskforce is composed of a designer, a work psychologist,

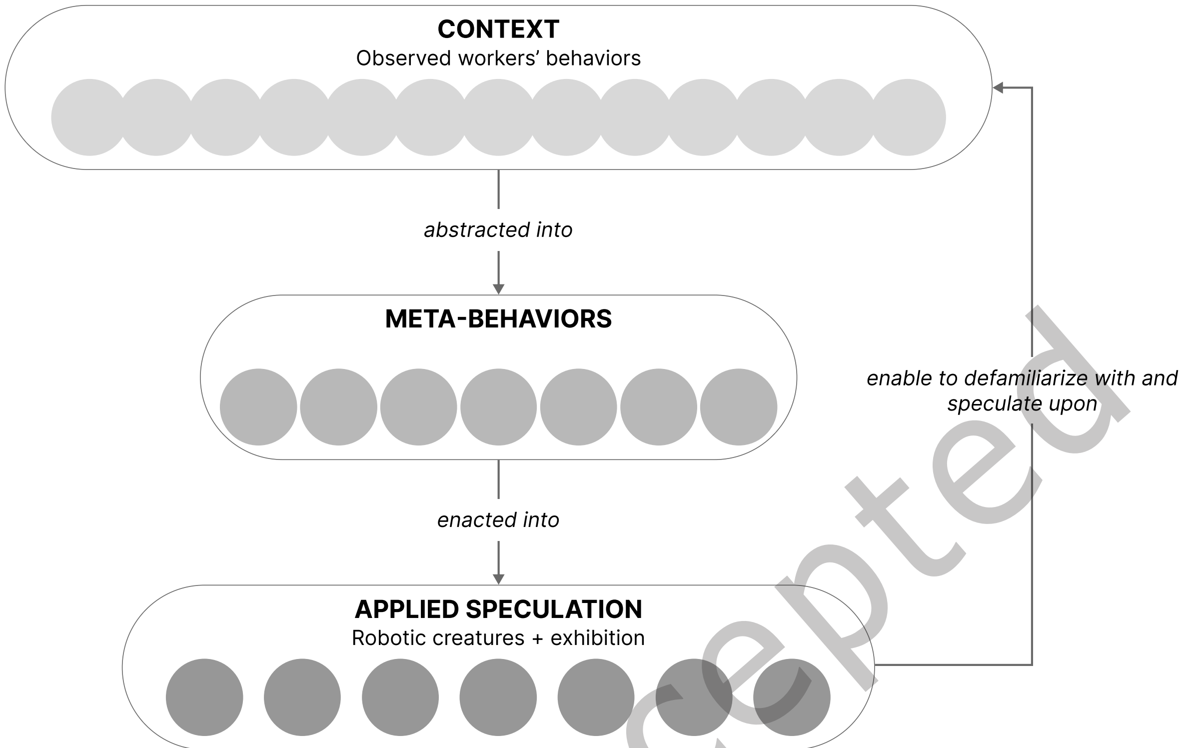

Fig. 1. Overview of the relationship between context, meta-behaviors, and robotic creatures. Behaviors were observed in the work context (Section 3.1), abstracted into meta-behaviors (Section 3.2), and then translated into experiential enactments by students and creative practitioners (Section 3.3) This artistic implementation forms the basis for an encounter where participants engage with a defamiliarized version of the original work practices (Section 4), which gives a ground for speculation (Section 5).

a roboticist, an organizational scholar, and an operation researcher, each of whom had 1-2 academic mentors serving as domain experts.

The TD Taskforce carried out several activities, which include shadowing and observation, in collaboration with a team of 8 baggage-handling employees that formed their industrial counterpart. The observations focused on several aspects of baggage handlers work, such as specific tasks and actions, ergonomics and aids, risks, efficiency and workflow, workers' behaviors, communication and collaboration, contextual conditions, and social aspects. Therefore, through the observation, the TD Taskforce was able to distill different notions eliciting workers' tacit knowledge, generating a rich ethnographic research that was synthesized in journey, task, and system mappings. These insights have been leveraged later on to identify and select meta-behaviors as it will be read in Section 3.2.

Beyond this, the TD Taskforce was responsible for knowledge sessions that also engaged 15 diverse stakeholders in the airport and baggage handling organization. These sessions were established to encourage and foster the creation of transdisciplinary knowledge and research methodologies, shared among all the actors taking part in the project, and to constantly align each stakeholder's objectives and scopes throughout the process.

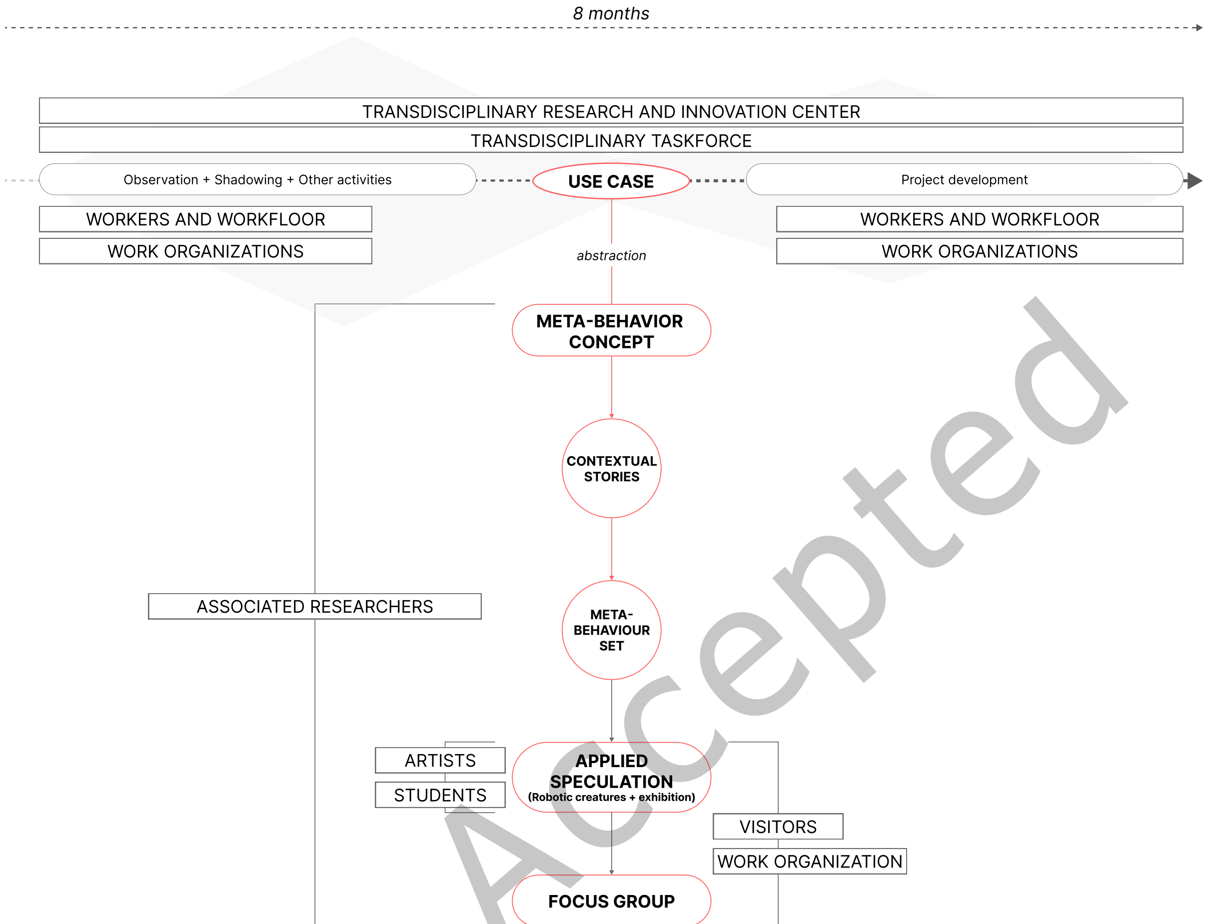

Fig. 2. Overview of the broader pilot project's and this specific study's flow: it shows the engagement of the TD Taskforce with the workers and the work organization to define a use case to focus the project on. It also defines how the study described in this paper fits into the broader collaboration.

Following a double-diamond framework [32], the first part of the project is set up for the TD Taskforce to gather enough contextual knowledge – in a transdisciplinary exchange with the workfloor – in order to define a use case to further focus the project on, as shown in Figure2.

The study in this paper constitutes an additional activity to the main and broader research, that is engaged specifically with design methodologies and aligns with horizon 3's goals. It is an experiment that tries to envision applied speculations about future work in the context of baggage handling by materializing robotic creatures and exposing them to a diverse audience. This endeavor was meant to explore possible and desirable work futures and the implications of introducing robots in the work environment.

In this specific study, the TD Taskforce shared the knowledge they gathered through the ethnographic research with the associated researchers involved, allowing them to better understand workfloor dynamics and the workers' performances. They further helped the researchers to connect back to the context.

The authors of the paper are two members of the TD Taskforce, three transdisciplinary mentors guiding the taskforce work, and three associated researchers who led the design and execution of the applied speculation. The mixed team aimed to leverage i) TD Taskforce's insights in comprehending the work context, the baggage handling system, the work processes occurring at the worksite; ii) their methodologies and activities of site visits, semi-structured and unstructured interviews, journey mapping; iii) the relations with diverse stakeholders.

3.2 Identifying meta-behaviors

The use case the TD Taskforce collaborative defined with stakeholders after the first part of the project is the articulated process of loading and unloading the baggage onto lateral conveyor belts or into carts and containers. This involves a variety of performative processes and activities, both on a cognitive and physical level, such as evaluating the status of the system and fitting the baggage in the correct spaces.

To make the rich, interpersonal, socio-technical knowledge manageable and accessible, we developed the concept of meta-behaviors. We see them as boundary objects [40] able to support conversations around the futures of work (robotization), facilitating knowledge sharing and integration in a transdisciplinary environment built between industry and several academic disciplines. Their purpose is not to exhaustively model work, but to support speculative reasoning about alternative human–robot relations grounded in observed practice.

Inspired by the case defined by the TD Taskforce and the information they gathered through observation, we identified a set of seven meta-behaviors. The identification of meta-behaviors followed three criteria. First, they had to be directly tied to the core task and to moments of reconfiguration within the baggage handling system, particularly breakdowns or disruptions where human coordination becomes explicit. Second, they needed to support narrative exploration, lending themselves to short stories of change, negotiation, or intervention rather than static descriptions of routine work. Third, as a set, they needed to span a broad conceptual space, including informational and physical, relational and activity-driven, and abstract and concrete forms of work. Therefore, the process of identification started from developing short and simple stories to describe particular situations observed within the use case, focusing on narratives that unfold from moments of change, crisis or reconfiguration within the system. In our specific case, the most relevant moment of crisis is defined by the malfunctioning in the correct flow of the baggage, which is communicated through screens to the employees. In this case, cooperation between coordinators and baggage flow controllers is required to regain control over the flow by altering it and moving other employees to different workstations. This process engages several employees with many sub-tasks, actions and performances.

Through extensive discussion, we selected seven of these performances to work with, from an initial palette of several more, because they best satisfied these criteria while remaining distinct enough to prompt different speculative trajectories. Furthermore, the choice of seven meta-behaviors is a pragmatic one: we knew we would have seven groups of students to work with. Since we wanted to achieve sufficient diversity in the materialization phase, it was useful to have each group work on a different meta-behavior, and there was not enough time for each group to work with multiple meta-behaviors.

Alternative sets were possible; however, additional or more fine-grained meta-behaviors were deprioritized as they either overlapped conceptually, emphasized taxonomic completeness over interpretive usefulness, or reduced the narrative and speculative openness of the exercise.

It is important to further note that these meta-behaviors are neither mutually exclusive nor defined along the same dimensions: we have intentionally picked meta-behaviors that are abstract versus concrete, informational versus physical and activity driven versus relational in order to cover a wide conceptual space with limited examples. While this selection has introduced certain challenges, as discussed in Section 5.1, we deliberately prioritized their alignment with the overall task and narrative focus over strict taxonomic clarity. The meta-behaviors were distilled to one or two-word titles, with short descriptions as shown in Figure3, and the whole set

Fig. 3. The meta-behaviors and the cards used to convey them. Each meta-behavior is characterized by i) a title that concisely sums it up; ii) a short descriptive text; and iii) an abstract yet evocative image generated by the research team. Participants were given these cards and asked to match them to the robotic creatures (Figure 6) as a structure for exploration of the experience.

of meta-behaviors was translated into cards to be used as prompts for the students to craft the speculation and the final visitors' experience of the exhibition.

3.3 Crafting a speculation around meta-behaviors

The speculative exploration of the defined meta-behaviors was carried out involving around 25 students with various backgrounds (design, computer science, architecture). As part of the Interactive Environment Minor course, they were briefed to create robotic creatures that in some way represented the meta-behaviors.

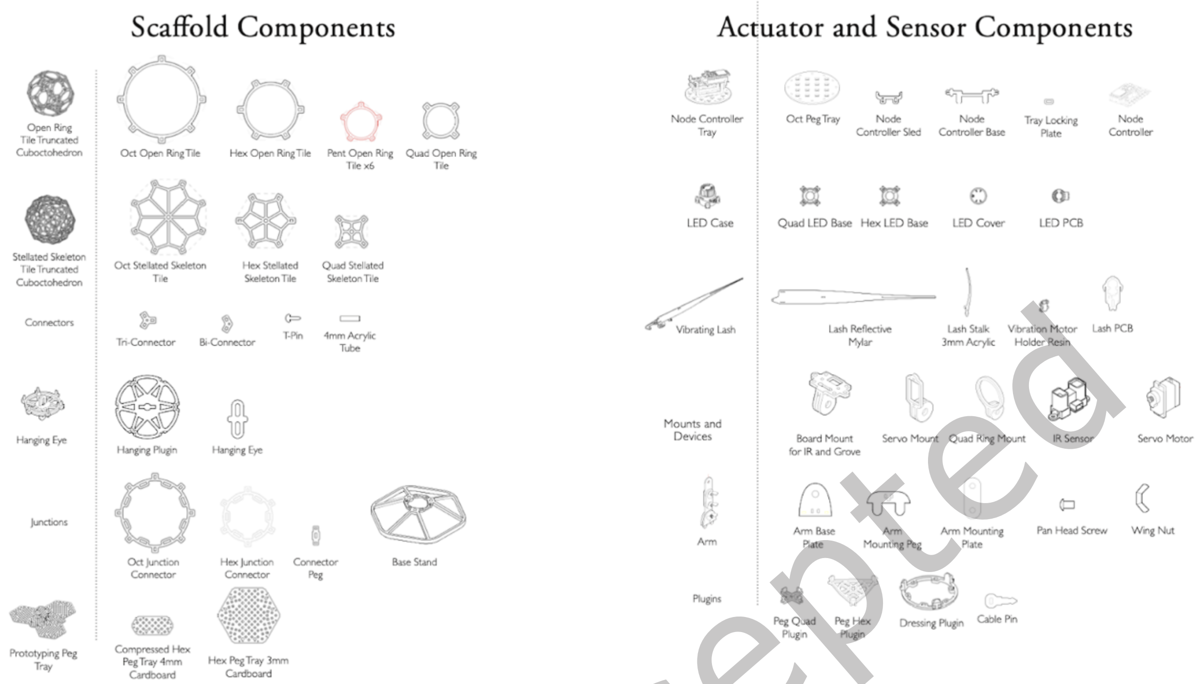

Fig. 4. An overview of the building elements designed by LASG and provided to the students during the workshop.

LASG which was involved in the course and in the workshop, by daily supporting students with precise feedback on their work, further provided a system of architectural elements, such as scaffold components, actuators, and sensors (Figure4) used to materialize the robotic creatures. The building elements were previously designed and created by LASG to realize their works, and specifically tweaked for the course and the workshop.

The robotic creatures designed relying on these materials inhabit a shared digital space, allowing for the creation of immersive, interactive robotic experiences that exhibit distributed collective behaviors in response to touch and proximity: actuators and sensors were limited in their capabilities on purpose, due to educational goals (i.e. teaching interaction design techniques to the students) and to demonstrate a coherent set of behaviors through the creatures. The physical elements provided assembling guidance to the students and formal coherence to their creatures, since one of our goals was to communicate a reasonably homogenous ecology of robotic creatures: utilizing the same building blocks, it was possible to create a shared form language across the creatures providing semantic and visual coherence to the exhibition and the experience.

The exhibition was staged in and around a scaffolding structure that provided power to the creatures and enabled them to be mounted on walls and ceilings (Figure5). Apart from the design and creation of the creatures, the students also participated in setting up the exhibition together with the associated researchers, selecting the placement of each creature to align with the narrative the exhibition aimed to convey.

The creation of the creatures and exhibition took place over a five-day sprint. The meta-behaviors were introduced to the students during the first day of the sprint, along with a presentation about the context from the TD Taskforce and the researchers to support translation.

The students spent the first two days building up the electronic and physical elements of the robotic infrastructure and familiarizing themselves with the technical possibilities while thinking about how to enact

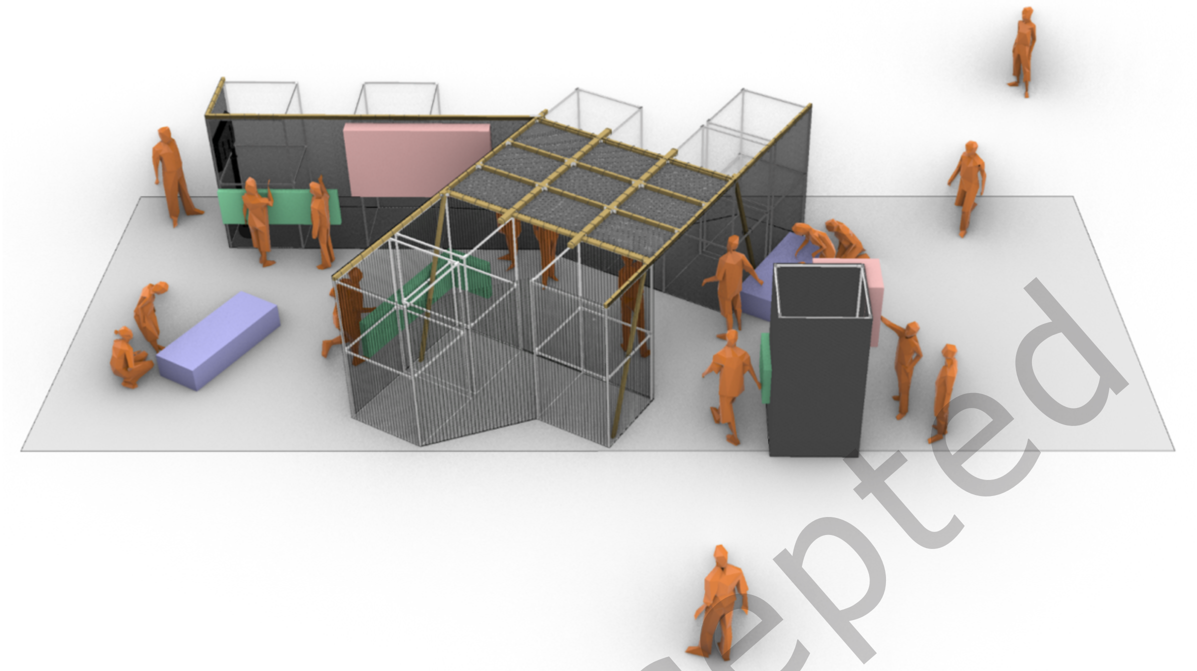

Fig. 5. An overview of the exhibition setup. This was realized in the main hall of the Industrial Design Engineering (TU Delft) faculty hall, semi-open to the public. It housed the robotic creature and provided some visual separation from the rest of the space as well as architectural support to allow the creatures to be configured on walls and ceilings.

meta-behaviors. On the third day they started to prototype robotic actions in response to the meta-behaviors, and at the end of the fourth day, (almost) all groups were able to realize their robotic creature and its interactive performance (Figure6). This could then be experienced on the final day, simulating and staging a possible futuristic baggage handling system where robots are strongly integrated.

4 Experiencing the speculation

To explore the possibilities of the materialized meta-behaviors for speculation, we defined a process for guiding stakeholders when visiting the exhibition, which would enable autonomous exploration of the experience on the one hand and a structured moment of reflection on the other. More precisely, through the workshop experience, the visit of the audience, and the focus groups we sought to answer the following questions:

- RQ1: *Were the creative embodiments of meta-behaviors as immersive experiences comprehensible to participants and relatable to industrial robotic capabilities?*
- RQ2: *Were the meta-behaviors and robotic creatures effective in fostering visitors' critical thinking concerning robotic work futures?*

4.1 Procedures and materials

As participants arrived at the exhibition, they signed a consent form and filled out their demographics and were then put into pairs. Each pair was given a pamphlet (see supplemental information) which gave a short

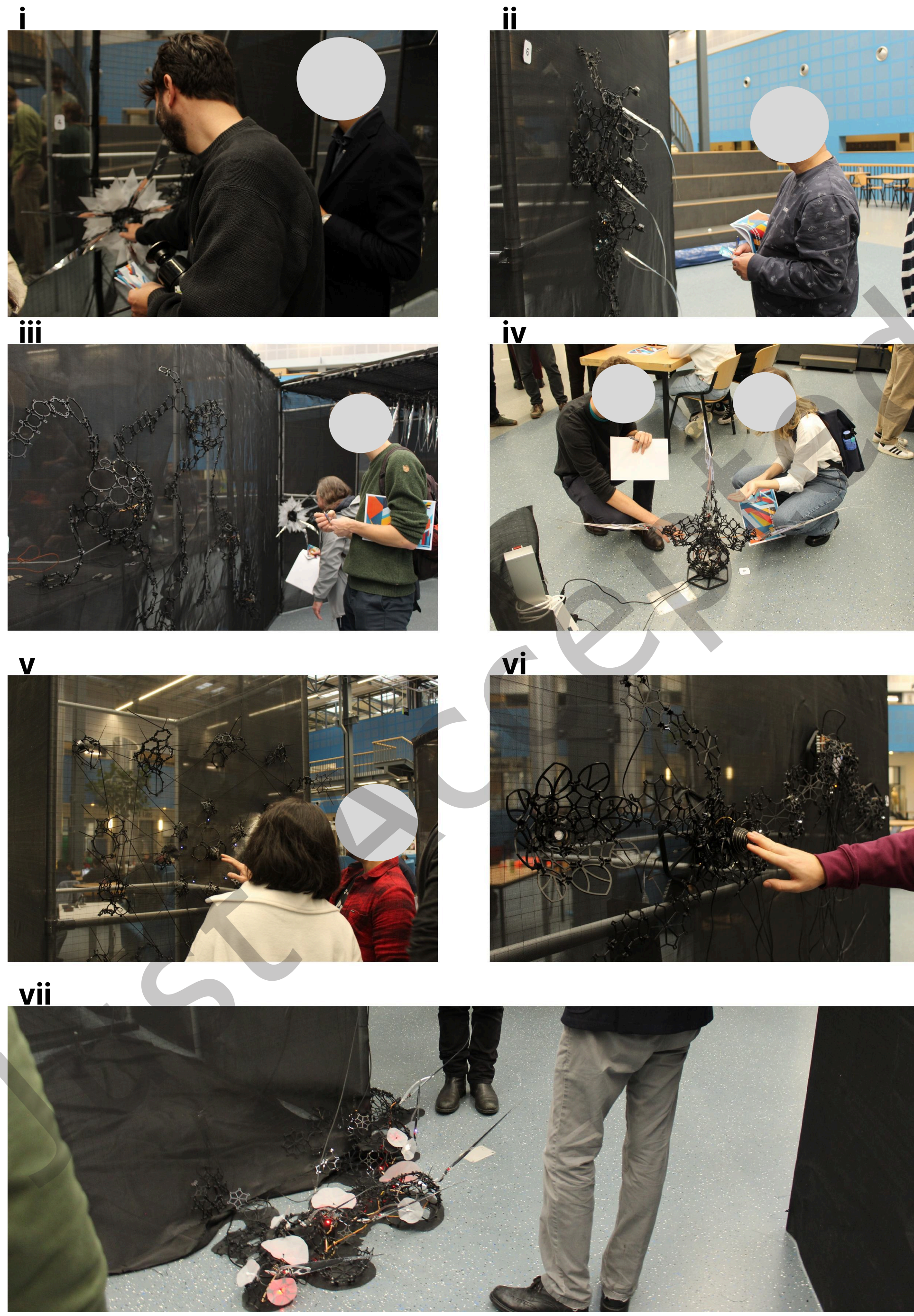

Fig. 6. The robotic creatures designed by the students. In reading order from the top, they represent: i) getting attention, ii) lifting and dropping, iii) loading and fitting, iv) making space, v) asserting control, vi) communicating the role, vii) protecting.

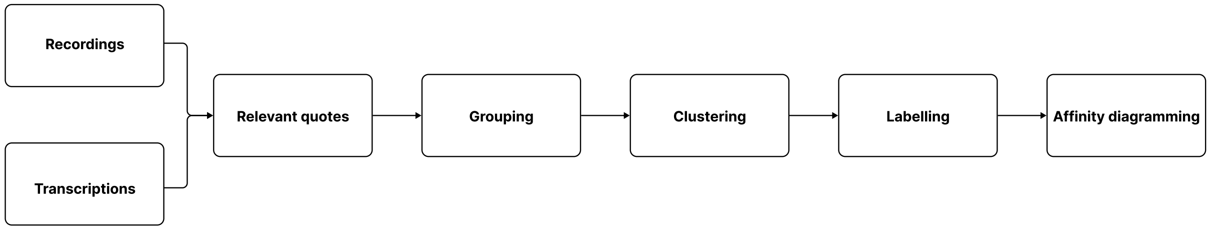

Fig. 7. Process overview of the focus group analysis.

description of the context, the crafting process, and meta-behaviors, as well as a card for each of the seven meta-behaviors (Figure 4). The robotic creatures were numbered, and the pamphlet instructed the visitors to try to match each meta-behavior card with the numbered creature. This task was designed to give a purpose to the exploration and stimulate discussion between the pair of visitors. By doing so, we sought to understand whether the tangible artifacts were effective manifestations of the meta-behavior and implicitly encouraged participants to start conversations around these.

After the visit, participants took part in focus groups, moderated by one or more research team members. Through these, we gained a better understanding of their impressions, reflections, and standpoints stimulated by the experience. Each focus group lasted around 45 minutes and was divided into three main activities, where participants were asked to:

- Discuss which meta-behavior each creature embodied, as a conversation starter and to assess how clear the embodiments were.
- Look at a system map of the baggage hall and discuss links between the experience and the context of future technologies in the baggage hall.
- Reflect on the overarching meta-behavior of asserting control, in order to drive discussions about possible HRI futures.

4.2 Data collection and analysis

Each focus group was audio recorded and live transcribed using Microsoft Teams. The first author checked and edited the transcripts for errors. We then conducted a qualitative analysis using affinity diagramming [59]. First, we highlighted quotes and passages from the data and collaboratively grouped them based on perceived similarities, without predefined categories. These groupings were iteratively refined through discussion to form meaningful clusters. We then labeled each cluster to identify the emerging themes within each of the three activities. The first author visualized the results into one affinity map per activity, which was then shared and discussed with the research team (Figure7). This collective review informed the findings presented in Sections 5.1, 5.2, and 5.3, which directly reference the original quotes.

4.3 Participants

The focus groups involved participants of different ages, professional backgrounds, and levels of experience with robotics and HRI, as well as varying degrees of familiarity with the baggage handling system at Schiphol International Airport. Participants were recruited by the course coordinator and the TD Taskforce through their professional and educational networks to assemble a heterogeneous group combining partial domain knowledge with varying levels of technical expertise.

This composition was appropriate for RQ1, which examines the comprehensibility of the speculative artifacts and meta-behavior constructs rather than their contextual fit or operational feasibility: if concepts and speculative prompts are understandable and discussable under conditions of uneven contextual knowledge, they meet a baseline level of accessibility required for later engagement with domain experts and workers.

The inclusion of participants with robotics and HRI expertise further supported informed interpretation and plausibility checks, enabling misunderstandings to surface during discussion. This mixed-expertise sampling prioritizes breadth of interpretation over depth of situated expertise, aligning with the exploratory aims of RQ1.

We acknowledge that this limits claims about workplace-specific constraints and worker imaginaries; these limitations are discussed in Section 6.2.1. Participant details are reported in Table 1. No remuneration was provided.

Table 1. Focus groups compositions and participants' background, experience with robots, and context knowledge.

ID	Size	Age range	Background	Robotic experience	Context knowledge
FG 1	6	21–50	3 professionals 2 academic faculty members 1 master student	Most have been interacting with robots for several years (2–25). Two have experience in programming robots.	None apart from being frequent travelers.
FG 2	6	21–50	4 professionals 1 PhD candidate 1 master student	All participants have been interacting with robots for several years. Four also have experience in programming them.	None apart from being frequent travelers.
FG 3	7	21–50	2 professionals 4 master students 1 PhD candidate	Few participants have experience in interacting with and programming robots.	Some of them work with different roles in the baggage handling system of Schiphol Airport.

5 Results

The initial findings from the focus groups are presented here organized by activity in Sections 5.1–5.3. Direct quotes are shown in "*italic*", without participant numbers. Alongside the findings from the focus groups, to give a practical account, we present a narrative account of how a single meta-behavior was defined, implemented and discussed in Section 5.4.

5.1 Activity 1: Meta-behavior identification

During the first focus group activity, the participants discussed the relationships between the meta-behaviors and the experience, identifying which of the creatures was enacting which meta-behavior (Figure8).

The main cluster produced was matching robotic creatures with meta-behaviors, primarily concerned with reasoning around why certain creatures were representative of a particular meta-behavior, which aligns to the main topic of discussion for the first activity of the focus group. Despite this direct and logical link, we still found the specific contents relevant for our investigation to assess how clear the embodiments were.

Some of these arguments were spatial — "*the one going up around the corner was protecting,*" or "*it moved downwards, and it created space around it*" — while some were metaphorical, such as "*opening up like a flower,*" or looking "*like a wall with spikes in front.*" Participants discussed how to interpret the meta-behaviors — questioning whether "*asserting control could be the machine or the human,*" and what "*could be a part of your role.*" Participants saw overlaps in the way the meta-behaviors could be interpreted, for example, that "*lifting and dropping or loading and fitting both involve moving stuff around,*" or that "*making space could be one way of protecting someone.*"

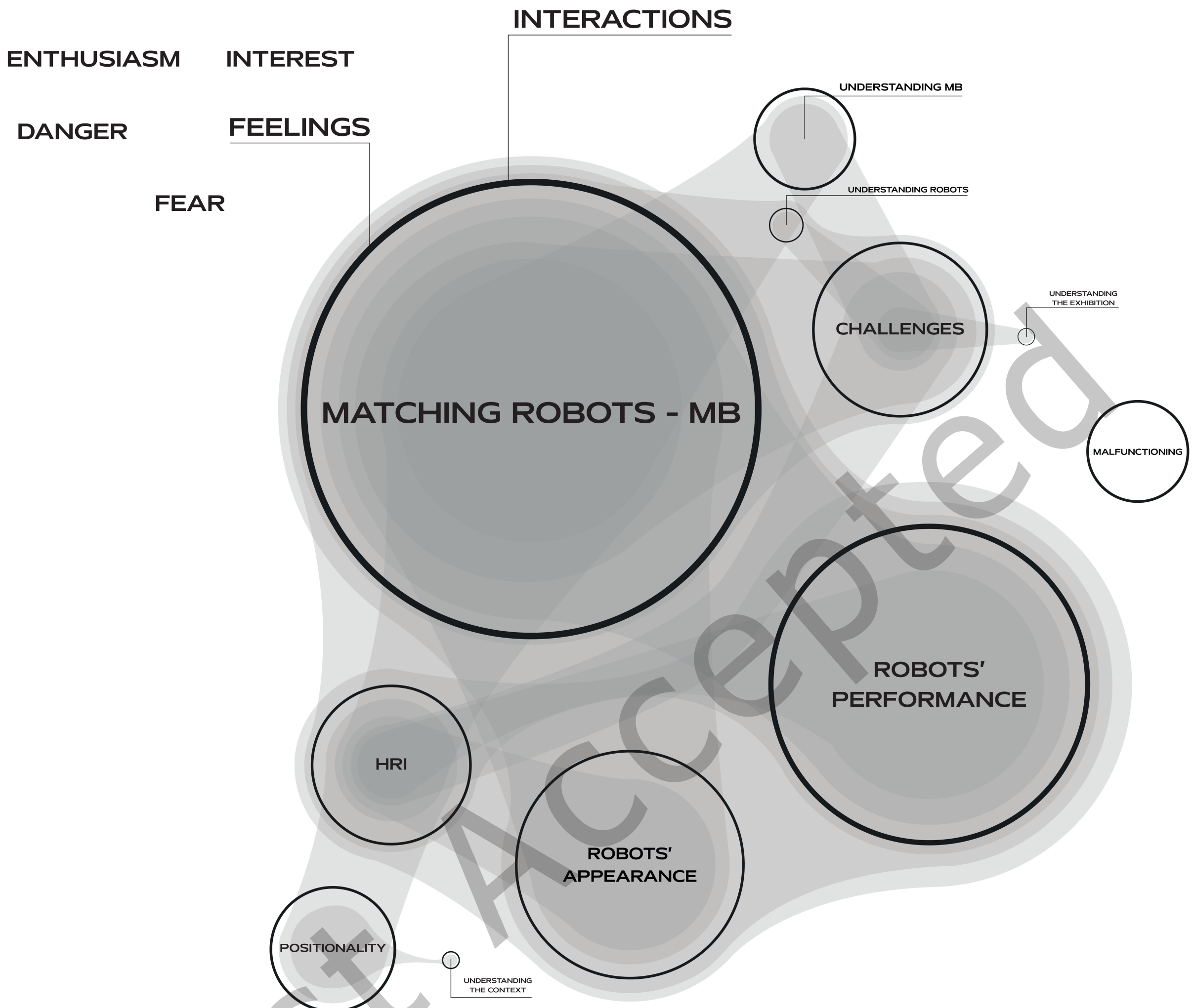

Fig. 8. Affinity map of the first activity. The dimension of the circles is proportioned with the number of quotes found in the cluster. The gray areas show the connection between the different clusters. The outside keywords refer instead to the HRI concepts that emerged.

This first cluster strongly linked to those on the robots' appearance and robots' performance, as these were the key parts of participants' reasoning - the visual cues that guided interpretation. There was discussion of how robots make space by "*start[ing] small and then ... expands to clear out some space,*" or how the "*leaves could be ... protecting both the humans and itself.*" The discussion of robots' performance considered their multi-sensory capabilities, whether they were interactive and "*reacted when you pressed it,*" or more autonomous and "*closed up and stayed [its] own like cocoon,*" as well as interpretations that "*it was the getting attention because of the lights and vibration.*" Some participants felt the robots "*looked all similar.*"

The found links between appearances and performances, and meta-behaviors informed us about what elements of the robotic creatures were relevant to recognize the origin meta-behaviors, and therefore, to assess the overall validity of the process we fostered.

At the same time, participants noted a number of challenges to the process. The "*ambiguity*" of both the enactments and the meta-behaviors made precise identification difficult. The strong form language and the relative similarity of the robots meant some thought they were "*not very different,*" and many participants expressed uncertainty. This was augmented by the malfunctioning of the prototypes, which were not always able to "*interact with them*" and, therefore, the participants "*might have experienced a different hint*" if the creatures "*responded to their actions.*"

To better address this ambiguity, we conducted a lightweight mapping between the intended meta-behavior of each creature and the meta-behaviors referenced in participants' discussions. For each creature, we identified whether participants' interpretations predominantly aligned with the intended meta-behavior, overlapped with adjacent meta-behaviors, or diverged toward other interpretations. Across the set of creatures, participants most frequently referenced the intended meta-behavior or conceptually adjacent ones, rather than unrelated behaviors. These overlaps reflect the intentionally non-exclusive nature of the meta-behaviors and the fact that they were not designed as a strict taxonomy. A summary of participants' choices can be seen in Table 2.

Table 2. Mapping of each creature against how often participants referenced the intended meta-behavior versus others.

Creature	Intended meta-behavior	Predominant reference	Secondary reference
C1	Getting attention	Mixed	Mixed
C2	Lifting and dropping	Lifting and dropping	Mixed
C3	Loading and fitting	Loading and fitting	Mixed
C4	Making space	Making space	Protecting
C5	Asserting control	Mixed	Mixed
C6	Communicating the role	Mixed	Mixed
C7	Protecting	Protecting	Making space

Lastly, a collection of quotes looked at the HRI aspects of the situation. There was discussion of the feelings and emotions evoked, from "*danger, fear of their threatening behaviors,*" and "*discomfort*" through to "*interest in discovering more about them and enthusiasm in interacting with them.*" Some participants felt they "*were really welcoming,*" while others felt "*surrounded by it and sort of reminded me of a science fiction monster.*" The readings included ideas that "*it was kind of pushing you away,*" but also that "*it's like a web*" and that in the center "*you're in control.*" More broadly, there was recognition that "*such a simple task as loading bags into a cart which you think that anyone can do, ... should be easy peasy for robot*" even if it isn't, and projected concern for the workers who "*don't want to have robots coming in and taking their jobs or changing the way they do things.*"

5.2 Activity 2: Contextual connections

In the second activity, the participants were asked to focus their discussions on the connections they had seen between the immersive experience and the Schiphol's baggage handling system. Comparing the sizes of clusters, HRI and positionality played a much greater role here (Figure 9).

FG1 and FG2 both noticed "*difficulties in embodying the perspective of the employees while referring to potential robotic applications*" due to a lack of stakeholders from the context, while FG3 contained more contextualized reasoning. Below a description of the main clusters emerged.

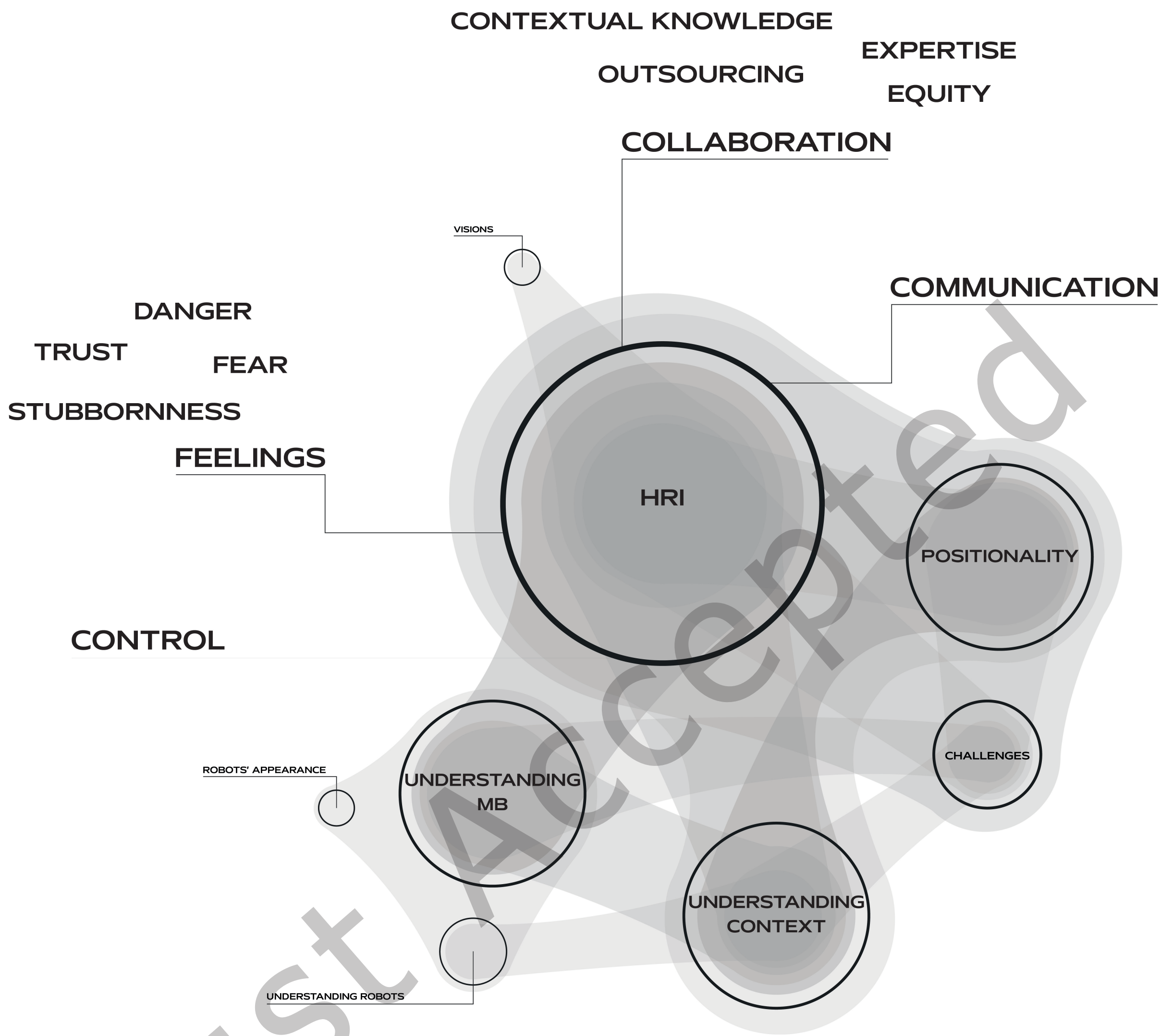

Fig. 9. Affinity map of the second activity. The dimension of the circles is proportioned with the number of quotes found in the cluster. The gray areas show the connection between the different clusters. The outside keywords refer instead to the HRI concepts that emerged.

5.2.1 Trust. Within the HRI cluster, there was discussion around the need for trust to be "*built between humans and robots,*" and the lack of trust being a potential factor in a "*low rate of adoption caused by employees' perspective and emotions,*" along with feelings of "*danger*" around the introduction of "*robots in the working context.*" Participants were concerned about the "*experience of interacting with robots, which could become stressful if the workers do not trust and like them;*" complications caused by "*contextual aspects and procedures, such as repetitive loading duties.*" However, these concerns were tempered by challenges interpreting some of the meta-behaviors and a "*lack of knowledge regarding the real context.*"

5.2.2 Control. There was a discussion of what control, power, and agency humans should have over the robots and the other way around. All participants suggested a perspective that sees the "*need for humans to still maintain control and power over them,*" and several mentioned "*fear caused by the idea of robots having some kind of power and control over humans.*" However, some participants did speculate that relationships could be on the "*same hierarchy level and based on trust.*" There was a recognition that "*stubbornness*" may pose a "*challenge of adoption and the individual perspective each worker may have with regard to collaborating and sharing decision power with robots.*"

5.2.3 Collaboration and working relations. There was rich speculation about possibilities for collaboration. Starting from the idea of "*outsourcing duties to robots*" and the "*consequent need for more contextual knowledge about the robots themselves.*" Some participants pushed their speculative and future-oriented thinking to imagine alternate modes of collaboration where the "*robots would act like reminders or task managers,*" opening up also to the topic of automation and the "*effective help*" it will bring to employees. Regarding knowledge, there was discussion on how robots would relate to the "*level of employees' expertise*" and how they could serve "*their need for just an amplification of what they already focus on.*" Lastly, some participants suggested a kind of "*equity between humans and robots should be enabled to achieve the desired collaboration to take place.*"

5.2.4 Communication. Strongly connected to collaboration, "*communication*" and "*the necessity or not for it and its emphasis*" was part of envisioning "*how humans and robots would interact with each other and within the Schiphol's baggage handling system.*" This was linked both with reasoning concerning the context and interpreting the meta-behaviors: "*because of the many stakeholders, employees, and people inside the Schiphol's baggage handling system, who carry out several and diverse actions, communicating the roles become a highly relevant matter.*" When asked which meta-behavior they considered to be the easiest to imagine implementing in Schiphol's baggage handling system, as well as communicating the roles, most of the participants referred to getting attention, because of the "*modalities needed for doing that and its feasibility in implementation.*" The robots' appearance and understanding robots clusters connected to these questions — for example, for getting attention, participants stated that relying on "*human-like aesthetic characteristics and mechanism of relation*" could be a way to establish meaningful and collaborative relationships, "*leveraging already existing mental models.*"

5.3 Activity 3: Visions for HRI

For the final activity, prior to the focus groups we chose a single meta-behavior – asserting control – as being a good site for further discussion. Participants were asked to reason in depth about how they saw this meta-behavior and to try to propose their visions around the matters of control, power, and agency for future HRI directions in the industrial context (Figure 10).

As before, the HRI cluster contained the most quotes, in connection to other clusters on visions, robots' appearance, understanding robots, understanding meta-behaviors, understanding the context, experience, challenges, troubleshooting, and positionality. There was one quote around positionality, from the industrial stakeholders, that in the workshop "*we don't look at it from our baggage perspective, but we are also looking at it from new perspectives.*" Within the HRI cluster, the key topics echoed those from Activity 2, so we highlight the new aspects of discussion here.

5.3.1 Trust and respect. Participants stated trust is "*built through the acquisition of knowledge on and understanding of the robots,*" and, therefore, "*based on the experience one has in using and collaborating with a particular (robotic) system,*" that proved to be "*efficient throughout time.*" This was connected to "*the safety perceived by employees while using them.*" Although most of the participants believed "*humans need to feel control over robots to trust them,*" a few of them framed this as "*respect built over time,*" highlighting the need to build a "*mutual relationship based on it.*" While trust was mainly defined "*for robots to be achieved towards humans,*" respect was mentioned as

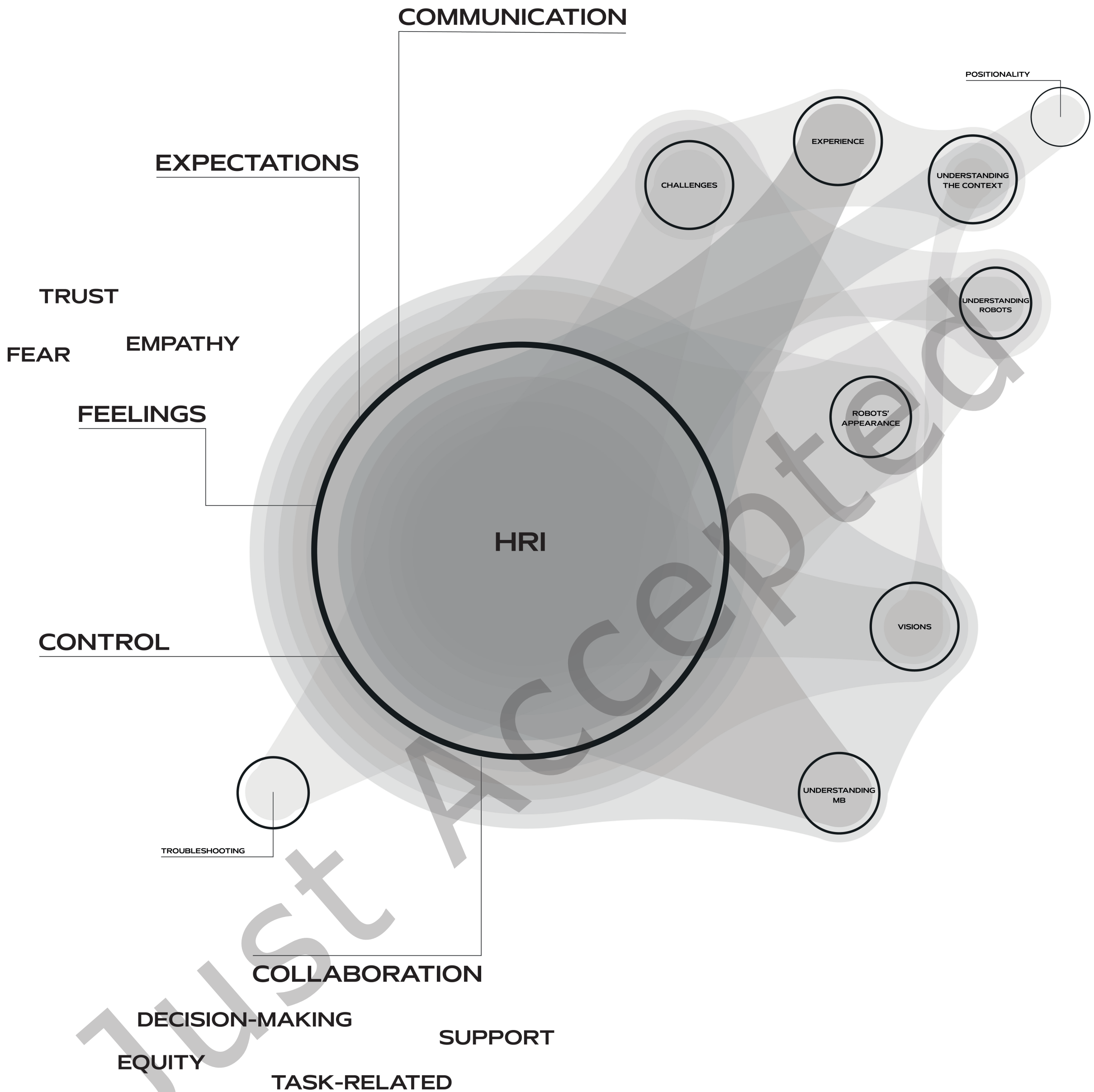

Fig. 10. Affinity map of the third activity. The dimension of the circles is proportioned with the number of quotes found in the cluster. The gray areas show the connection between the different clusters. The outside keywords refer instead to the HRI concepts that emerged.

a key enabler for "*meaningful collaborations*" between the two. Therefore, respect referred to a "*more mutual dimension,*" fostering "*empathy,*" and a sense that "*there should be some sort of respect for [the robots'] work.*"

5.3.2 Control. Following Activity 2, participants reiterated that "*humans need and must be in control over the robots*" and "*the robots should be dependent on the humans.*" One interesting reflection concerned the potential for robots "*to be taught and replicate human movements which then they should perform in the working space,*" and the sense that "*asserting control can only happen if you have good signals.*"

5.3.3 Collaboration. There was a richer discussion of possibilities for collaboration between humans and robots. Participants were sensitive to pragmatic and grounded matters, such as whether robots were seen as "*support,*" giving assistance in "*troubleshooting*" complex problems, helping "*give people more context about ... something that they can't see,*" but they generally held to the position that "*robots should act as aids for humans both for physical and cognitive tasks, without substituting them.*"

They also explored future scenarios where "*in the Schiphol's baggage handling system, machines and robots will make decisions without inputs from humans*" or where "*all the physical tasks will be performed by robots.*" They reasoned then about the type of collaborative relations that should be built with robots, asserting that the shape of these collaborations "*would be mainly task dependent,*" but maybe leveraging the "*flexibility to creativity of the human and the strength and the stamina of the robot.*" References were made also to "*employees' expectations*" of robots, especially with regard to the "*necessity of not creating false promises, and supporting the employees' correct mental models to understand what the robotic systems do*" and, consequently, "*how to collaborate with them.*" Lastly, some thinking was made with regard to "*automation,*" stating that it could be "*a desirable and achievable goal,*" especially with the "*support of other digital technologies.*"

5.3.4 Communication and appearance. Intertwined with collaboration was the topic of communication, which was seen as "*necessarily mutual*" and "*necessary to provide employees with more information about the context and the robotic system,*" by "*making visible and accessible what they can't see or see happening.*" Good communication was seen as key for empathy "*for humans to be reached,*" and whether there are "*certain aspects of robots that can facilitate this process, such as their appearance.*" Interestingly, fear emerged also as a "*potential means for communication to be exploited to avoid potentially dangerous situations for humans,*" even at a basic level such as "*there is a flashy light watch out.*" Despite the extremely non-human nature of the robotic technologies used here, there was a pull towards discussion of "*humanoid robots' appearance*" which led participants to also share "*fears and concerns*" that "*we are gonna become robots or they are going to take over.*" This was balanced by a sense that "*to understand something or someone when it has traits that you have too is easier.*"

5.3.5 Visibility and interaction. Giving humanoid features to robots was discussed also with regard to "*interactions:*" some participants proposed not only to "*transfer to them human-like appearance and aesthetic characteristics*" but also to "*make them interact more humanly with us and each other.*" Opposed to this standpoint, and highlighting a "*knowledge-related challenge,*" other participants suggested instead that "*robots should be as humanoid as needed in order not to hinder employees, making their functioning less comprehensible,*"defining "*visibility*" (of the robotic system and its functioning) as a "*relevant issue also for trust and usage.*"

5.4 Narrative: From definition to discussion

To better contextualize the focus group findings, both in terms of the industrial context and the research project, we present a narrative account of a single meta-behavior, starting from its definition and ending with what the visitors discovered through their encounter with its robotic translation (Figure 11). We focus on asserting control as this was both a particularly overarching meta-behavior and part of the narrative used to define the others.

5.4.1 Origin. Asserting control has its roots in what happens inside the control room, where employees oversee the baggage flow throughout the system. If something changes in the correct flow, information on the screens warns the employees who should regain control by modifying the flow or assigning employees to other stations.

Fig. 11. The robotic creature derived from the asserting control meta-behavior. Touching the central element would cause a coordinated reaction in this creature's elements and in those of the others.

This performance was observed by the TD Taskforce through their site visits and context analysis. There is a rich set of practices behind this concept: it touches on the physical sensory stimuli indicating loss of control, the cognitive responses to re-organize work processes, and the inter-relational question around re-assigning employees to different stations. In order to support easy communication and open interpretation, the research team reduced this complex contextual knowledge to a simple phrase: asserting control.

The intent was to create a boundary object, which should act as a provocative prompt when instantiated and leveraged to design the tangible artifact while still being representative of the employees' performance.

5.4.2 Students. We observed challenges for the students in re-interpreting this concept while prototyping. It embodies a relatively high level of abstraction, compared to the more physically oriented behaviors; it has a very particular contextual meaning that was not immediately available to the students; it was also ambiguous who was asserting control over whom.

Given this open possibility, they chose to work with asserting control through physical appearance as well as the interactions, shaping the robotic creature as a network of wires and 3D printed elements, which turn from chaotic to arranged by moving toward the center of the creature itself. They made a choice that the robot was a vehicle for control, and when a human pressed the button at the center, it triggered a behavioral and inter-relational response from the surrounding robotic elements – much like the employees in the control room must modify the baggage flow and change the distribution of employees at the other working stations. Their choices focused on the idea that through a particular interaction actively performed by the human – pressing a button – the robot would then be able to directly influence the other robotic capabilities of the system, changing their behaviors and modes of interaction. This can be read as a move towards a mutual and reciprocal take on HRI and collaborations.

5.4.3 Visitors. During the focus groups, the visitors experienced difficulties in making sense of this particular meta-behavior and its translation. The form caused some issues during the matching activities carried out inside the exhibition space, partly due to the distributed response, and partly due to technical issues. Secondly, they were challenged to understand which kind of relationship the meta-behavior wanted to suggest and what the students tried to demonstrate with its physical and interactive shape. Analyzing the focus group dialogues, its subtle interactions were not always clear to the visitors, which emerged as an ambiguity-centered challenge during the focus groups. Despite the difficulties in precisely locating the form and locus of control, the presence of the meta-behavior supported a wide-ranging discussion of different forms of control, particularly in the third focus group, where more contextual knowledge was present. It seems that the ambiguity of the meta-behavior contributed to reflections concerning the form and nature of control. In the focus groups, the participants were cognitively engaged in a process of critical thinking through the physical and interactive involvement stimulated by the real encounter with a tangible artifact, which let them deconstruct the enactment of context, resulting in new future-oriented dialogues and visions.

5.5 Methodological trade-offs observed in the study

The use of abstract robotic creatures entailed a set of trade-offs that shaped participants' engagement and the type of insights generated. Abstraction enabled participants to reason beyond immediate operational constraints, supporting creative, metaphorical, and relational interpretations of the creature in the context. This is evident in Activity 1, where participants relied on spatial and metaphorical cues to interpret meta-behaviors, and in Activities 2 and 3, where discussions extended to trust, respect, power, and future collaboration rather than concrete task execution.

At the same time, this abstraction reduced contextual grounding. Participants frequently expressed uncertainty about how the creatures related to the actual baggage handling context, and some defaulted to non-worker perspectives, particularly in focus groups with less contextual knowledge. This suggests that while abstraction supported speculative breadth and imaginative projection, it limited participants' ability to assess feasibility, procedural fit, and exposure to the practical limitations and failure modes that task-based robot interactions would more readily surface. Importantly, ambiguity functioned both as a generative resource and a challenge.

As shown in the meta-behavior mapping (Table 2), participants' interpretations often clustered around intended or adjacent meta-behaviors, indicating baseline comprehensibility, yet overlaps and mixed readings persisted. Rather than signalling failure, these ambiguities prompted negotiation, reinterpretation, and discussion of control, agency, and automation, particularly in Activities 2 and 3. However, they also risked flattening distinctions between different forms of robotic action, especially when form language and behavior appeared too similar.

Compared to task-based interactions, the abstract-creature approach in this study prioritized creativity, relational reflection, and futures-oriented dialogue over exposure to concrete system constraints, breakdowns, and performance limitations. This trade-off was evident in how participants engaged with the creatures and structured their discussions across the three activities. While this aligns with the exploratory aims of the present work, it also delineates the boundaries of the claims that can be made based on these results, as it will be further read in Section 6.2.1.

6 Discussion

6.1 Applied speculation: A work-centric approach

Although we relied on experiential techniques similarly to [48, 56], and fluidly draw on notions and methods that can be linked back to various types of critical and speculative design practices, here we are attempting to develop ways to carry out "*applied speculation*", that is strongly grounded within a context and also feeds back into that context. A traditional speculative approach usually looks at trends, weak signals, and drivers of change to imagine and envision alternative and possible futures as a playground for critical reflections and questioning about the present [6]. In our case, we looked instead at workers' performances as drivers and inspirations for our speculations, making them work-oriented. Workers' performances became sources to define situated and contextualized stories and distill meta-behaviors from them. Exploring the meta-behaviors with the students, and playfully enacting them as material instances brought them to a fluid, defamiliarized state. Finally, these enactments acted as prompts for visitors' further critical reasoning about future possibilities.

In this sense, we can define our research as an applied speculation: we leveraged observable and observed practices to create speculative encounters that allowed participants to envision alternative futures of work, with a view to socio-technical innovation [104]. We investigated the current context of work, and used it as a basis for thinking into possibilities for work robotization. The speculation was carried out in two parts: the students made a speculative translation of existing practice into speculative forms that provided the basis for an encounter. This encounter became a "lure" for a speculative mode of thought in the participants [101] giving them a route into a less propositional, freer space for thinking, but the thinking was still about the specific work context. This form of applied speculation has some different characteristics from most of the work surveyed in Section 2.3: the work context, and the specific tasks that we engaged with through the meta-behaviours, meant that we did not envision public and social robots as done by [7, 60, 85]. Because meta-behaviors were grounded in simple, everyday tasks and interaction patterns, the resulting physical embodiments remained closely tied to familiar work activities, thus resisting exaggerated or fantastical interpretations. Indeed, we intentionally tried to avoid superhuman or science-fiction–like characterizations of robots as part of carefully engaging with the industrial stakeholders. We didn't focus on robot design as the central element of our speculation in contrast to e.g. [62]: form-giving was limited and bounded by the building elements provided by the LASG, which allowed the students to explore the speculative nature of artificial creatures, but left the participants to engage more with the relationality of the robots than the particular manifestation. Together, this characterises a particular mode of speculative practice, that can explore and communicate a holistic vision of how technology could be embedded into the sociotechnical contexts of the future, presenting critical projects as tangible alternatives to current technology practices [104].

6.2 Speculative encounters through robotic meta-behaviors

In order to successfully carry out this process, we needed: i) ways to extract knowledge from the workfloor, in our case in the form of the meta-behaviors and their derived physical embodiments, ii) a framing that sets the research questions and orients the work, which for us was the broader transdisciplinary environment where the research had been developed, and iii) modes to talk about what emerged both before and through the applied speculation, which the meta-behaviors framed as boundary objects might be capable of doing. To explore the overall effectiveness of the speculative encounters process, we return to our original research questions.

RQ1: *Were the creative embodiments of meta-behaviors as immersive experiences comprehensible to participants and relatable to industrial robotic capabilities?*

From the focus group discussions, the answer is an emphatic “somewhat”. In general, participants were able to correctly identify most of the meta-behaviors, but there remained substantial ambiguity. Some of the difficulty of identification was driven by the meta-behaviors themselves: for instance, lifting and dropping can be seen as overlapping with loading and fitting. In this case, some detail of the context did not come through so strongly – despite the descriptions differentiating the “cognitive demand” of fitting from the “actual physical actions” of lifting, a cursory reading of the behaviors certainly overlaps. The form of the installation caused other difficulties, sometimes through malfunction but often due to the abstracted and ambiguous nature of the robotic creatures.

Beyond the correct identification of which creatures were designed to embody which meta-behaviors, there is the question of how strongly this spoke of robotic capabilities to the participants. Here, the positionality of the participants is important. The lack of industrial stakeholders allowed space for confusion, in particular about whether they were encountering the robots as travelers through the airport – a situation they were all familiar with – or baggage handlers supporting the travel process. In terms of engaging with knowledge, in the second activity which asked the participants to link the provocative artifacts with the real context, they were not set up for a deep discussion into robotic capabilities in the baggage hall. There was a good level of discussion on general HRI possibilities, but especially in the groups without contextual stakeholders, discussion stayed very high-level.

RQ2: *Were the meta-behaviors and robotic creatures effective in fostering visitors’ critical thinking concerning robotic work futures?*

Here we are concerned both with the quality of the discussion generated, and an unpicking of the context and factors that supported it. Looking at the most relevant clusters that emerged during the second and the third activity of the focus groups HRI, understanding robots, understanding context, and understanding meta-behaviors, both the meta-behaviors and the robotic creatures proved to be a means for stimulating participants’ critical thinking concerning the possibilities of work robotization. Participants developed thinking around key questions of agency and autonomy, the relationality between humans and robots thinking into potential models for co-working and collaboration. They were further able to speculate about potential future robotic applications within the industrial context. In the third activity particularly, looking at a relatively high-level meta-behavior allowed for moves like enhancing trust with respect to concretely explore different relationalities. This also allowed a greater integration between contextual stakeholders and others, as there was a more even sense of collaboration and engagement.

Looking at the process, the gradual distancing of knowledge from the context, through abstraction into meta-behaviors and then robotic creatures led visitors to experience an estrangement and defamiliarization with the context itself, which proved to be effective in provoking their thinking. Analyzing the dialogues and discussions that emerged during the first activity of the focus group and with reference to the high number of quotes related to robots’ performance and appearance, the encounter with the robotic creatures had been able to stimulate their reasoning and provide rich material for discussion. On the other hand, this estrangement made it more difficult to relate the tangible artifacts with robotic capabilities. With regard to this, the ambiguity experienced was sometimes seen by the participants as a confusing and blocking element, rather than a source for reflections. As ambiguity is seen as a key driver for fostering unconventional thinking in speculative practices [60, 66], finding ways to more carefully manage the participants' relation to ambiguity would be useful.

Lastly, on the question of 'futures', the work here has an uneasy relation. We have asked the participants to think about how things might be, but not provided any particular tools to carry out rigorous futuring: no scenarios, analysis of change, exploration of drivers, and so on. As a result, the speculation carried out is relatively general. For the purpose of this work, this is appropriate – it is aimed at relatively early-stage 'fuzzy front end' explorations [83].

6.2.1 Limitations and reflections. Although the entire process reported in this contribution has shown potential for bringing speculative, creative, and loosely grounded practices into the field of HRI, some limitations deserve to be addressed. They should be read not only as shortcomings of the study, but as methodological trade-offs (Section 5.5) inherent to the use of abstract, speculative artifacts within a transdisciplinary and exploratory research setting. Many of the challenges observed, such as ambiguity, reduced contextual grounding, and difficulties linking the creatures back to concrete work practices, are directly tied to the same abstraction that enabled creative reinterpretation, relational reflection, and futures-oriented discussion in the focus groups:

- The abstraction of complex contextual information into simply defined meta-behaviors created challenges for the students carrying out their implementation and for the visitors recovering links to the context. This led to ambiguity and dissonance, which was seen as partly generative but needs managing to avoid a sense of confusion or lack of clarity.
- The abstract nature of the creatures posed a threat for linking them back to real robots and work contexts, making it challenging to assess how these robotic creatures can help reimagine robotic futures. At the same time, we were mostly interested in understanding how interacting with these can prompt new imagery of collaboration with robots in the work context. Furthermore, the degree of abstraction of the creatures was a means to provoke reflections beyond a mere functional dimension, trying to tap into more relational aspects of the collaboration.
- Hardware and software constraints represented a challenge for the students: once the meta-behaviors had been understood, they had to identify some of their characteristics and aspects to be transferred into their formal and functional synthesis. During this synthesis process, by establishing moments of confrontation and discussion, students were constantly required to maintain provocative and unconventional perspectives, to ensure their creatures were designed to further foster critical and speculative thinking.
- The initial experimental design was set up for stakeholders from the industrial context, and, more specifically, workers; however, in practice, this was not achieved. This is a challenge with this kind of industrial engagement. At the particular stage the larger project was at, it was important to be extremely sensitive to trust and demands on the industrial stakeholder, which - counterintuitively - made recruitment of workers less possible that it might otherwise have been. However, the result of the speculative project was increased trust in these kinds of design practices, so if resources allowed a second iteration, it would have been possible to involve the workers more deeply. The offsite location was also a significant barrier, so future work would have involved bringing the speculative experience physically closer to the worksite. This reflects a core complexity of transdisciplinary work: it is difficult to isolate discrete units of research that can be abstracted, as the scientific process is inherently entangled with the socio-political efforts of building trust, forming networks, and creating potential for action [96].
- The difficulty of recruiting actual workers meant that less contextual knowledge was available for discussion than hoped for, and led to some confusion, e.g. participants acting as travelers rather than

baggage handlers. We believe a higher involvement of stakeholders would have provided richer dialogue and reflection and given more insight into how effective the abstraction and defamiliarization processes were. There is also space to explore whether the presence of more stakeholders would create more tension between the abstractions and their personal beliefs and imaginaries of robotization in their workplace. The mixture of some non-stakeholders and some robotics experts appeared to be useful for rich discussion; however, this means that we cannot speak to how well the particular speculations fit with the constraints of the worksite, or whether the methods would work with the particular stakeholders. Instead, we have focused the discussion on how the techniques worked as part of a larger transdisciplinary process (Section 6.3) and how the meta-behaviors served as encapsulations of context (6.4). For future works, a balanced combination of participants with contextual knowledge and experience and others with a deeper understanding of robotic systems and capabilities should be looked for to aim at more complex discussions and insights.

- In terms of relating methods and goals, it should be noted that there were four separate projects at play within this moment of activity: i) an international artistic effort to create artworks based on modular, reprogrammable robotic architectures, whose goal was to test out fabrication, design and technical components, as well as convince university stakeholders to invest in the project; ii) an educational project to develop student facility with interactive networked electronics, as a creative component of a design degree, with student learning as the goal; iii) a large transdisciplinary project whose goal is to better imagine and design for worker robot relations in the baggage hall; and iv) this particular work, whose goals were to contribute scientific knowledge around the use of speculative design for working in industry, and to advance the larger TD project. The work presented here was somewhat opportunistic in bringing the various actors together; this meant there were impedance mismatches between the timescales, commitments and resources of the various projects, and they had a diverse set of goals. In most cases, this was a coordination challenge, but did not get in the way of the research: the artistic goals and the research goals coexisted quite happily, while being entirely distinct; the research goals and the educational goals had a certain level of synergy, as students could connect their educational activities to wider practice, and their creative efforts supported a speculative space to play. The main challenge (as discussed above) was connecting the particularities of this piece of work to the larger TD project, despite the alignment in their goals - see Section 6.3 for a fuller discussion of how this connection plays out.

6.3 Transdisciplinarity and robot futures

Although this work was not centrally committed to transdisciplinarity and transdisciplinary research, it fits into a broader project with strong transdisciplinary engagement. Transdisciplinary work [68] entails making linkages between scholarship and practice, as well as across disciplinary boundaries [51]. Looking at the entire process of meta-behaviors' creation, up to their translation into artifacts and the encounter with visitors, we argue that the meta-behaviors create ground for transdisciplinary discourse. Dialogues between the TD Taskforce and the research team helped to articulate and translate the knowledge they had gathered and co-created with the employees and the work organization, bringing into connection with a range of other disciplinary perspectives.

Certain parts of the process, however, had a more interdisciplinary feel: bringing the students together around the meta-behaviors demanded the shared use of knowledge from architecture, computer science, and artistic practices, but did not have the overarching sense of values or stakeholder involvement that would signal a true transdisciplinary practice. To get a better sense of the transdisciplinary aspects here, we turn to van der Bijl-Brouwer's framework [96], which discusses three ways design can support transdisciplinarity:

- As a knowledge integrator within multi-level, purposive transdisciplinarity, the work here gave a way to translate knowledge from one site to another, for creative analysis and re-use in other sites. The

meta-behaviors started as descriptions of what exists, connecting up to questions of what we are capable of, while also stimulating debate about what we want to do, and what the meanings behind that might be. The epistemologies [35] of the various groups involved in the process certainly grew, and the participants were able to fluently look ahead into new frames for the concepts at hand. The meta-behaviors enabled this process by acting as intermediate-level knowledge and as boundary objects – we discuss this further in Section 6.4.
- As collaborative practice in participative transdisciplinarity, the work here functions as one part of the puzzle. The broader project is brought together under the idea that societal problems need to frame research questions and practices [51]. As such, the research framing has been co-designed with the stakeholders in the context of social problems and strong normative views about the future of work and robotization. The meta-behaviors translate here the participatory and observational practices led by the TD Taskforce, to allow a wider engagement around the research questions being developed.
- As part of a transdisciplinary social learning process the process shows promise, but the execution has not yet been delivered. In order to achieve this, it would require sharing the materials and the results with the employees, engaging in the baggage hall, and transferring the obtained knowledge more broadly with the stakeholders, together with Worker-Robot Relationships related knowledge. While this is currently the least developed aspect, it is also where we see the most potential for this kind of work, as experiential and speculative processes can provide vivid, engaging explorations of complex areas, and have the potential to be strong social catalysts.

6.4 Meta-behaviors: Between intermediate-level knowledge and boundary objects

We have cast meta-behaviors as boundary objects, recognizing their ability to crystallize performance-based patterns as knowledge-based instances situated in a particular context, enabling us to link specific work practices with broader ideas and concepts. Through this process, they can enhance the capacity of these instances to be transferred between different knowledge domains and across boundaries [40]. Looking at Bergman et. al's framing of the role of boundary objects in design [94], two particular aspects resonate: the meta-behaviors worked to transform design knowledge gathered from the worksite into a new, experiential form. This was part of mobilizing the knowledge for activity: bringing the participants into correspondence with the concepts distilled from the worksite.

Going back to Star's original conception of boundary objects [86], we can look at the ideas of identity and plasticity as the meta-behaviors move through the larger project. Each phase of life for the meta-behaviors involved a different group and drew on different knowledge: The TD Taskforce had acquired deep contextual knowledge through careful observation and co-creation with stakeholders on the worksite; the meta-behaviors gave a clear identity to a small subset of this knowledge. The research team, along with the TD Taskforce, drew on theoretical and practical knowledge of critical, speculative, and imaginative design practices, to refine both the concept and particularities of meta-behaviors; abstraction here served both to solidify the identities and create space for plasticity and re-interpretation. The students, with the support of the artistic team and their practices, used the meta-behaviors as frames for creative exploration: they drew on the identities as seeds and exploited the plasticity to have space in which to bring together the provided materials and technologies with their own disciplinary and creative practices.

As previously discussed, the boundary nature of meta-behaviors is especially visible when linked to the concept of transdisciplinarity due to their power to catalyze distributed knowledge. In this case, the formal representations of the meta-behaviors are only hooks on which to hang the knowledge that resides in multiple people more or less closely associated with the work.

While addressing the concept of boundary objects and their applications to HRI, this work fits also in the discourse concerning designerly ways of knowing in this field [27, 60], in particular, the need for intermediate-level knowledge [63]. The meta-behaviors are more abstract than particular practices, they move away from the sweat and toil, and particular configurations of material; they are also less generalized and abstracted than theories would be, without a dependence on coherence or descriptive power. They serve as generative knowledge, despite their empirical roots. They do not necessarily have the same generalizability or rigorous characterization as strong concepts [52] but are closer to the sense of patterns.

However, this is distinct from Alexander's usage of design patterns to combine common problems and their solutions [3], which have already found application in HRI, e.g. [53]. Rather, these are common patterns of performance, observed in the interplays between workers, material and technological infrastructures – a move towards Suchman's notion of "dynamic processes of knowing and acting", and support the idea of knowledge that deals with "multiple, located, partial perspectives that find their objective character through ongoing processes of debate" [89, p. 92], and critically for HRI leave open the boundary between machine and organism [46]. There is the hope that they suggest the possibilities of re-thinking how capacities for action are configured at the human-machine interface without presupposing particular divisions of planning or action [88].

The role of the robotic creatures is more nuanced; one might argue that rather than being 'mere instantiations' of the patterns themselves, they are distributed artifacts, pointing back at the context while also engaging visitors for discussion. As immersive, artistic creations, Bennet's notion of crossings is useful here: they are movements of knowledge from one space into another, but more than that are "capable of inspiring wonder, with room for play and for high spirits" [12, p. 31]. By serving as a source of enchantment, through surprise, charm, and the "uncanny" [12, p. 5] they create the space for reflection on new kinds of relation [59]. Pragmatically, the robotic creatures are strongly present and striking, but knowledge is situated around them, more so than in the artifacts themselves, so they catalyze more than embody. Just as steering wheels [58] or digital cameras [11, 78] provide standpoints for engaging with advances in technological capabilities, the idiosyncratic expressions here provide reflective spaces.

In conclusion, we can note how i) meta-behaviors as boundary objects allowed us to move freely between and across different discipline domains, creating a ground for transdisciplinary discourses and exchanges, while ii) meta-behaviors as action patterns for intermediate-level knowledge provide a generative form of transferable knowledge, that can potentially be recognized in other situations and used as a form of connective tissue in advancing HRI work.

7 Conclusion

In this work, we have brought together experiential practices with speculative framings in order to support creative discussion about the future of work robotization. We have described a process where knowledge is abstracted from detailed investigations of a particular worksite into 'meta-behaviors' that function as boundary objects. These meta-behaviors are used as the basis of a creative, experiential investigation by people unfamiliar with the context, which then feeds speculation about the context itself. We have shown that – with some caveats – these abstractions were comprehensible to the participants, and that they were both relatable to robotic capabilities and generative of rich discussion about future worker robot relations.

This work develops the possibilities for what we would term 'applied speculation' within HRI: approaches that draw on the creative possibilities of speculative design in order to think into future relationships, but that also stay connected to technical possibilities and the characteristics of the worksite. In particular, it looks at how extremely open abstractions of knowledge can serve both as boundary objects for collaboration within diverse transdisciplinary teams and as intermediate-level knowledge that helps to build a fabric for the understanding of future worker-robot relations.

More broadly, this is part of an ongoing effort to bring together designerly practices and HRI advances. As the possibilities for social and cognitive robots grow, so too does the need to answer questions that are increasingly rooted in social and relational areas. There is a growing need to support the design of worker-robot relations [107], and as such we need methods that help to work with robotic technologies that are increasingly agential but are also fraught with particular imagery and conceptions of what robots are, as well as being deeply intertwined with the politics of labor and the identities of workers. By bringing together the experiential and the critical with a strong industrial focus, we provide both theoretical and practical possibilities for understanding and designing a preferable future around robotic technology.

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