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Co-Designing Companion Robots for the Wild: Ideating Towards a Design Space

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ABSTRACT

Autonomous systems such as robots are permeating our daily lives increasingly every day, which are now adorned with social elements, bringing them closer to synthetic companions. While used in fields like well-being, education, guidance, and entertainment, companion robots also hold great potential for outdoor uses, particularly accompanying people in the wild with numerous potential benefits. However, current studies lack a comprehensive understanding of the possible uses, functions, and behavior of companion robots outdoors. To explore this area, we have run a co-design study consisting of 5 design workshops with 30 participants, including interaction designers, product development experts, engineers, robotics experts, and frequent forest goers. The study resulted in nine valuable design themes, transferred into five design concepts, which were then interpreted into a comprehensive design space that can be leveraged by designers and researchers in creating companion robots for the wild.

KEYWORDS

Robots; human-nature interaction; companion robots; human-robot interaction; co-design; speculative design

1. Introduction

We live in an era where autonomous systems, such as robots, are becoming a major part of our daily lives. These systems are developed in an attempt to make day-to-day activities easier and less mundane. Robots are no longer limited to industries and have entered humans' personal space, helping them with different chores at home (Cakmak & Takayama, 2013), such as assisting in cleaning the house, cooking food, washing dishes, and even driving cars for humans. Similarly, robot abilities are not limited to sensing and actuating anymore as designers are giving robots more social capabilities to allow for more seamless integration with human lives (Dautenhahn, 2007). Robots are now created with more expressive physical traits, such as moving body parts (e.g., eyes, head, hands) to create gestures and facial features to express emotions (Fink, 2012). Advanced machine learning and natural language processing algorithms are also being added to some robots so they can comprehend and react to human speech. Through the integration of the aforementioned features, robots have been shaped as companions in different aspects of daily life (Ahmed et al., 2022).

Companionship, in the scope of this paper, is defined as the phenomenon of having someone or something as a friend in different times and situations, creating a sense of fellowship in the process (Ahmed et al., 2024; Dix et al., 2004; Ye et al., 2024). The term companionship is also linked with social support which then contributes to psychological well-being (Rook, 1987). According to Ahmed et al. (2024), companion robots have so far been deployed mostly in healthcare and well-being scenarios which mostly focus on the indoor uses of robotic companions. In contrast, recreational uses of robotic companions in outdoor scenarios or in the wild are relatively unexplored although they are very relevant. The recreational value of outdoor activities, such as spending time in nature is well known (Aasetre & Gundersen, 2012). Companion robots in recreational outdoor activities have the potential to provide social connection (Cacioppo & Patrick, 2008) and create shared experiences among various stakeholders involved in the interaction (e.g., human-robot-nature, human-nature-human, and human-robot-human). These shared experiences in nature can take many forms, such as highlighting unique aspects of the environment, offering alternative perspectives on natural phenomena, or engaging in collaborative activities like identifying flora and fauna) (Arts et al., 2021; Zylstra, 2018). However, beyond fostering social engagement, robots hold unique potential to transform the way humans experience and interact with natural environments, particularly forests. Companion robots offer a unique way to enhance forest experiences by actively facilitating engagement with nature rather than distracting from it. Unlike screen-based technologies, robots can dynamically interact with the environment, drawing attention to ecological details, encouraging exploration, and introducing playfulness (Ahmed et al., 2024; Cabibihan et al., 2014). Beyond engagement, they might enhance safety and accessibility by assisting with navigation, identifying environmental elements, and providing security in remote areas. Also considering the current presence of robots, for example for industrial uses in forests (Oliveira et al., 2021), the exploration of how robotic companions can be a part of outdoor recreational activities has a potential to inform the field regarding how to develop this

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machinery in a more friendly way to both humans and to nature.

In the scope of this study, nature or the wild refers to environments that are minimally impacted by human structures or control, where ecological processes operate independently and offer a dynamic, sensory-rich setting for interaction. This includes forests, wilderness areas, and other outdoor landscapes characterized by diverse flora and fauna and unpredictable, non-linear natural elements (Bertran et al., 2023a). Such environments present unique challenges and opportunities for human-robot interaction, as they demand adaptability and responsiveness to surroundings that are inherently untamed and rich in sensory stimuli (Bertran et al., 2023b). By framing these spaces as complex, interconnected ecosystems, the study emphasizes the importance of designing robots that can not only navigate but also engage with the intricacies of the natural world.

Currently, we are missing design knowledge that can inform us about the ways of designing companion robots for outdoors which would facilitate better engagement with nature and overall, an enhanced experience of being in the wild. To address this gap, we have conducted a detailed and rigorous co-design workshop series, exploring the design of robotic companions in the outdoor and nature context. More specifically, we attempted to explore the design space of robots that can accompany humans in forests and nature in a meaningful manner. We took inspiration from Bartneck et al.'s framework (Bartneck & Forlizzi, 2004) claiming that the design of a social robot should include its form (appearance), interaction modalities, social norms, autonomy, and interactivity. We also leveraged Axelsson et al.'s framework (Axelsson et al., 2022) which includes several co-design canvases for different aspects of a social robot's design. While these frameworks are useful for solidifying aspects of social robot design, the design of human-robot companionship for nature presents specific opportunities and challenges as this context provides many different actors (e.g., animals, plantations, weather conditions) that might take part in how companionship could be formed and mediated through. This dynamic interplay requires rethinking design considerations to ensure that the robot not only interacts effectively with humans but also harmonizes with the broader ecosystem. Furthermore, it emphasizes the need for adaptable designs that respond to diverse and unpredictable natural elements, which promotes a sense of coexistence and mutual respect among all actors in the environment.

As part of the co-design activities, we have included different stakeholders, including forest-goers, interaction designers, robotics experts, and product design experts in the design workshop series. The series consisted of 5 workshops attended by a total of 30 participants, where each workshop focused on different aspects of the design. The primary objective of the study was to speculatively understand how robotic companions can be designed for accompanying humans in the wild, i.e., nature and forests. The design process directed participants to explore their ideas in the wild, i.e., outdoor nature, which can be referred to as a real-world interaction environment for the concepts and designs they create. In addition to that, we also tried to derive possible scenarios where this human-robot companionship aspect would bring meaningful influence on the interaction between humans and nature. As a primary contribution, we have developed and presented a design space for companion robots for the wild. Additionally, we contribute design knowledge through (1) nine design themes and (2) five concepts of robotic companions for the wild.

2. Background

2.1. Role of technology in human-nature interaction

Humans, both cognitively and affectively have evolved to function surrounded by nature (Levin & Unsworth, 2013) as being immersed and interactive with nature has positive well-being benefits (Lackey et al., 2021; Olafsdottir et al., 2020; Tillmann et al., 2018). Inversely, being distanced from nature has been found to have negative consequences for well-being (Lackey et al., 2021). According to Frumkin et al. (2017), people who spent a significant amount of time in forests and green spaces had lower blood pressure and depressive symptoms than those who did not. The frequency and duration of visits were also associated with a higher level of physical activity. Other studies (Olafsdottir et al., 2020; Soga & Gaston, 2016) found that walking in nature reduced stress more effectively than walking on a treadmill or watching green scenes on television. Meanwhile, a negative association was found between urban green space exposure and mortality, heart rate, and violence (Yale E360, n.d).

While technology and urbanization have advanced many aspects of human life such as accessibility to information, communication, transportation, and even enjoyment, in the quest of creating a better life for humans, the interaction between humans and nature has started to diminish (Soga & Gaston, 2016). Even though technology has been blamed for human detachment from nature, it is still a major part of human evolution as human-technology integration is seen as the next step of this evolution by many (Sugar, 2002). If carefully designed, technology might be one of the facilitators that would strengthen this weakened bond between humans and nature (Bertran et al., 2022; Roco, 2004). Technology for improving human-nature interaction might range from simple mobile apps that would facilitate some kind of communication between nature and humans to drone swarms navigating autonomously through the forests (Bjurling et al., 2020; Jacob et al., 2020). There have already been some developments in the shape of location-based games (Avouris & Yiannoutsou, 2012), AR/VR applications (Carmigniani et al., 2011) as well as exergames (Göbel et al., 2010) to create a better bond between humans and nature. However, there is scope for further investigation using more advanced technologies that can create a sense of agency or companionship when humans interact with nature (Nyholm, 2018). Recent advancements in robotic technology in terms of navigation, social features, and intelligence might allow robots to be taken outdoors and be effective in creating a more intriguing nature experience.

2.2. Outdoor usage of robots

Robots in recent times have been deployed outdoors mainly to leverage their navigation capabilities through mapping and intelligent decision-making (Crespo et al., 2020; Mingyang & Shuang, 2022). They have also been used for trash collection, gardening, site inspection, and even as mobile air conditioners (Zied Chaari et al., 2021). Several other use cases have been explored, especially in service providing scenarios, such as delivery service (Lee et al., 2022) and autonomous trash collection (Kulshreshtha et al., 2021). Functional abilities of robots to explore outdoor environments have also been investigated where they have been designed to traverse difficult terrains (Dupeyroux et al., 2019) and autonomous navigation in challenging paths (Wang et al., 2024). However, these robots do not have any social qualities, and they are strictly task-based robots.

In terms of providing companionship, a robot needs to create a sense of fellowship so that it can affect the users socially. According to Ahmed et al. (2022), robots so far have been deployed as companions mostly in healthcare and well-being scenarios while other domains are relatively unexplored. In terms of deployment facilities, outdoor implementation of robotic companions has also been relatively low. A parrot-inspired companion robot, KiliRo (Bharatharaj et al., 2022) has been developed to improve terrain perception for their human counterparts. It uses image recognition technology to assess different terrains and warns the human user about changes in terrain so that they are aware and do not fall. This is especially useful while navigating in unknown places, such as the forest.

Robotic jogging companions have been explored to some extent using drones where the drones are portrayed as companions and motivators for keeping up a specific pace as well as following a specific path (Graether & Mueller, 2012; Mueller & Muirhead, 2015). The jogging companion robots helped the users to keep pace by creating peer pressure, staying side by side with the user, and dictating the path. Trials and analysis showed that the users perceived the robot as a companion and felt positive about changing their jogging behavior (Mueller & Muirhead, 2015). They also reported having a social connection with the robot. Another study explored robots as outdoor walking companion and investigated how having a walking companion robot might influence overall walking experience (Ahmed et al., 2024). The findings also suggest that walking companion robots reshape the walking experience a lot in terms of how humans perceive walking outdoors with a companion, their awareness of the surroundings, and how their sense of control is affected.

Previous studies show that outdoor companion robots have the potential to change human perception of how they approach outdoor activities through social and assistive features (Dautenhahn, 2007). This indicates the significant potential of outdoor robotic companions which can be expanded beyond robot-accompanied exercise, such as exploration, recreation, and educational interventions. However, currently, the design space of those robots is underexplored, and to the best of our knowledge, design knowledge produced by a wide set of stakeholders has not been reported.

2.3. Design aspects of companion robots

Bartneck and Forlizzi (2004) mentioned several aspects to consider when designing a social robot, such as the form (appearance), interaction modalities, social norms, autonomy, and interactivity. To be more elaborate, there should be a logical match between the robot's appearance and its abilities so that it can match the expectations of the user. Furthermore, the robot should be able to relate to the user by employing social behavior and norms, communicate effectively with the users, and manage communication failures if it occurs. While this framework provides some much-needed glossary on the main aspects of designing social human-robot interaction, it also calls for further deliberation on how these aspects might unfold when designing for specific scenarios. Axelsson et al. (2022) complemented this framework by introducing co-design canvases for social robots. These canvases allow for a more hands-on approach for designing social robots for different purposes and provide a platform to go into fine details. While both these frameworks hold their own, they lack depth in addressing the unique characteristics and challenges that emerge when designing robots tailored for specific functions or environments. They may overlook the finer nuances and diverse requirements that arise in a specialized application such as companion robots in the wild. The design requires consideration for not only how humans and robots interact with each other, but also other actors (e.g., plants, animals, ecosystems, etc.) that come into play because of the interaction environment. In addition to that, the design needs to consider the unpredictability of the environment and have recommendations for unknown, unplanned, and unstructured interactions that might occur.

Effective human-robot interaction requires careful consideration of the **environment** where the interaction takes place. The environment can be made suitable by considering safety, consistency, engagement facilitation, and proper accessibility that can improve bi-directional communication (Rich et al., 2010). Zacharaki et al. (2020) suggest factors such as the clear perception and predictability of working principles of the software and hardware, or transparency, and awareness about the robot's physical affordances should be considered to ensure safety in human-robot interaction. Herrmann and Melhuish (2010) go further and divide safety into physical and behavioral. Physical safety indicates that the hardware and physical components of the robot are safe to interact with, while behavioral safety is concerned with the bi-directional communication channel between humans and robots using different modalities. Especially when the interaction is taking place in an uncontrolled environment such as outdoors, many external factors come into play, which might affect the interaction in many ways (Hong et al., 2021). For effective communication between humans and robots, either the environment needs to be controlled so that external factors are transparent, or the robot needs to be contextually aware of possible unknown situations (Riley et al., 2010).

The appearance of a robot plays a very significant role in human-robot interaction as it affects human perception of robots, especially in terms of human likeness and competence (Fink, 2012; Jia & Chen, 2024). The appearance of a robot might vary depending on how and where it is intended to be used. For example, social robots that are intended to interact with humans are designed to have appearances that are familiar and endearing to humans. These types of robots are usually designed as human-like (anthropomorphic), such as Pepper (SoftBank Robotics America Inc, n.d), or animal-like (zoomorphic), such as Joy for all robot cats (Companion Pet Cat, n.d) so that their appearances can promote social interactions. There are robots that are given soft exteriors to encourage physical touch by people, such as the Paro robot (PARO Therapeutic Robot, 2023). The appearance of robots might also vary depending on their operating environment. A robot designed to operate primarily indoors does not need to be as robust and sophisticated as a robot that will mostly operate outdoors (Goetz et al., 2003). Also, the operating environment usually determines how a robot's navigation would work. If they are operated indoors, then they would only need to move on flat surfaces, whereas outdoor robots require the ability to operate on uneven terrain. Outdoor robots are also given harder exteriors to add protection and durability (Katz & Halpern, 2014).

The behavior of a companion robot needs to be very carefully designed as it affects the interaction in many ways, such as responsiveness, personality, social skills, autonomy, contextual adaptation, and personalization (Phillips et al., 2017; Walters et al., 2008). Robot responsiveness can be defined by determining the group of stimuli that influences its responses, whether they are pre-programmed or external stimuli. A robot appears to be more contextually aware of and responsive to its surroundings if it recognizes external stimuli along with pre-programmed ones (Stipancic et al., 2016). A robot's personality represents its characteristics in different situations, which include its way of responding to specific situations as well as its level of extroversion in social situations. Personality aspects of robots help create an emotional bond with humans which can then result in more meaningful interactions (Lee et al., 2006). Another important aspect of a robot's behavior is how it reacts depending on its mode of operation. There need to be clear behavioral changes for interventions that are human-controlled, semi-autonomous, or fully autonomous (Schöner et al., 1995).

A major part of a robot's behavior is what kind of social skills they have and how they adapt to different social encounters through these skills (Dautenhahn, 2007). An intelligent robot should be able to adapt its behavior based on the situation and the cultural norms of the people it is dealing with. Cultural sensitivity needs to be implemented in robots for them to adapt to different cultural encounters (Wang et al., 2010). This includes being able to read nonverbal signs including body language, tone of voice, and facial expressions, and responding accordingly (Yoon et al., 2019). It can also be framed as personalization, where the robot is expected to understand user preferences and act accordingly. In addition to this, the behavior of a robot needs to be transparent for humans to understand, which can then create a sense of trust and reduce anxiety in the interaction (Chien et al., 2025; Kim et al., 2022; Syrdal et al., 2007). Finally, autonomy is another important aspect of a robot, especially for creating its own distinct identity which separates them from other command-following entities controlled by humans (Torre, 2021). In order for a robot to be considered a companion, it needs to exhibit traits that allow them to be perceived as social beings (Henschel et al., 2021).

This section explained how technology has influenced the human-nature interaction domain in ways that have affected the human-nature relationship both positively and negatively. While technology might be blamed for distancing humans and nature, it also has ways to strengthen the bond. Robots are already used in forests for industrial purposes and their rapid development in social scenarios promises a lot. Outdoor adaptation of robots has been limited so far, which also means that there is a lot to explore in this domain. As a first step in understanding the design of outdoor companion robots, we explored their different design aspects and then used those aspects as the focus of our co-design workshops. We also take a look at several design-oriented frameworks, use the knowledge they have created, and identify the aspects where we could contribute new knowledge.

3. Method

To understand the design space of robotic companions for nature and forest experiences, we adopted a Speculative Design approach (Auger, 2013). Speculative design allows challenging the standard or norms of the current design practices by promoting a more thoughtful and democratic approach through curated discussions and debates (Auger, 2014). This enables a departure from conventional ideas, established traditions, and contextual expectations to rethink objects and entire worlds motivated by various ideologies or motives.

We attempted to involve stakeholders in the design process through co-design workshops (Steen, 2013), that we call Fusion workshops. We organized five (3 Atoms + 1 Synthesis + 1 Fusion) workshops to address different aspects of the design process (Buruk et al., 2021; Buruk & Hamari, 2021). Stakeholders were involved throughout the whole design process, each participating in one Atom, a Synthesis, and a Fusion workshop. Atom workshops are separate workshops that focus on the different aspects of the robotic companion for nature exploration, in our case the appearance (APPR) and behavior (BHVR) of the companion as well as the environment (ENV) of the interaction. The main objective of an Atom workshop is to get the participants familiarize with the problem space, inform them about the theoretical understanding of the problem, and facilitating their brainstorming process towards a comprehensive understanding of the design problem. The participants were given deep knowledge of the problem space through lectures and group discussion activities in the Atom workshops. Then the participants brainstormed in groups to come up with specific design themes connecting to their workshop focus. We used several social robot design canvases proposed by Axelsson et al. (2022) during brainstorming sessions as they offer a comprehensive set of questions and directions for having deep discussions. These workshops were designed in a way that helps the participants sensitize (Waern et al., 2020) themselves to the different aspects of robotic companions in nature through embodied interaction and bodystorming (Márquez Segura et al., 2016).

The other two workshops were called Synthesis and Fusion workshops respectively, where all the participants from the previous Atom workshops gathered together to build on their findings from the Atom workshops. As indicated by the name, a Synthesis workshop aims to synthesize all the knowledge gathered through previous (Atom) workshops though knowledge sharing and conceptualization in groups. This workshop is a crucial step for this study setting as it is imperative to share, distribute, and synthesize the knowledge gathered in 3 Atom workshops, ensuring each participant has a clear and comprehensive understanding of the problem space. In the Synthesis workshop, participants worked in groups to create concepts that covered all the design aspects. Here, all the discussions, findings, and experiences from the three Atom workshops were merged to create a comprehensive overview of the possible design solution. The objective of the Fusion workshop is to refine the concept created in the Synthesis workshop, concretize it, and create low-fidelity prototypes. In the Fusion workshop, participants worked in the same groups as the synthesis workshop, developed these concepts further via storyboarding (Truong et al., 2006) and video sketching (Zimmerman, 2005). We attempted to communicate the knowledge generated in the design process of the workshops through themes (Baniassad & Clarke, 2004), concepts (Höök & Löwgren, 2012), and finally a design space (MacLean et al., 1991). For future research and design of robotic companions in the context of nature and forest experiences, our work can be considered a rich source of guidance and inspirational knowledge. The whole research process and summarized outcomes are visualized in Figure 1.

3.1. Participants

The workshops were conducted during the final week of October and the first week of November 2022. A workshop course was designed and developed at the university which was then made open to all personnel that included students, researchers, and university staff. The course was advertised through internal channels at the university as well as external channels such as social media groups relating to forest explorations and social robotics to attract people from different domains. A registration form was distributed, which consisted of questions related to the participant's expertise, frequency of nature visits, and previous experience in their fields. It helped us understand their relevance and possible role in the workshops. Table 1 contains details about participants' education levels, their domains of education, and their frequency of forest visits per week.

A total of 51 people expressed their interest, and 30 people were selected to participate. This selection was done by analyzing each person's background, prior experience, and relevance to the workshop, while frequent forest-goers were given preference. *User experience and interaction designers* were included to better understand the user experience perspective. Participants with *Electrical Engineering* backgrounds were included to add their knowledge of building feasible and technically sound systems. *Software professionals* contributed their knowledge of how different systems can be integrated with software and make them more accessible. *Experts in Robotics and AI* were included to gain a more focused understanding of the current state of the technology including the feasibility and acceptance of the system. We also included *Information Technology professionals* in the workshops to use their knowledge of information systems, what the best practices are, and how they can be implemented efficiently. The experts in the study were not only included to help create designs that can be implemented with the currently available technology, but also to facilitate creating realistic concepts that can be implemented in the foreseeable future, if not right now. Finally, we included frequent forest goers in the workshops so that they could help everyone relate to the experience of forest exploration, and how robots fit into this scenario. The target user group for the study is those who visit or plan to visit nature and forest on a regular basis and would benefit from novel ways of interacting with nature.

Nine out of 25 graduate level participants were considered experts because of their prior professional experience in software engineering ($N = 2$), backend software development ($N = 1$), product design ($N = 1$), user experience consultancy ($N = 1$), machine learning ($N = 1$), automation ($N = 1$), robotics programming ($N = 1$), and mechanical design ($N = 1$). Participants' expertise was not strictly classified in relation to their education level or domain, rather based on their prior experiences in educational and professional life. The other 16 graduate level participants were considered non-experts for this study because they either did not have any professional experience in related domains of the design problem, or did not have any professional experience at all. Out of the other five participants, one was a doctoral researcher in the field of machine learning and was considered an expert in the field while four participants were undergraduate-level students and thus were considered non-experts.

Among all the participants, five reported visiting nature more than three times a week while 11 other participants visited nature or forest two to three times per week. Informed consent was taken from the participants for collecting data in the form of images, videos, and design notes. All the participants were compensated with a minimum of

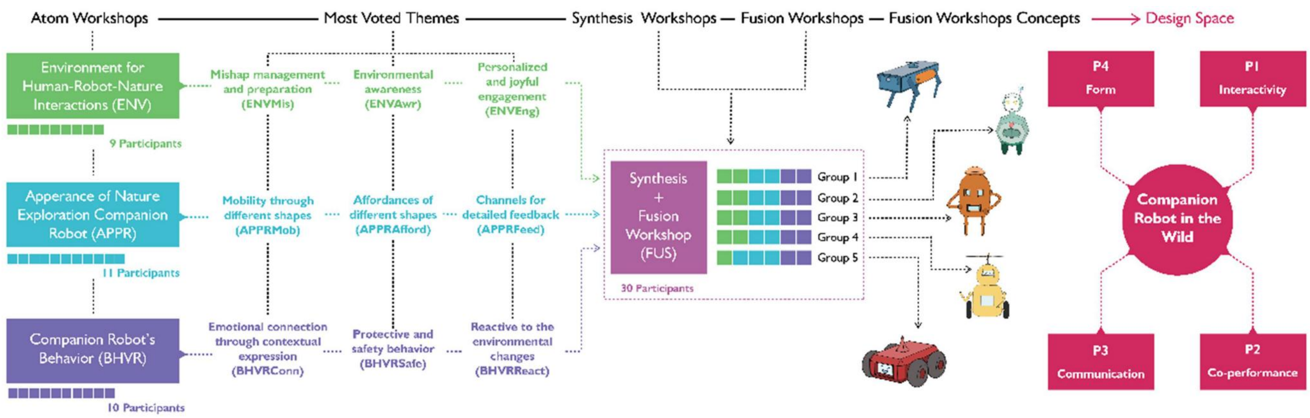

Figure 1. Research process and summary of outcomes.

Table 1. Workshop participants.

Education level	Education domain	Total number of participants	Number of experts	Participants with > 3 Forest visits/week)	Participants with 2-3 Forest visits/week)
Doctoral	Machine Learning	1	1	1	0
Master	Human-Technology Interaction (11), Electrical Engineering (4), Information Technology (3), Sustainable Digital Life (3), Automation Engineering (1), Machine learning (1), Robotics and AI (1), Embedded Systems (1)	25	9	3	9
Bachelor	Electrical Engineering (2), Software Engineering (2)	4	0	1	2
Total		**30**	**10**	**5**	**11**

two credits toward their studies with the option of gaining one extra credit by writing an essay on the workshop topics.

3.2. Procedure

3.2.1. Atom workshops

Three Atom workshops were conducted following a similar structure, with only the focused design aspect being varied between them (ENV, APPR, and BHVR). At the beginning of the workshops, participants were divided into groups of three or four and performed a warm-up activity. This was followed by a lecture by the moderator about the workshop topic, schedule, practicalities, and design problems at hand. The next activity was a 3-12-3 brainstorming (Buruk et al., 2021; Gray et al., 2010) session. This is an effective and quick way to get the participants thinking and brainstorming about the topic which consists of a 3-minute keyword generation, 12-minute combining and conceptualizing, and a 3-minute presentation of the ideas. Through this, the participants came up with keywords that are related and important to the solution space and started thinking about combining those keywords to form conceptual solutions. To give them a more unified direction and discussion cues for further brainstorming, social robot design canvases (Environment, Appearance, and Behavior canvases) designed by Axelsson et al. (2022) were provided. These canvases consist of different aspects of designing social robots and come with several questions for each aspect. The keywords and directions were then expanded into a rich variety of ideas through a free form brainstorming session.

After lunch, we attempted to gather all the ideas generated in the brainstorming stage by creating an affinity diagram and then categorizing all the ideas into specific themes. The participants then voted on the themes and the three most voted themes (MVTs) were chosen for further deliberation. This part was video recorded for future reference and analysis. In the next phase, the participants elaborated on the three MVTs in groups and extended them into more concrete concepts. Each group was then instructed to experience those concepts through bodystorming (Márquez Segura et al., 2016) which helped them replicate a real-life scenario and to understand how the interactions would work in action. The groups then acted out the bodystorming concepts and the observing participants as well as the moderators provided constructive feedback. The bodystorming acts were video recorded.

The atom workshops were mainly designed for topic familiarization, ideation, brainstorming, and theme generation. Although it would be ideal to have the exact same number of participants, ENV had 9, APPR had 11, and BHVR had 10 participants, creating a slightly uneven distribution. However, this did not influence the outcomes of the workshop as all insights were gathered through group activities and no activity or outcome was directly influenced by any single participant, minimizing the risks of uneven distribution. Moreover, we ensured even distribution of expertise, education, and experiences between each group to obtain uniform distribution of insights, further reducing the effect of slightly uneven group distribution.

3.2.2. Synthesis workshop

The synthesis workshop brought together all the Atom workshop participants to share insights and generate comprehensive concepts by combining their knowledge. The 30 participants were divided into five groups, where each group would work towards their own unique concept, in order to create more substantial design knowledge. Each group consisted of at least one participant from each Atom workshop, ensuring that each group had comprehensive knowledge of the topics and themes they would build their concepts upon. Additionally, we tried to streamline the group distribution by ensuring one participant who visited nature more than three times per week, one designer, and one software expert. The workshop started with a discussion on the nine MVTs from the Atom workshops. Then the participants were asked to share their experiences, learning, and ideas from the Atom workshops with their group. At this point, we assumed that all the participants had a good grasp of what happened in the Atom workshops and moved on to merging the concepts. Participants were given the *Interaction* canvas by Avouris and Yiannoutsou (2012) which prompted them to think about interaction modalities, scenarios, and how those modalities fit the explored scenarios.

After lunch, the participants were given the *Robot Design MVP* canvas by Axelsson et al. (2022) which directed them to the most important aspects of the design. This canvas combines the primary questions from the other canvases to create the minimum viable product by presenting a complete design solution. Through this activity, we aimed to provide the participants with a clear idea of the things that they must include in their concepts as well as ideas that can be left behind without losing focus. The next phase was for creating a complete concept in groups for which participants had to make sure they kept the following things in mind: nine MVTs, interaction scenarios, interaction modalities, and the outcome from the MVP canvas. After the concepts were created, the participants bodystormed their concepts and prepared a detailed presentation. Each team was given 10 min to present their concept, followed by a 5-minute feedback session with other groups and the moderators. This presentation and feedback-giving session were video recorded. Figure 2 shows two groups acting out their concept through bodystorming.

3.2.3. Fusion workshops

The Fusion workshop was designed to focus on creating prototypes of the concepts designed in the Synthesis workshop. This workshop was arranged on the very next day after the Synthesis workshop so that the concepts and findings were fresh in the minds of the participants. The participants continued working in the same groups created for the Synthesis workshop. This workshop started with summarizing the ideas and concepts created the previous day. Each group was then asked to modify and improve their concepts considering the feedback received from others. After improving the concepts, the participants created storyboards of their concept by mapping out each distinct frame of their scenario. Storyboarding (Truong et al., 2006) is a low-fidelity prototyping process where every scene or frame of a scenario is mapped out which includes interactions and the flow of how the interactions pan out. Figure 3 shows some of the storyboards created by the groups.

After lunch, participants engaged in creating a video sketch (Zimmerman, 2005) of the concept they had developed during the storyboarding activity. Video sketching enables participants to swiftly share their ideas while recognizing the flaws of their design during preparation as they act out the designed scenarios and try to understand if their concept is feasible in the real world. Until this stage, the design and ideation process were conducted indoors using props for rationalizing the designs in outdoor context. However, for creating video sketches, the participants were required to go out in the wild to experience their concepts in a real-world setting. This not only helped them visualize their concepts in an environment they had designed for but also provided them with valuable insights into the environmental dynamics, spatial constraints, and sensory elements that could affect the interaction between humans and the companion robot. By acting out their scenarios outdoors and having a situated engagement grounded their designs in reality, developing a deeper understanding of how their concepts might actually unfold and be experienced in the wild.

Each group then presented their video sketched prototype to the remaining participants and received constructive feedback. This presentation session was video recorded. Participants were also asked to rate each concept (other than their own) on a scale of 1 to 7, where a higher number represents a better concept considering its comprehensiveness to incorporate all MVTs as well as its relevance to the human-robot-nature interaction scenario. These ratings were given by each participant to concepts from the groups other than their own. These ratings were considered for calculating the average rating for each concept. Figure 4 shows some snapshots of the video sketches.

3.2.4. After workshops activities

After each Atom workshop, the participants completed a survey of their overall impression of the design process. Participants were also asked to write workshop diaries in which they explained how they came up with their concepts, how their concepts represented the nine MVTs, and how they improved their concepts throughout the process of ideating, conceptualizing, prototyping, and video sketching.

3.2.5. Data collection

Multiple data sources were collected throughout the workshops to ensure a comprehensive understanding of the design process and outcomes. Video recordings captured key moments, including brainstorming sessions, bodystorming activities, and concept presentations, providing rich qualitative data for later analysis. Surveys were administered post-workshop to gather in-depth insights into their experiences and reflections. They were asked to reflect on the concepts they created, explaining the rationale behind specific design choices and offering insights into their decision-making processes. Additionally, participants provided reflections on concepts created by other groups, enabling a comparative perspective and encouraging critical thinking. The survey also

Figure 2. Two groups bodystorming their concepts.

Figure 3. Three storyboards created in the fusion workshop.

Figure 4. Snapshots of two video sketches (left: G4 and right: G3).

explored participants' thoughts on the overall workshop process, including how activities like bodystorming and video sketching contributed to refining and developing their concepts. Workshop diaries were utilized to document participants' reflections on their iterative design journey, particularly regarding the incorporation of the nine MVTs and the evolution of their concepts. Tangible outputs like affinity diagrams, storyboards, and video sketches served as evidence of idea generation, scenario mapping, and low-fidelity prototyping. These outputs were complemented by ratings of each concept on a numerical scale, enabling a comparative evaluation of concept quality. Participant discussions and feedback sessions were also documented to capture real-time critical analysis and group dynamics. Together, these data sources support an in-depth analysis of how concepts were developed, evaluated, and refined, enabling insights into effective practices, and challenges.

3.2.6. Analysis

The moderator of the workshops (first author) documented the concepts and the use cases by analyzing the workshop diaries and the video sketches created in the Fusion workshop. The video sketches represented each concept in a frame-by-frame manner, incorporating a story while the workshop diaries provided rationale for different design choices for those concepts. This documentation and rationalization were done manually for each concept by consulting respective workshop diaries of each group. The MVTs were then extracted and reflected on using workshop videos where participants and the moderator discussed them in detail. The videos were transcribed and participants' opinions about the MVTs were recorded including what each theme represents, why that theme is important, how they relate to the workshop topic, and how they add value to the design space. Workshop diaries were consulted in case any part of the video recordings was unclear.

All the MVTs, affinity diagrams, and concepts were then presented to the other researchers involved in this study who are experts on interaction design, user experience, human-nature interaction, and gamification. A 2.5-hour in-house workshop was then arranged to reflect on all the findings of the workshop which resulted in the creation of the final themes through affinity diagramming in Mural. In this workshop, all the researchers discussed and tried to understand each theme, their connection to the created concepts, and their underlying intentions. The first author noted down the common and impactful themes as well as their connection to the concepts and MVTs. Implications for design were formed based on the design concepts, specifically looking at the design choices along with their justifications. As the created concepts were video sketched, their visual representation was needed for demonstrating them in the paper, which was done by the second author. Additionally, average ratings of each concept were calculated from the individual ratings they received from participants from other groups.

Although the implications themselves were actionable, designing robots as companions for the wild might have many different specific use cases as demonstrated in the findings section. This means, there might not be a one-size-fits-all approach for this and designing for a specific use case might yield better outcomes. This led us to ideate a design space that would allow designers to apply their own contextual choices to fit their needs. For ideating the design space, we arranged a second in-house workshop where we analyzed all five concepts (video sketches) again along with the implications to unearth the underlying design choices, design polarities, and impacts of scenario-based differences. Although all five groups designed their concepts by incorporating the same themes, they clearly represented different design choices, leading to a spectrum of possibilities for each design aspect. Furthermore, designing in different parts of the spectrum creates substantial distinctions in the concepts. In the end, the design space was ideated by discussing these insights and critically analyzing how each insight would influence design practices.

4. Findings

4.1. Most voted themes (MVTs)

The most important findings from the Atom workshops are the MVTs as they were used in both the Synthesis and Fusion workshops for concept creation and prototyping. This section broadly elaborates on the themes found in each Atom workshop along with their meanings and the participants' view on selecting these themes. Table 2 lists all nine MVTs along with their explanations.

4.1.1. Environment for human-robot-nature interaction (ENV)

In the ENV Atom workshop, 9 participants were asked to brainstorm and focus around a high-level question: "How can we design a suitable environment for human-robot interaction in nature?" along with some lower-level sub-questions: "What does a safe environment for human-robot-nature interaction look like and how can we prepare it?"; "How can the environment influence better engagement between humans, robots, and nature?"; "What external components can be added to the environment?", and "What kind of data is generated and how can it be collected?". The Environment design canvas by Axelsson et al. (2022) was provided to the participants to aid in focusing their thoughts.

The findings and discussions in the ENV Atom workshop mostly revolved around creating a safe environment for human-robot-nature interaction. Participants discussed being aware of the environment and creating a connection to it through personalization facilitated by a robot companion. The most voted theme of ENV was Mishap management and preparation (ENVMis). It represents the safety factor of the environment and envisions the robot being aware of potential threats, and unwanted situations, acting as a barrier between the user and any harmful entity. The second most voted theme of ENV was Environmental Awareness (ENVAwr). This can be elaborated to being aware of the weather and forecast, pollution in a specific area, and mapping the surroundings for situational awareness. The final MVT was Personalized and joyful engagement (ENVEng). It represents the idea of having personalized content in the environment that creates a playful engagement with nature, for example, remembering a pleasant memory connected to a specific place and suggesting and facilitating users' favorite activities in nature.

Although ENV was solely about trying to understand the environment of human-robot-nature interaction, participants

Table 2. Most valuable themes (MVTs) from 3 Atom workshops.

Atom workshop	MVT	Explanation
Environment for Human-Robot-Nature interaction (ENV)	Mishap management and preparation (Mis)	Safety of the environment where the interaction takes place. It can include rescue aid and calling for help in case of emergency, danger detection, and intervening in situations where the user is in contact with any potentially harmful entity or object.
	Environmental awareness (Awr)	Being aware of the environment where the interaction takes place. It can include being aware of the weather and forecast, pollution in a specific area, and mapping the surroundings for situational awareness.
	Personalized and joyful engagement (Eng)	Having personalized responses that enhance engagement with nature. Examples can include memory assistance for remembering positive things about a specific place and being aware of objects or artifacts that the user is fond of in the forest.
Appearance of nature exploration companion robot (APPR)	Mobility through different shapes (Mob)	Robot's ability to be mobile in different environments and terrains through different shapes facilitating navigation. For example, the ability to navigate inclined paths, and to navigate in different weather conditions such as snow and rain. Circular shapes, wheels, legs, and tank-like conveyor belt navigators can be examples of such shapes.
	Affordances of different shapes (Afford)	Understanding and leveraging the affordances of different shapes of body parts. For example, the robot's eyes can act as a flashlight when it gets dark, body parts can be detachable for different purposes, and body parts can have the ability to change color as well as temperature.
	Channels for detailed feedback (Feed)	Having multiple channels for detailed feedback on everything about the interaction. It can include detailed information about the weather, specific facts about the surroundings, and feedback about any activity whether it is safe or not.
Companion robot's behavior (BHVR)	Emotional connection through contextual expression (Conn)	Robot's ability to create an emotional connection with the user through expressive emotions in different contexts. It can include cheering on achievements, gestures, being excited to see the user, and telling stories that are enjoyable for the user.
	Protective and safety behavior (Safe)	Robots are protective and always concerned about the safety of the user. It can include being aware of potential threats, detecting sound and movement nearby to be alert, and assuring the user that everything is going to be fine.
	Reactive to the environmental changes (React)	Robot's ability to sense and react to changes in the environment. It can include the robot recognizing the difference between indoors and outdoors and reacting to sudden changes in the weather, for example, the robot tries to protect the user from getting wet if it suddenly starts raining or tries to protect its own mechanical parts from the rain.

frequently moved away from focusing on the environment to think about more robot-related aspects. The reason could be that the participants were thinking more about the whole interaction and experience rather than thinking only about the environment. As a result, the themes that emerged from ENV were more focused on how different factors of the environment can be included, recognized, or tackled for facilitating human-robot companionship.

4.1.2. Appearance of nature exploration companion robot (APPR)

11 participants joined the APPR Atom workshop, and they were asked to brainstorm and focus on "What appearance should a robotic nature exploration companion have" as the main high-level question. They were then asked to focus on some lower-level sub-questions to be more specific in their design thinking, such as "What should a robotic companion look like?"; "What body parts should the robot have and how would they benefit the experience?", "How can the robot's appearance make the interaction more engaging and meaningful?", and "What visual features of a robotic companion can create companionship?". The Form design canvas by Axelsson et al. (Axelsson et al., 2022) was used here as well.

The major discussions in the APPR workshop revolved around having flexibility in terms of appearance that provides a functional advantage. In addition to that, the importance of having multiple channels for seamless feedback was apparent in the discussions. The most popular theme of APPR was Mobility through different shapes (APPRMob), which mainly concerns the robot having the ability to navigate in different terrains and weather conditions. Affordances of different shapes (APPRAfford) and Channels for detailed feedback (APPRFeed) were the other two MVTs. APPRAfford includes robots having body parts that are shaped to afford related functionalities, e.g., eyes acting as flashlights, and body acting as a heater while APPRFeed ensures that there are multiple straightforward communication channels to get from detailed to simple feedback from the robot.

The participants were asked to discuss both the appearance type and the body parts, but surprisingly they focused mostly on the functionality of the appearance including different body parts. At this stage, the workshop participants opted to associate the robot's appearance with its functions. The various themes explored were geared towards configuring the robot's appearance to enhance diversity and efficiency in its functionality.

4.1.3. Companion robot's behavior (BHVR)

10 participants joined the BHVR Atom workshop. They were encouraged to brainstorm and focus on the primary high-level question "How should a companion robot behave while interacting with humans in nature?" along with some other specific questions such as, "What type of personality should the robot have?", "What kind of social behaviors should the robot exhibit?", "Which verbal and non-verbal behavior are desirable?", "How can robot's behavior make forest/nature exploration more interesting/fun?", and "What are the external factors/contexts that influence robot's behavior?". They were provided with the Behavior design canvas by Axelsson et al. (2022) to anchor their thoughts.

The discussions and findings of the BHVR workshop revolved around the robot's protective behavior, reaction to the environment, and creating an emotional connection through behavior. The most voted theme was Emotional connection through contextual expression (BHVRConn) which focuses on having context-based and personalized behavior from the robot to create an emotional bond with the user. The next MVT was Reactive to the environment changes (BHVRReact) which refers to the robot's change in behavior depending on the changes to the environment. The final MVT was Protective and safety behavior (BHVRSafe) which focuses on the robot's cautious behavior for always protecting the user from harm.

BHVR findings can be linked to some of the findings of ENV where safety was considered to be the most important. Another trend that can be observed is the preference toward contextual awareness of robots. Some of the participants talked about co-existence behavior as well, but it did not seem to be more important than safety and contextual behavior.

4.2. Concepts created

Five concepts were created by the five groups in the Fusion workshop. All five concepts were designed by attempting to incorporate the MVTs found in the Atom workshops, and as a result, they similarly attended to the points which were found important by participants throughout Atom workshops. For example, all the robot concepts possess flexible mobility, can navigate to different places, have safety behaviors, and provide feedback through different mediums. Ratings on a scale of 1-7 were collected from each participant for concepts other than their own to understand the plausibility of the concepts. No concept received an average score of 5.46 out of 7, meaning all of them maintained a reasonable standard. However, each concept has its own way of representing different features. The following subsections will reflect on these unique aspects of each concept along with each group's thoughts behind their approach to the concept design. The concepts are visually represented in Figures 5 and 6.

4.2.1. Zeus (group 1)

Zeus is a quadrupled mobile robot that can be a companion both at home and outdoors. It can carry necessary things like emergency equipment (e.g., a buoy) (Figure 5 - A1) and snacks for outdoor activities (APPRAfford). It can detect and assess various environmental factors, including temperature extremes, potential hazards, and safety conditions such as the thickness of ice on a frozen lake to determine whether it can be walked on (ENVMis, ENVAwr, and BHVRSafe). It does so with detachable body parts, such as drones which include sensors (Figure 5 - A2) (APPRMob). Keeping the

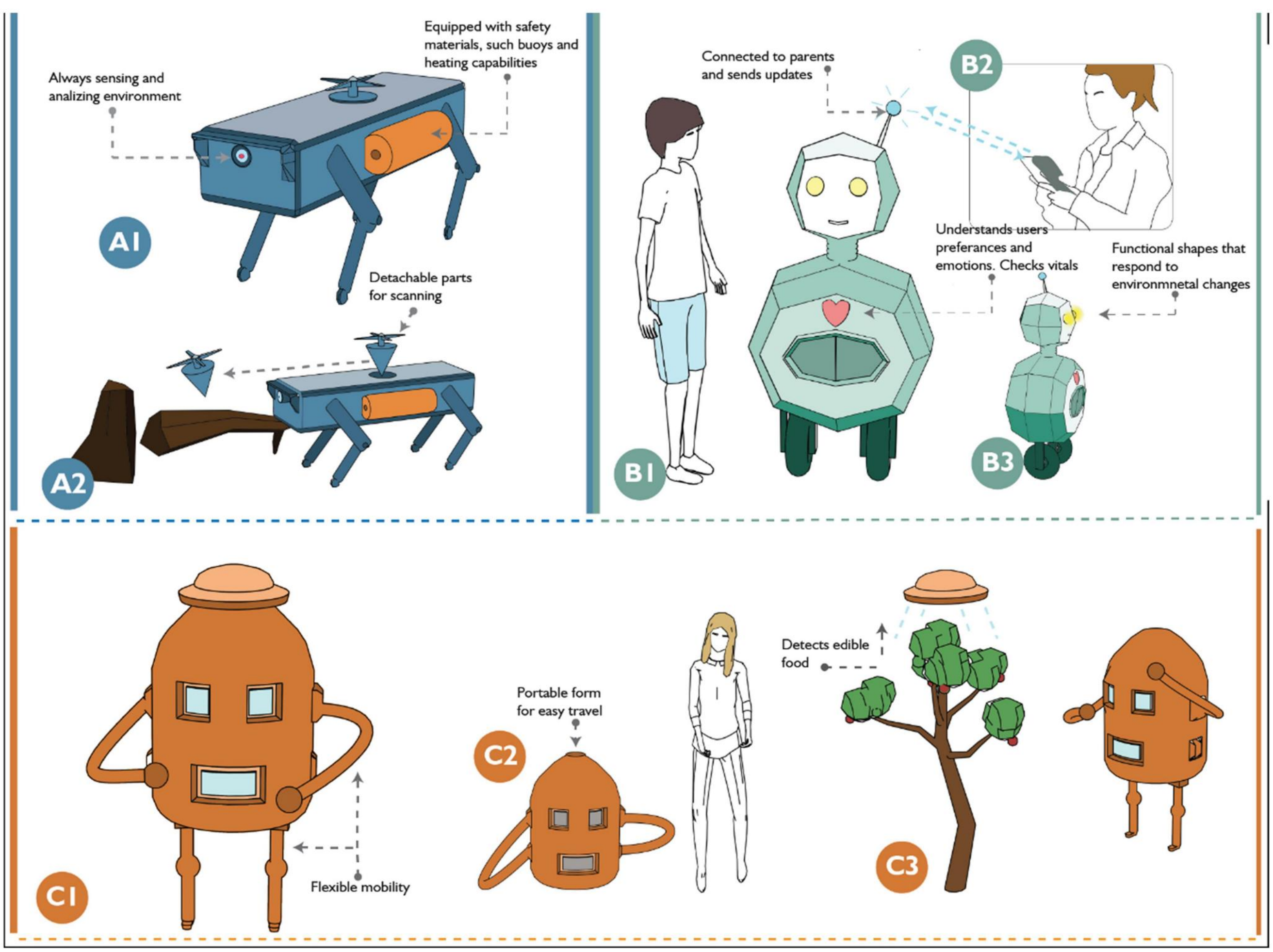

Figure 5. Fusion workshop concepts (Zeus, greeny, and G3).

weather aspect in mind, it can also change the temperature of its body to provide warmth to the user (APPAfford). The robot mostly used voice as the main feedback channel and explained situations well through conversations (APPRFeed).

The most notable design choices for this concept were the safety behavior (e.g., the robot scanned the frozen lake and suggested the user not walk on it) of the robot and the user's lack of trust in the robot's suggestions (e.g., the user did not trust the robot when it advised them to not walk on the frozen lake and walked on it anyway) (ENVMis). It was also shown that the robot did not leave the user alone even if the user would not listen to suggestions. If the user chose to ignore suggestions, the robot would respect this and not continue to bring it up. It fulfilled its companion duties and stayed with its user, saving them when their choice led to them getting into trouble. According to one of the participants, "*We illustrated the potential for human error, including when the robot gives rational advice and cautions which the human ignores. This contrasts with our story from last time, in which we showed how a human could get into trouble by placing absolute trust in a fallible robot*". This concept received an average rating of 5.46 out of 7.

4.2.2. Greeny (group 2)

Greeny is a mobile robot that has features like seamless connectivity between multiple devices and can act as an intelligent social proxy for a secondary user (Figure 5 - B2). This concept attempted to promote meaningful engagement with nature, e.g., the robot recognizes a wildflower and presents interesting information about it to the user (ENVEng). This concept uses the physical affordances of the robot in a different way than Zeus by having a storage unit to store the user's favorite chocolates) (APPRAfford). Another example is that the robot's eyes transform into flashlights when it gets dark outside (Figure 5 - B3). Similar to Zeus, it has voice-based interaction capabilities, but it adds to that with the introduction of an interactive display (APPRFeed). The robot has the capability to connect emotionally with the user, especially by consoling them when they are upset (Figure 5 - B1) (BHVRConn). The robot intervenes to prevent unwanted situations, e.g., the robot sees a harmful animal around and takes the user to a different path to be safe (BHVRSafe).

A unique design choice for this concept is the introduction of secondary users. The scenario presents a parent who trusts the robot to provide safety for their child and lets them go out in the park. The sense of trust is conveyed by seamless communication between the users, as the parent is always linked to the robot via their phone, allowing them to request updates and confirm that everything is going. The concept also demonstrates that the robot has the ability to make the users feel happy and safe through personalized interactions (ENVEng). The robot was also portrayed as a logical being that senses potential mishaps and acts accordingly. According to one participant, "*We designed the robot to make a logical decision not to let the child go near the lake or even swim in the lake because the water is too cold, and it is very dangerous. So, in this case, the robot didn't abide by the instructions from the user because it followed the ethics that the child's life is more important than the child having fun. I feel like our concept was detailed enough and it included an uncertainty aspect when the robot needs to decide and use its logic*". The concept received an average rating of 6.17 out of 7.

4.2.3. G3 (group 3)

G3 is a portable mobile robot that can transform from a compact form that fits inside a backpack into a full-body robot (Figure 5 - C1/C2) (APPRMob). It has a detachable flying object (e.g., a drone) for area surveillance, and can recognize objects and their edibility (Figure 5 - C3) (APPRAfford). It can make animal noises to repel dangerous animals (repulses a tiger when it comes too close) (BHVRSafe). The concept also shows a concerning aspect of the robot that it can make mistakes. Similar to the other concepts, this robot employed voice and an interactive screen as feedback mechanisms, however, it also added gesture-based communication (APPRFeed). This concept introduces emotions during interactions that are similar to other concepts. The robot exhibits emotions in different situations (e.g., being sad if it makes a mistake). In addition to showing emotions, the robot can dance with the user which indicates another way of creating an emotional connection by enjoying something together (BHVRConn).

The most notable design choice of G3 is its ability to change shapes between a backpackable object and a full-fledged mobile robot (APPRMob). This makes the robot easy to use in the sense that if anything happens to the robot during outdoor activity, it can be easily carried back home. Here, the form and weight of the robot were taken into consideration. Another important aspect that this concept considers is that robots can make mistakes. One of the participants says, "*Camping was a fun concept. You could find a companion in your robot if no one else is interested in nature or camping or berry picking or something. It is like someone guiding you, so you don't feel lost or alone, it is comforting*". On a scale of 7, this concept received an average rating of 5.79.

4.2.4. G4 (group 4)

G4 is an object-shaped robot that does not have mobility for its whole body, rather it accompanies the user through a detachable flying object (e.g., a drone) (Figure 6 - D2) (APPRMob). It has a display and voice as feedback mechanisms through which it can provide detailed information about the environment (Figure 6 - D1) (APPRFeed). The robot encourages and facilitates the user's immersion into nature by prompting them to listen, smell and look at different natural elements (Figure 6 - D3) (ENVEng). The robot uses humor as a mechanism for creating an emotional connection with the user (BHVRConn).

One unique aspect of this concept is that the robot initiates the interaction and suggests activities for the user to be more active. Also, it has a very good example of engaging with nature through the robot (ENVEng). Another notable

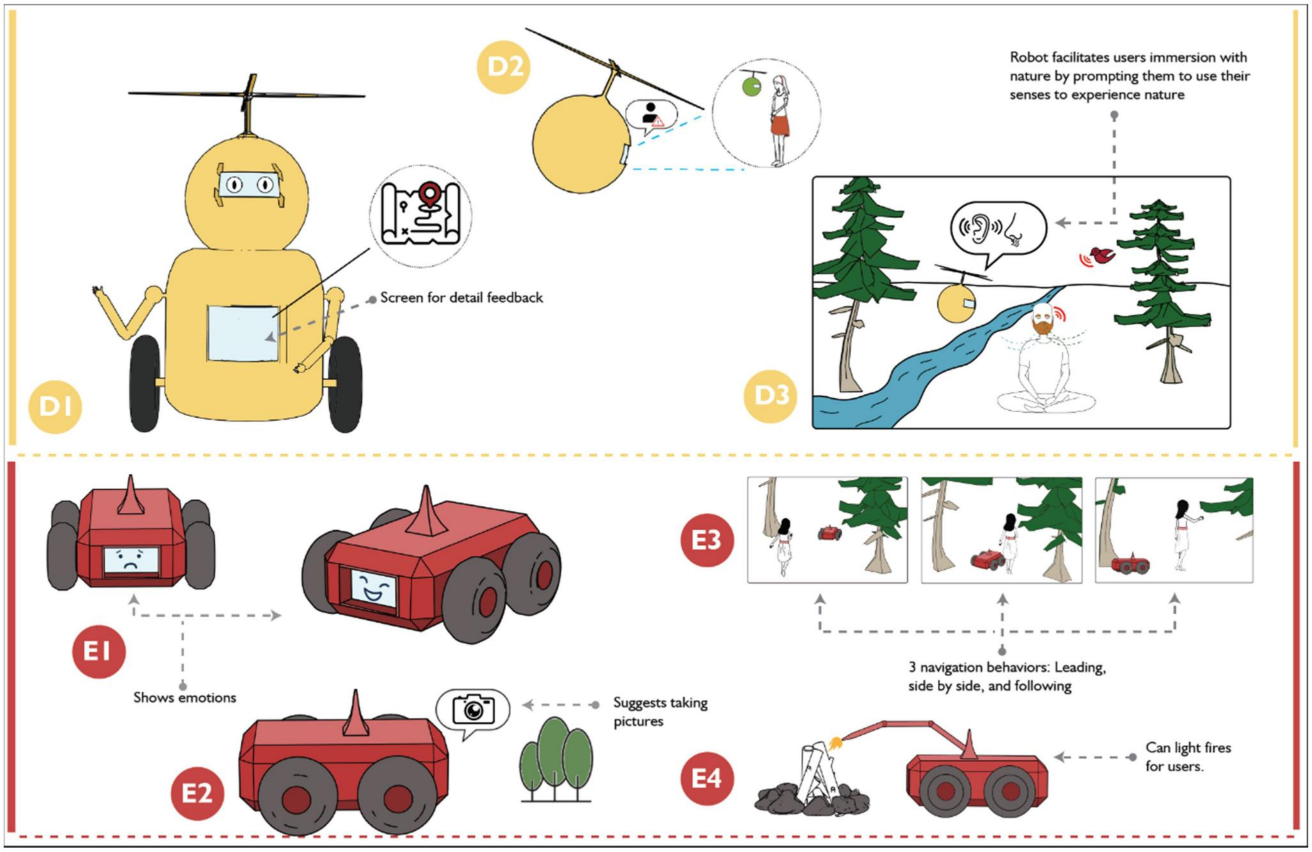

Figure 6. Fusion workshop concepts (G4 and boombot).

feature of the concept was that the robot saves the user from an unwanted encounter and helps them have a peaceful time. This may lean slightly towards desocialization since the robot assists the user in avoiding meeting others; however, this feature can also be used to socialize as the robot can find people in the forest and introduce them to one another. According to one of the participants, "*Our robot has a recommendation function, and they are sometimes more proactive than users on going outside (just like dogs I would say) or seeking interesting activities. Niceties just like having a hangout with friends in nature or taking a picture/video can create positive memories with nature which is helpful in encouraging users to seek novel experiences in nature*". This concept received an average rating of 5.62 on a scale of 7.

4.2.5. Boombot (group 5)

Boombot is a box-shaped robot that has a display for both information sharing and portraying a face with which it can exhibit different emotions such as happiness, sadness, and indifference (Figure 6 - E1) (APPRFeed, BHVRConn). It has three walking modes, showing the path to the user, following the user, and walking side by side with the user (Figure 6 - E3). It also encourages the user to interact with the environment by suggesting that they go to specific places and take photos to remember the experience (Figure 6 - E2) (ENVEng). Unlike the other concepts, this robot has facial feature-based emotional expressions which can help in the creation of an emotional connection with the user (BHVRConn). The robot also recognized that the user was feeling cold and reacted to the situation by creating a fire which can be interpreted as both safety and reactive behavior (Figure 6 - E4) (BHVRReact). It can be assumed that the robot knows safety measures and will act accordingly when it tries to create a fire (ENVMis, BHVRSafe).

This concept shows that the robot exhibits different types of emotions in different scenarios which can lead to a deeper connection with the user and better overall companionship (BHVRConn). Walking side by side is another example of the robot behaving more like a companion rather than an entity that follows or leads. The robot also applies common sense to avoid returning home immediately, recognizing that the rain would likely begin before reaching the destination. Instead, it suggests seeking shelter as a more practical course of action. It is also capable of safely lighting a fire to create a warmer environment for the user (BHVRSafe). One of the participants said, "*The feeling that a human has another companion that is not another human can be a great thing. I have seen people who had difficulties interacting with other human beings. Basically, people who live isolated lives. We tried to portray the emotional connection with the user. We designed the interaction with the user so that it can create such an emotional connection. A friendly robot with a friendly voice that can provide the user with a feeling of familiarity.*" An average rating of 5.87 out of 7 was given to this concept by the participants.

Table 3. Planes of the design space and their dimensions.

Plane	Dimensions	Meaning
Interactivity	Individual	Focus on interactions that occur exclusively between the human and the robot, with minimal acknowledgment or involvement of other actors, where nature plays a passive or background role. This approach emphasizes direct, one-on-one engagement.
	Planetary	Expands interactions to include humans, robots, and the surrounding environment, considering all elements of nature—such as weather, plants, animals, and terrain—as active participants. The robot becomes a mediator, facilitator, or one of the actors, encouraging holistic engagement that strengthens the bond between humans and nature.
Co-performance	Leader	The robot assumes an authoritative or proactive role, initiating actions and guiding the interaction without needing explicit instructions. It takes responsibility for navigating situations, making decisions, and influencing human actions when necessary.
	Follower	Positions the robot as a subordinate entity that responds to human instructions and cues without taking the initiative. It prioritizes human preferences, performing tasks as directed and refraining from imposing its own decisions.
Communication	Straightforward	Emphasis on clarity and precision in the robot's communication, ensuring that information is conveyed in a direct and easily understandable manner. Messages are concise and leave little room for interpretation, which is especially important in scenarios where safety, efficiency, or critical decision-making is required.
	Ambiguous	Introduces a degree of unpredictability or subtlety in the robot's communication, relying on indirect cues, nuanced behavior, or context-dependent messages. This approach encourages curiosity, creativity, or emotional engagement by prompting the human to interpret and infer meaning.
Form	Utilitarian	Emphasis on functionality and practicality in the robot's design, favoring shapes, features, and materials that enhance performance and utility. The robot's appearance reflects its purpose as a tool or assistant, often prioritizing durability, mobility, and task efficiency over aesthetic or emotional appeal.
	Affective	Focus on creating a design that evokes emotional responses and establishes a sense of companionship. Robots with affective forms often adopt anthropomorphic or zoomorphic traits, using familiar or relatable features to build empathy, trust, and connection.

5. Design space for companion robots in the wild

The 5 concepts designed in the fusion workshop represent a wide spectrum of design choices and dimensions. These concepts have incorporated specific directions provided through the atom workshops. However, the design rationale is specific to each concept and it is important to unpack them in order to understand the design space of robotic companions for the wild. The objective of a design space (MacLean et al., 1991) is to facilitate the transition from theoretical deliberations to the practical dimensions of design. We have critically analyzed the 5 concepts and created a design space for companion robots in the wild.

The design space comprises four planes: *interactivity, co-performance, communication, and form*. Each plane addresses a key aspect of designing companion robots for the wild, providing a framework for creating robots tailored to various scenarios. By combining and adjusting the levels of these planes, designers can craft unique and context-appropriate companion robots. The *interactivity* plane spans from "Individual" to "Planetary" interactions, defining the depth and scope of engagement between humans, robots, and their environment. At the "Individual" end, interactions are limited to direct exchanges between humans and robots, with nature playing a passive or background role. Conversely, the "Planetary" end represents a holistic approach where humans, robots, and all elements of nature interact as active participants, enriching the overall experience by integrating the entire environment into the interaction. The *co-performance* plane explores the robot's role in human-robot-nature scenarios, ranging from "Leader" to "Follower." A "Leader" robot takes initiative, actively participating and making decisions independently, even without explicit commands—ideal for scenarios requiring guidance or proactive support. On the other hand, a "Follower" robot responds only when instructed, prioritizing human direction and maintaining a more reactive and subordinate role. The *communication* plane addresses how the robot conveys information, balancing between "Straightforward" and "Ambiguous" styles. "Straightforward" communication ensures clarity and precision, making it suitable for tasks requiring safety, efficiency, or critical decision-making. In contrast, "Ambiguous" communication relies on subtlety and nuance, encouraging users to interpret cues and encouraging curiosity or emotional engagement. Finally, the *form* plane ranges from "Utilitarian" to "Affective" designs. A "Utilitarian" form prioritizes functionality, with a focus on practicality, durability, and efficiency, often emphasizing the robot's role as a task-oriented tool. An "Affective" form, however, incorporates anthropomorphic or zoomorphic traits, aiming to evoke emotional responses and build a sense of companionship, making the robot more relatable and engaging. Table 3 provides a structured overview of the four planes of the design space along with their dimensions and what each dimension represents.

We converged all the findings into the design space in an iterative manner and through multiple meetings. We tried to categorize the design choices into major structural directions. This structuring pointed to the different dimensions applied to specific design aspects in the concepts, for example, the robot's appearance ranged from being functional or tool-like to being fully humanoid. It was also evident in the concepts that varying or changing these specific design aspects along these ranges significantly affected the overall interaction. As a result, we considered each major design direction as a plane. After the planes were defined, we took a top-down approach for each plane to analyze how each concept leveraged them. This was an iterative process where the planes as well as their components were reframed and redefined. For example, the "Trust" plane was changed to "Communication" as it covered a lot more than trust only and the trust factors mostly generated from different levels of communication. The final version of the design

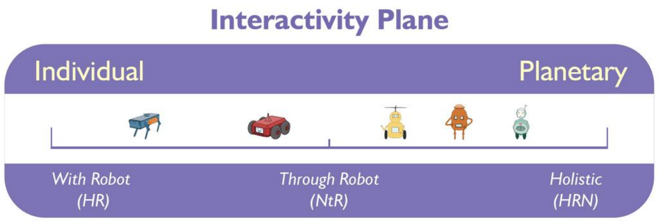

Figure 7. Positions of all 5 concepts on the interactivity plane.

Figure 8. Positions of all 5 concepts on the co-performance plane.

space successfully captured the key design elements of all five concepts.

5.1. Interactivity plane

The interactivity plane presents a range between individual and planetary interaction in nature, demonstrating the degree of engagement from the main actors in the interaction (e.g., human, robot, and nature). The range here represents interactions that start as human-centered and spans towards planet-centered while balanced out in the middle exclusively through robot's mediation. The human-centered interactions focus on the human and the robot while nature stays in the background. Planet-centered interaction indicates the possibility of robots interacting with other planetary entities in nature. Towards the middle of this range, interactions are facilitated through the robot, creating a bridge between human and nature. Figure 7 visualizes the interactivity plane along with the positions of each concept created in the workshops.

In the "individual" end of the spectrum, the designer focuses on micro-interactions revolving around humans and robots (HR). Here, nature remains a passive environment whose influence stays limited to triggering events for human-robot interactions to happen and/or being affected by those. For example, individual interaction can be seen in Zeus where the robot provides warmth to the soaked human, in Greeny where the robot offers a treat to the human to make them happy, and in Boombot where the robot captures a picture of the human for memory keeping. In all these cases, nature stayed in the background and did not affect the interaction directly. However, these interactions were triggered by events that happened in nature. Designing towards the individual end of the spectrum means that interactions focus on human's interaction with robots individually while complying with nature as the environment that moderates the affordances of the actors. A designer focusing on this end would consider nature solely as the trigger of interactions whereas the interaction design would be for human-robot rather than thinking how nature could take part in these interactions.

On the other end of the spectrum is planetary interaction which encapsulates all possible interactions in the wild on a planetary level that centers around all three main actors, i.e., human, robot, and nature (HRN). Planetary interaction is holistic in the sense that it includes the interaction between any component of nature (Bridle, 2022). Examples of planetary interaction in our consideration can be between the robot and nature, for example the robot interacting with a bee to take it away from the human in Greeny, and the extension drone from the robot mapping out the nearby area in G4 without the active involvement of humans. However, such interactions between robots and nature will always influence how humans experience nature. For example, in G3, the robot was listening to sounds from nature and alerted the human in case it deemed the sound to be dangerous. Designing on the planetary end of the spectrum indicates that interactions are more holistic where human, robot, and nature are not the only components but everything that belongs to the planet can be considered. Examples include navigating and adapting to natural landscapes (such as forests or mountains) while accounting for weather patterns like rain or sunlight, which may affect their operation or safety considerations. They can also interact with flora and fauna, observing plant life or carefully moving around animals to minimize disruption, and interact with geological elements by monitoring soil composition or terrain stability. Such interactions have a major effect on how humans might perceive nature, resulting in a more conservative, sustainable, and ecologically aware approach.

In the balance point of the spectrum, interactions consider the interplay between humans, robots, and nature where interactions usually flow through the robot. Notably in such interactions, all entities have their own roles and robots are primarily the facilitator of the interaction between human and nature (NtR). Robots as mediators in interaction have been investigated quite extensively, for example, as social mediators for conversations (Tahir et al., 2020) and support group facilitation (Birmingham et al., 2020). These interactions are usually mediated through the robot's affordances. Examples of NtR can be found in G4 where human perceived different natural components like sound and smell by the direction of the robot, in Greeny where the human explored the wild through the robot as the robot was dictating what they interacted with and in some cases, preventing the human from engaging with the wild, and in Boombot where the robot took the human to an unknown place and prompted them to explore it.

The interactivity plane helps purposefully direct the focus of the design to all interactive components for HRI in the wild. The "individual (HR)" end puts the designers' focus more on micro-interactions between human and robots, whereas "planetary (HRN)" end helps ideate the all-inclusive macro interactions. And finally, NtR attempts to create a balance between the micro and macro interactions, ensuring a similar level of involvement for humans, robots, and nature. The notable part of this spectrum is the planetary end and the contrast between it and the individual end. In designing companionship interactions, this plane navigates designers' attention in regard to varying levels of nature involvement in them: Planetary-end invites designers to become aware of complex relations among humans, robots and the natural elements holistically by also considering possible robot-nature interactions without the involvement of humans. On the other hand, the "individual" end directs designers' attention to human-robot micro-interactions, while also calling for careful design of the robot's affordances and interactive features by considering how nature might initiate or react to individual interactions.

5.2. Co-performance plane

Design points on the co-performance plane range from leader to follower. This plane decides the level of engagement and authority of the robot with humans and the wild. A robot designed as a leader always engages in interaction and takes authority more often than not. On the other end, a follower robot stays mostly on a standby mode where it only intervenes or responds when called upon. Towards the middle point of the spectrum, the robot is harmonious through a balance of promptness, authority, and companionship. Figure 8 visualizes the co-performance plane along with the positions of each concept created in the workshops.

Designing the robot as a leader makes it be on the foreground of the interaction through promptness and constant interventions. Robot's have been explored previously in leadership scenarios (Samani et al., 2012) and they tend to provide a different interaction dynamic compared to being led or to co-perform (Edward Cichor et al., 2023). This design choice regards the robot as the decision maker and the interaction can be dominated by the robot. It requires caution but might be needed, especially in situations where safety is required as the robot might be able to obtain a better sense of the wild through its sensors (e.g., water temperature, weather) and other extensions (e.g., detachable drones). However, a robot-led interaction might yield a more restricted experience as safety of the human is deemed more important than the spontaneity of the intervention. In the concept of Greeny, the robot appeared to be very cautious about the safety of the human and actively intervened whenever the human wanted to do something potentially dangerous. This makes the cautious robot more authoritarian in interactions. In short, designing on the leader side of the spectrum makes the interaction potentially safer but more restrictive.

On the other end of the spectrum, designing the robot as a follower would place it to the background and reduce the possibilities of intrusive actions. Majority of the robots developed in the early stages of robotics have had this characteristics of being a command-following entity (Ahmed et al., 2024). While this allows for more freedom of action and interactions on the user's part, if the robot only intervenes if called upon, the interaction becomes dependent on the human. This results in distancing the interaction from a companionship scenario and reduces the possibilities of unexpected informative interactions with nature e.g., robot's recognize species in the forest and inform the user about it, or robots sensing possible unwanted situations and warning the user. For example, in G3, the robot mostly was on a standby mode and performed tasks when the human prompted it to, such as surveying the area or finding a place to rest. Choosing the robot to be a follower might introduce more freedom for the human in terms of free exploration in the wild without continuous intervention. Free flowing interaction can allow the human to interact with the wild more spontaneously, which might lead to an embodied and sensory interaction guided by their own will and desires. For example, in G4, although the robot expressed its own thoughts, it mostly stayed in the background and did not intervene or contradict the user, letting the user explore on their own terms. On the contrary, the lack of intervention from the robot can also lead to dangerous situations which could be avoided if the robot promptly monitored the safety aspects. To summarize, designing on the follower end of the spectrum allows more free-flowing interaction while reducing the safety and companionship aspects.

Towards the middle of the spectrum, the human and robot are in a harmonious state, complementing each other's affordances and equally contributing towards a holistic interactive experience (Kim & Lim, 2019). Here, the robot promptly reacts to the interaction while incorporating different aspects of being in the wild into the interaction. There is constant negotiation between human and robot both bodily and verbally about how co-performance is happening. While having separate physical bodies and affordances, this harmonious state allows the interventions in collaboration as if they were a unified entity. The robot in this case is more reactive and responsive as it brings its own views and affordances into the interaction. The robot neither follows nor leads the interaction, rather plays an equal part in it. For example, in Zeus, the robot always had its say on deciding factors and expressed rational opinions about the human's choice of path and interactions in the wild. Designing in this part of the spectrum allows the robot to become a companion where the human and the robot co-perform their way into the interaction.

The robot's activeness or passiveness subsequently adds or removes the co-performance and companionship aspects of the interaction. However, both bring valuable intricacies to the interaction in terms of safety and engagement. While the robot's engagement as a leader might make the interaction safer, it also potentially restricts the flow and spontaneity. On the other hand, a follower robot might allow for more free-flowing interaction while potentially reducing the safety aspects. Deciding which point of the plane to choose in a specific design will largely depend on the focus, priority, and objectives of the intervention. This design plane guides designers by elaborating how the different roles of humans and robots in their co-performance might be designed with different contexts and relationalities in mind.

5.3. Communication plane

The communication plane is represented by a range from straightforward to ambiguous. This plane directs the degree

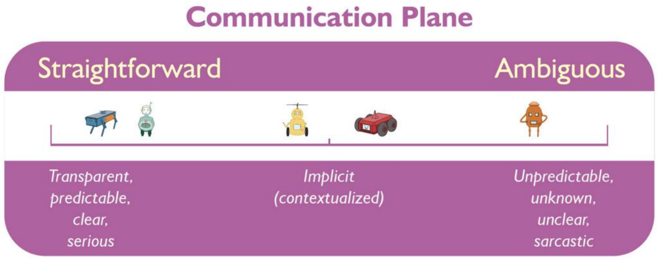

Figure 9. Positions of all 5 concepts on the communication plane.

of clarity and purposefulness of the robot's communication with humans in the wild. Here, a robot designed as straightforward clearly conveys information about its state and is predictable. In contrast, robots having ambiguous communication refer to their unpredictability and indistinctiveness in conveying information to the human. A robot's communication towards the middle ground in this spectrum can be implicit where the robot is not fully straightforward, but its state and actions can be understood through contextual cues and interactivity. Figure 9 visualizes the communication plane along with the positions of each concept created in the workshops.

Designing a robot's communication towards the straightforward end of the plane can significantly impact human-robot interaction by enhancing clarity, reducing uncertainty, and ensuring that the human user remains well-informed about the robot's intentions, status, and actions (Sanders et al., 2014). When a robot communicates directly, it eliminates guesswork and leaves little room for ambiguity, which proves particularly valuable in complex or potentially hazardous environments, like the wild. For example, Greeny, a robot designed to assist humans in natural settings, used straightforward communication to clearly convey environmental factors, preventing unwanted situations and ensuring safety. Although this transparency occasionally dampened the human's sense of adventure as Greeny's constant alerts left little to the imagination, it reinforced the interaction's reliability and trustworthiness, allowing humans to navigate unpredictable environments with a sense of security. However, while this communication style is a safeguard, too much predictability can lead to a rigid interaction dynamic, reducing spontaneity and exploration. The consistency of straightforward communication may result in an experience that feels safe but potentially monotonous, as each outcome is anticipated, and interactions follow predictable patterns. This rigidity can make the interaction feel more like a sequence of commands than a fluid, collaborative experience, which can hinder the formation of companionship. Ultimately, while straightforward communication enhances safety and reliability in human-robot interactions, particularly in challenging settings, it can also limit the engagement, depth, and enjoyment of the interaction, potentially affecting the human's perception of the robot as a true companion.

Designing towards the ambiguous end of the spectrum can have both positive and negative consequences. Here ambiguity encapsulates concepts such as unpredictability, unknown, sarcasm, lack of clarity, and opacity. This end of the plane introduces unpredictability in the interaction which might become even more apparent coupled with the vast unpredictability of the wild. Ambiguity can facilitate intriguing interactions by fostering curiosity and creativity (Yamada & Miura, 2016). However, ambiguity in the form of miscommunication might result in a dangerous situation in the wild, especially during decision making in challenging circumstances. For instance, in Zeus (group 1), the robot failed to understand the user and conveyed important information in a sarcastic way that failed to capture their attention, resulting in an unwanted situation. Similarly, in G3, the robot mistakenly wakes up the user and implying that they are in danger. This can also be linked with the robot's inability to understand the contextuality and struggle in conveying the information in the right manner. It is not all bad though as this mistake by the robot led to them joining up a group of people and helped them have a good time. It indicates that unpredictability leaves room for surprise elements which might end up creating a positive experience. Sarcasm can be another element of ambiguity which can have both positive and negative impacts. For example, G3 joked about how it is safe from being eaten by a tiger as it is not alive, and G4 used sarcasm to lighten the mood after its human companion woke up in the morning. In contrast, Zeus demonstrated that conveying important information in a sarcastic tone can lead to danger. Lack of clarity in communication can also be triggered when information is conveyed through mediums other than voice, such as expressions, sound, light, or gestures. An example of this can be found in G3 where the robot uses hand and face gestures to indicate affirmation, negation, happiness, sadness, and confusion. Boombot also uses an expressive face to add to the communication. This communication method is commonly and popularly used by humans; however they can become ambiguous if not designed properly. Designing towards the ambiguous end of the spectrum allows playful and intriguing interactions, however, it comes with a major risk of creating confusion and even dangerous situations in the wild.

Balancing in the middle of the ambiguous and straightforward ends of the spectrum, implicit communication can be designed to introduce the excitement of surprises with reduced ambiguity through contextualization. Implicit communications, while not coming straight to the point, allows the involved parties to an understanding through contextual inquiries and speculativeness (Sanoubari & Young, 2018). Implicit communication relies on subtle cues, shared context, and inferred meanings to convey information without directly stating it, transforming interactions by allowing participants to interpret meaning through context and nonverbal signals. This creates a more organic and engaging experience, introducing playfulness and curiosity as users actively make sense of the robot's cues, similar to human-to-human interaction. Rather than merely following commands, a robot using implicit communication might adapt its behavior, like adjusting its pace in response to subtle gestures from its human companion, suggesting awareness and enhancing companionship. This approach aligns with more-than-human design principles, viewing the robot as an autonomous social agent rather than a command-driven machine (Genç et al., 2024). In dynamic natural environments, implicit communication proves particularly valuable, as adaptable interactions can respond to unpredictability. For instance, a robot companion in a forest might subtly signal hazards or changes in terrain through shifts in position or quiet sounds, allowing the human to intuitively interpret these cues without disrupting the tranquility of the setting. By communicating contextually, the robot becomes a supportive presence that harmonizes with nature, enhancing the experience by providing guidance and companionship while respecting both the natural environment and its inhabitants. For example, in Boombot, the robot finds a scenic place for the human but does not inform how and why it might be of interest for the human. And while on their way to the place, the human starts discovering why it would be interesting through contextualizing and conversing with the robot. This also introduces a playful way to communicate where information is framed as a reward obtained through interactivity. Despite some positives, implicit communication design needs cautious deliberation as its effectiveness largely depends on how contextualization is done by both parties. Misinterpretation of communication cues can lead to even worse outcomes compared to ambiguous or straightforward interventions.

To summarize, designing towards the ambiguous end of the spectrum might introduce excitement and curiosity, leading to more exploratory interactions both with the robot and nature. However, this ambiguity, combined with the sheer complexity of nature, might not be suitable for certain scenarios and even might lead to dangerous situations. On the contrary, designing towards the straightforward end of the spectrum makes the interactions more predictable and safer although it might restrict the flow and spontaneity. Implicit communication attempts to improve on the ambiguity by designing a way to contextualize them, potentially creating safer communication while still leaving some room for exploration, although careful deliberation is necessary to ensure that cues are contextualized in the right way.

5.4. Form plane

The form plane presents a range from utilitarian to affective as it aims to direct design decisions regarding how the robot looks and what it means for its affordances. A utilitarian robot's appearance is designed to maximize its utility by questioning how it could be more efficient functionally. On the other hand, the appearance of an affective robot aims to maximize affection and emotionally influence the interaction. Balancing out these two ends of the spectrum is a companion/holistic robot that is capable of connecting with humans emotionally while also being functionally useful. Appearance of robots play a vital role in defining interaction dynamics in human-robot interaction, especially depending on how the appearance resonates with robot's behavior and competencies (Abubshait & Wiese, 2017). Figure 10 visualizes the form plane along with the positions of each concept created in the workshops.

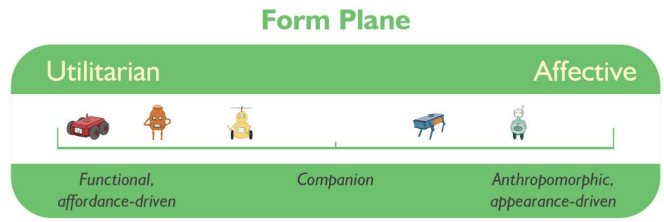

Figure 10. Positions of all 5 concepts on the form plane.

Designing on the utilitarian side of the spectrum ensures that the focus and objective of the robot is to leverage its functionality to the fullest. This design choice prefers functions over emotion or utility over affection. It can also offer flexibility in terms of mobility and ease of access, especially in the wild. For example, G3 is a robot with a functional shape as it can be carried in a folded form inside a backpack but can reshape itself to a mobile robot when needed. Designed with similar thoughts, G4 is a functional robot that uses detachable body parts (e.g., drone) to maximize utility. Also, Boombot has a boxy shape that resembles a car with four wheels that helps it have better navigation capabilities. While some of the design choices have added features that help with affective qualities as well, utility overpowers them in these designs. Undoubtedly, utility is of great value, especially in the wild, however, too much focus on utility might frame the robot as more like a tool and less like a companion (Merrill et al., 2022). If humans perceive the robot merely as a tool, it can lead to a transactional relationship where interactions are driven solely by functional outcomes rather than emotional engagement (Appel et al., 2020). This mindset may hinder the development of trust and companionship, limiting the robot's effectiveness in supporting human needs, especially in challenging or unpredictable environments. Thus, this approach is more suitable for cases where functionality in human-robot companionship is more important, such as facilitating navigation in dense forests, providing real-time environmental data during outdoor explorations, or assisting with physical tasks like carrying equipment during long hikes. In these scenarios, the robot's ability to perform practical tasks efficiently complements its role as a companion, ensuring that it adds value to the overall experience while still fulfilling its utilitarian purpose.

On the affective end of the spectrum, focus is more on the emotional influence of the appearance while utility stays in the background. Prioritizing the affective aspect of the form might lead designs towards anthropomorphic and zoomorphic robots. For example, Zeus is a four-legged zoomorphic robot that resembles a dog and Greeny has a human-like appearance. Their human-like or animal-like appearances and behaviors evoke emotional responses and create connections with humans. This is visible in Greeny where the human (a child) considers the robot as their guardian and interacts with it through emotions (e.g., sadness, happiness, anger). Their familiar gestures and features make them relatable, fostering empathy and trust. By mimicking lifelike qualities, they create a sense of social presence and emotional bonding, making interactions more personal and engaging. However, designing an affective companion robot for the wild has shortcomings such as potential conflicts with the natural environment. Highly anthropomorphic or zoomorphic designs might disrupt the authenticity of outdoor experiences or unintentionally affect wildlife behavior. Additionally, focusing heavily on affective qualities may compromise functionality, especially in scenarios where practical tasks like navigation or data collection are critical. The emotional bonding such designs aim to create could also lead to unrealistic expectations or over-reliance on the robot, creating challenges in contexts that demand adaptability and resilience over emotional engagement.

While robots with affective qualities introduce emotional cues in the interaction, they could still have functional qualities, which brings us to the middle of the spectrum. This balance between utility and affectiveness allows for designing robots that not only assist humans in practical tasks but also promote emotional connections, enhancing the user experience by making the robot feel like a genuine companion. When both functional and emotional elements are thoughtfully integrated, these robots can respond adaptively to situational demands, offering practical help when needed and providing comfort or companionship in quieter moments. While the depth of companionship depends on human perception and expectations, a well-designed companion robot that balances functionality and emotion opens up richer possibilities for interaction, creating a more meaningful relationship that respects both the practical and emotional aspects of human-robot communication. Despite the middle ground's promise of balancing the positives of both functional and affective qualities, there are inherent challenges in achieving this equilibrium. Striking the right balance requires meticulous design choices to avoid compromising either utility or emotional engagement. Overemphasizing one aspect may lead to a robot that feels incomplete—either too utilitarian and impersonal or overly emotional at the cost of practical reliability. Additionally, designing for dual purposes demands advanced technologies and nuanced design strategies, which can increase complexity and development costs. Furthermore, the success of such robots often hinges on user perceptions, which can vary widely based on cultural, personal, and situational factors, making it difficult to create universally effective designs.

To summarize, designing towards the utilitarian side of the spectrum ensures the robot to be functionally capable with less focus on the emotional side of the interaction. On the other hand, designing for affection will make the robot more of an emotional entity, keeping the functionality in the background. Designing towards the middle of the spectrum allows the robot to become a companion that has both functional and emotional qualities, although it poses an interesting challenge of creating a proper equilibrium.

6. Discussion

6.1. Using the design space

This design space provides a structured way to design companion robots that can navigate the complexities of human-robot-nature interactions. It allows designers to consider essential aspects like interactivity, communication style, and co-performance, creating robots that blend utility with companionship. The design space can be useful in two major aspects, firstly, from a design perspective, researchers and designers can use it to make informed, adaptable design choices tailored to specific environments, while also critically evaluating existing robots to identify strengths and areas for improvement. For design, the design space supports everything from guided design choices and balancing function with affect to fostering flexible, adaptable robots and facilitating iterative prototyping. Secondly, from a critical perspective, it allows researchers to map and compare existing systems, identify design gaps, evaluate alignment with specific environmental needs, and encourage a more-than-human perspective in robot interactions. It also allows researchers to ask questions and seek answers of the ramifications of going into different directions of the design and play with the design space to explore possibilities. By guiding design toward both functional and ecological alignment, the design space supports the creation of robots that are not only effective tools but also meaningful companions in the wild.

We have analyzed two (Zeus and G3) concepts created in the workshops by using our design space as a critical analysis and reflection tool to identify gaps in the design and evaluate their suitability of potential deployment in the wild as companions to humans. We have tried to understand which design choices work well, which choices are less relevant, and what are the missed opportunities. Based on the analysis, we have modified and extended the two design concepts (Zeus and G3) to better suit their purpose. It is important to note that the proposed modifications are not absolute, and the concepts can be modified differently based on what someone is trying to achieve. For example, if safety is our biggest concern, then we can design a robot as a leader with straightforward communication, which will significantly reduce the harmony and pleasantness of the interaction. Likewise, if we want utmost functionality, we can shift the design towards the utilitarian side of the form plane, which ensures that all focus is on providing the best service. The analysis has been done by looking into the concepts through the lenses of each plane. Figure Y represents the extended versions of the concepts through the design space.

6.1.1. Analyzing and expanding Zeus

With the initial design, Zeus is situated more towards the individual side of the interactivity plane which means that the interactions are mostly between the human and the robot while nature stays in the background and planetary elements are rarely interacted with. Another observation is that many of the interactions in the concept would be possible and could still happen even if they were not in the wild. Analyzing through the *co-performance plane* shows that the robot is more of an authoritarian, always cautious, and tries to control the human-nature interactivity. The concept shows that the robot always intervenes and provides strong opinions on whatever the user intends to do. While some of the interventions were timely and important, the robot's overall approach towards authority undermines their significance. This also links to the way the robot *communicates* with the human in Zeus. The robot appears to be a serious and straightforward communicator which sometimes undermines the effectiveness of the communicated information, resulting in a lack of trust in the robot. Being a leader and trying to have authority does not help in gaining trust and might create hostility instead. Finally, Zeus's *form* is mostly suitable for human-robot-nature interaction, especially due to its qualities like anthropomorphism, ability to traverse difficult terrains, and emphasis on safety. All of this combines into a companion that has a familiar form, capable of accompanying humans in the wild, and functional capabilities to add substantial value to the interaction.

If we want to improve the human-robot-nature interplay, the *interactivity* plane of Zeus can be adjusted towards the planetary end through increasing the robot's engagement with the natural environment. For example, Zeus could be equipped with environmental sensors to identify specific plants, animals, or geological features, and then relay this information to the user in real-time. We could increase human-nature interactions through robots by designing it to be a facilitator of thoughtful and ecologically sound ways of interacting with natural elements. These changes would shift Zeus away from individual-focused interactions and towards promoting triadic engagement between human, nature, and robot. In terms of *co-performance*, Zeus's authoritarian tendencies could be softened to adopt a more collaborative and supportive role. Instead of intervening strongly and directing the user's actions, Zeus could provide subtle nudges or prompts that allow users to make their own decisions. For instance, if the user is approaching a potentially hazardous area, Zeus could issue a gentle warning or offer alternative paths without overtly taking control. Similarly, in less critical situations, the robot could encourage exploration by asking open-ended questions like, "*Do you think this trail might lead to something interesting?*" Choosing to modify Zeus's design in this way would mean that the safety aspects might be compromised, whereas collaboration and harmony would increase. These changes would reposition Zeus between the harmonious and follower ends of the co-performance plane. We can modify Zeus to incorporate more implicit interaction methods that make its *communication* feel more natural and less formal, compared to the straightforward style that was initially adopted. For example, rather than issuing direct verbal commands or instructions, Zeus could use nonverbal cues such as gestures, changes in posture, or even subtle lighting effects to convey information. Additionally, physical communication mediums like touch-based feedback (e.g., a gentle nudge or vibration) or visual cues (e.g., dynamic displays or emotive eye-like features) could enhance its communication capabilities. Finally, as Zeus already possesses qualities like anthropomorphism and terrain adaptability, minor adjustments can be done to its form to incorporate suitable communication mediums. The updated position of Zeus on each plane after the suggested modifications is shown in Figure 11.

6.1.2. Analyzing and expanding G3

G3 initially stands near the planetary end of the *interactivity* plane as it engages with natural elements a lot, however it does not really act as a bridge between the human and nature, rather engages by the direction of the human. Planetary interactivity however influences human-nature interaction a lot, making the robot's actions very influential. Analyzing through the *co-performance* plane, the robot appears to be a follower and usually responds to the human's wishes, doing whatever it is asked for. The robot also exerts emotions with an inferiority complex. As a result, it does not appear to be a companion and poses itself as a command-following entity. Also, the robot's lack of confidence might make it difficult to be trusted in challenging scenarios. G3's *communication* is affected by its lack of confidence. This combined with its sarcastic behavior and unpredictability increases ambiguity, making communication opaque at times. Finally, the form of the robot is affordance-driven, which works well for the wild where its functional capabilities may be useful. This increases ease of use and improves safety. This is a design choice that depends largely on the use case, especially if functionality and safety are priorities.

We could move G3 toward a more balanced position on the *interactivity* plane, which will make the robot more of facilitator of human-nature interactions. For instance, G3 might guide users to notable natural features (e.g., rare plants, hidden trails) or recommend activities based on environmental conditions, such as suggesting a hike after assessing weather patterns. This modification gives G3 the role of a mediator of human-nature relationships and allows it to become a more active actor in the interventions. We also reimagine G3's *co-performance* to make it a collaborative partner instead of a command follower. G3 could offer informed suggestions, such as recommending a safer path during a hike or proposing a break based on fatigue detection. By adopting a supportive and proactive role, G3 would appear more like a capable teammate rather than a subservient tool, taking it towards a more harmonious position on the plane. We also imagine G3 to boast a clearer and more empathetic interaction styles, reverting back from a submissive entity. While having a more straightforward *communication* style might reduce interaction delicacies, it could make it less error-prone and more commanding. Adding implicit cues, such as dynamic lighting or subtle vibrations to signal agreement or warnings, can further make communication intuitive and definitive which might be suitable if we focus on giving the robot a distinct personality. These changes would shift G3 toward the balance between implicit and straightforward communication. While G3's functional *form* suits its role in the wild, slight aesthetic adjustments could enhance its affective qualities without compromising utility. Visual cues, combined with its rugged, affordance-driven design, could make the robot feel more relatable while retaining its functional appeal. Such modifications would shift G3 closer to the middle of the form plane, balancing function and emotional resonance. The updated position of

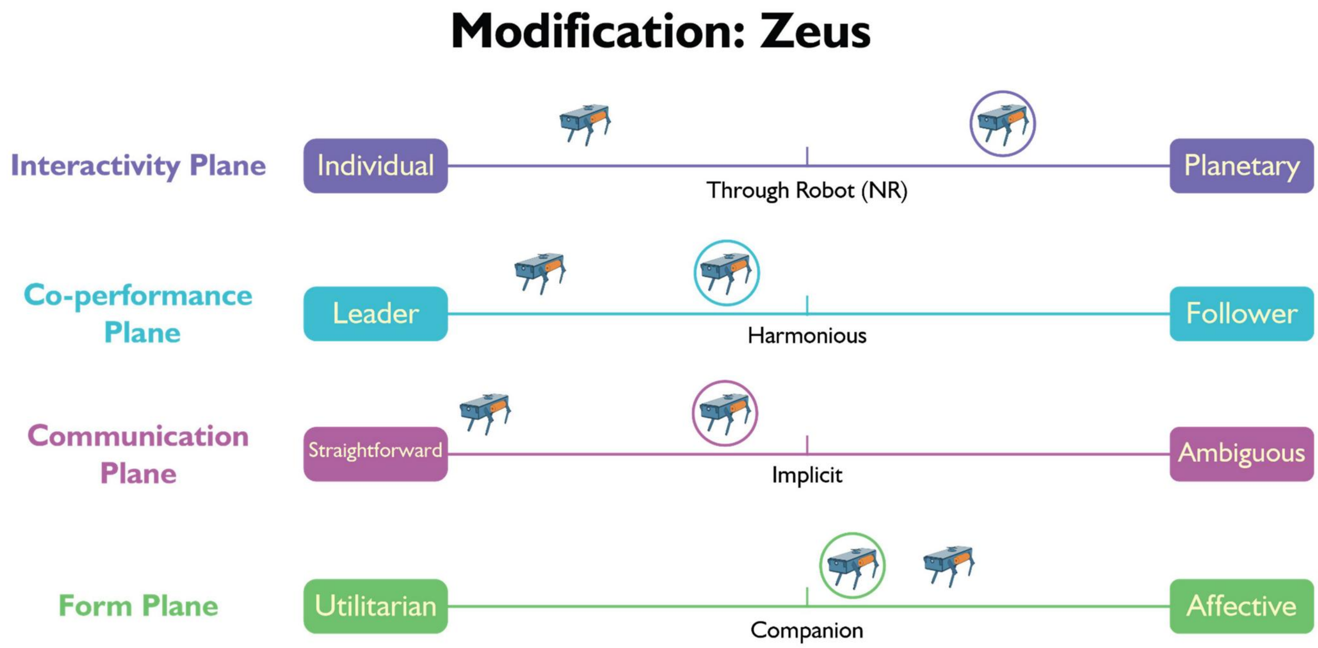

Figure 11. Updated positions (marked with circle) of zeus after modifications along with initial positions.

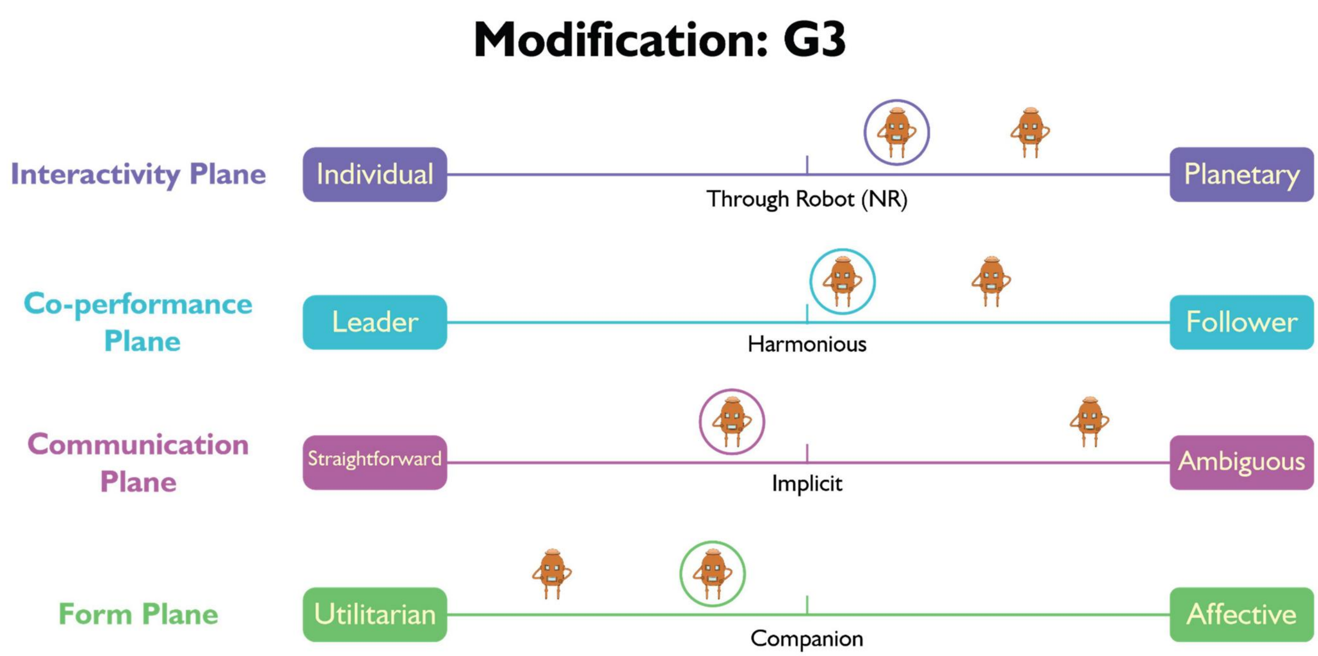

Figure 12. Updated positions (marked with circle) of G3 after modifications along with initial positions.

G3 on each plane after the suggested modifications is shown in Figure 12.

6.2. Limitations and future work

The primary limitations of this study and the proposed design space are twofold: methodological constraints and potential areas for refinement within the space itself.

To promote creativity, the design workshop series did not restrict out-of-the-box ideas and encouraged participants to think beyond the capabilities of current technology, possibly ideating how the future might look like with companion robots in the wild. The experts in the workshops played an important role in striking a balance and making sure that the concepts did not become so futuristic that we cannot imagine them ever being realized. As a result, while it has brought many implementable ideas, the technical feasibility of some others remains questionable with currently available technology. For example, the robot being able to swim in freezing water and take a drowning human to the shore might not be feasible in the current technological context. However, speculative design studies always tend to challenge the current technological space, and further research will attempt to create potential solutions by implementing prototypes based on the outcomes.

A more varied background of participants would impact on the results significantly. Most of the participants had technical backgrounds and their educational backgrounds pointed to them being a more tech-savvy group. Having considered that, we gathered as many forest-goers (people who visited nature at least 2-3 times per week) as possible to understand real-life nature exploration scenarios. We also made sure to assign at least one participant who visits nature more than three times per week to each of the design groups. However, more participants who visit nature frequently, especially those who are more connected to nature from an educational and livelihood point of view could diversify the results by providing better insights into their specific needs.

Given the emphasis on creating concepts that are not restricted by technological boundaries, these concepts may not be realized with current technological capabilities. However, our study might shed light on how to design companion robots driven by the knowledge of diverse stakeholders which can also affect the types of technologies that need to be developed for future advancements in the field.

The design space, while offering valuable insights into designing companion robots in nature, has certain limitations rooted in both its current scope. Being developed from the analysis of five design concepts, the design space may not fully encompass the diversity of potential scenarios or design considerations, leaving room for additional or more nuanced dimensions to emerge with further exploration. For instance, broader analyses might reveal the need for new planes or adjustments to the existing ones—Interactivity, Co-Performance, Communication, and Form—to better capture factors such as cultural influences, long-term user engagement, or ecological considerations. Furthermore, the design concepts were analyzed and discussed by mainly the first author with the help of deep discussions among all the authors, which might bring a sense of bias in the analysis. While qualitative design research is always subjective to some extent, further analysis of the concepts by independent experts might bring out more insights, marking it as a future work. Additionally, this design space is not intended to replace existing frameworks but to extend them by addressing gaps specific to nature-based robot interactions. This complementary role may create ambiguity about its integration with established methods, necessitating greater clarity in its purpose and adaptability. Future efforts to expand its application and refine its dimensions will ensure that the design space remains both practical, relevant, and comprehensive for diverse contexts.

7. Conclusion

In this study, we reported the co-design process of a robotic companion for nature interaction which involved 30 participants. We have contributed to the field through (1) design themes, (2) holistic concepts of robotic companions along with usage scenarios, and most importantly a (3) design space for ideating and critically analyzing robot design concepts for human-robot-nature interaction. This study is the first of its kind to investigate the design space of a robotic companion for the wild, through an ambitious and rigorous structure, and by involving stakeholders in the design process.

The amount of design knowledge created in the workshop is significantly large, which will help future designers to focus on specific and important aspects of their design process. For this study, our scope was limited to finding design themes, creating concepts, and ideating a design space. The concepts were low-fidelity prototypes and as a result, implementation and testing of the concepts were not included in the scope of this study. We plan to continue the design work by attempting to implement the concepts in real-life scenarios and understand their effectiveness in a human-robot-nature interaction context.

Author contributions

CRediT: **Eshtiak Ahmed**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Writing – original draft, Writing – review & editing; **Laura Diana Cosio**: Conceptualization, Data curation, Resources, Visualization; **Çağlar Genç**: Conceptualization, Data curation, Formal analysis, Methodology, Validation; **Juho Hamari**: Funding acquisition, Supervision, Validation; **Oğuz 'Oz' Buruk**: Conceptualization, Formal analysis, Methodology, Supervision, Validation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval

Informed consent was obtained from all participants before the study began which included clear statements about confidentiality, data security, and publication of research results. As per the guidelines provided by the Finnish National Board on Research Integrity (TENK) (https://tenk.fi/en/advice-and-materials/guidelines-ethical-review-human-sciences), this research did not require an ethical review, hence we did not apply an ethics approval.

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