Tampere University

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CAT-ROBOT INTERACTION

A Qualitative Study of Feline Social and Predatory Behaviours Towards Robotic Pets

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ABSTRACT

Ludwika Pilch: Cat-Robot Interaction. A Qualitative Study of Feline Social and Predatory Behaviours Towards Robotic Pets.
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This thesis contributes to the field of Animal-Robot Interaction and Animal-Centred Design, by prioritising animals and their needs in the design processes. The goal of this thesis was to investigate interactions between eight domestic cats and robotic pets originally designed for human users across four households, in the presence of their owners. The following research questions have been raised in this thesis. RQ1: How do cats perceive cat-like and bird-like robotic pets? RQ2: Can cat-like robot facilitate a natural social interaction with a domestic cat? RQ3: What design improvements would benefit the future research of Cat-Robot Interaction?

The thesis presents relevant research in the field of Animal-Robot Interaction, and the historical background of Biomimetic Robots. Existing studies in the field of Cat-Robot Interaction have been demonstrated to emphasise the novelty of this thesis work, and the lack of research of feline sociality. As cats are considered a predatory species of rather solitary nature, a cat-like robotic pet and a bird-like robotic pet were used in the study and evaluated in four different households to see which type of robot would facilitate a more natural interaction with eight cat participants. Despite initial hypothesis that either cat-like or the bird-like robot would prove to be better suited for interacting with cats, both robots elicited meaningful reactions from participating cats. The cat-like robot evoked more social behaviours, whereas the bird-like robot was treated more as a toy or prey. Data was collected through recorded observations of the interactions and interviews with the owners, and analysed through affinity diagramming, thematic coding and the use of ethogram of cat behaviours and emotional responses. Cats' interaction with robots was analysed with the following themes, emerging from the data: approach towards the robot, emotional and behavioural cues indicating cats' reactions, and perception of the robot.

As an outcome of this thesis, a framework for Cat-Robot Interaction was introduced, including design suggestions for the future development of the robotic pets, together with an adaptation of UX Goals for Cat-Centred Design. This provided an overview of how the future of Animal-Robot Interaction could be shaped, and consequently, create more ethically sound and animal-oriented use of technologies. The framework could be tested and improved in the future, to contribute to further studies of feline behaviour, and establish a better ethological understanding of domestic cats and other feline species.

Keywords: Animal-Robot Interaction, robotic pets, Biomimetic Robots, Animal-Centred Design, domestic cats, social and predatory behaviour of cats.

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PREFACE

With the previous experience of writing a literature review on rat-robot interaction, for a bachelor's thesis, I was determined to continue studying animal-robot interaction. This research idea has been sparked by the love for animals, and the deep-rooted need to give back the good they bring into human life. That is why I would like to dedicate this thesis to my cat, Kardamon, who inspired me with his beauty, motivated me with his calming presence, helped me take breaks by lying on my laptop and demanding attention, and provided his feline expertise, in choosing the prey-like robot for the study.

Kardamon, however, was not the only one who contributed to this research. I am incredibly grateful to my supervisor and mentor, Aino Ahtinen, who had the patience and endless energy to guide me through this process. Thank you for leading me when I felt lost and pushing me forward when I could not take the next step myself. Aino's PhD students, Apa, Vero and especially Chia, also had significant impact on my work, and their contribution should not go unnoticed. I was honoured to share this experience with other members of the supervision team – Saba and Ayesha, who provided me with great feedback, support, and accountability system.

Last, but certainly not least, I would like to give credit to my friends and family – the most important people in my life, who helped me become the person that I am today. Thank you for believing in me when I was losing hope and for giving me strength with your love and encouragement. You were standing by my side every step of the way, and it is because of you, that I am now at the end of this incredible journey.

Tampere, 1st of September 2026

Ludwika Pilch

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LIST OF SYMBOLS AND ABBREVIATIONS

ACD	Animal-Centred Design
ARI	Animal-Robot Interaction
CC license	Creative Commons license
DoF	Degrees of Freedom
EDP	Enterprise Data Protection
HCD	Human-Centred Design
MEAU	Method for Evaluating Animal Usability
UX	User Experience
URL	Uniform Resource Locator

1. INTRODUCTION

The following chapter provides an initial perspective on the theoretical concepts in Animal-Robot Interaction, by defining the relevant terms used in the thesis. It also holds an overview of the scientific background and motivation for this topic, by presenting existing knowledge in the field of Animal-Robot Interaction, Biomimetic Robotics, and animal research. Moreover, it outlines the methodological approach and defines the research questions, along with presenting the research gap in the discipline, with the particular focus on domestic cats. Finally, it presents the structure of this thesis.

1.1 Background and Motivation

1.1.1 Theoretical Concepts and Terminology

Biological features of animals have been an inspiration for building robotic implementations, prompting the field of **Biomimetic Robotics** to emerge. Biomimesis is based on a concept, which can be explained with the following statement: "*by mimicking animals that are most capable of performing certain specialized actions (...), one could build robots that can surpass any other in performance, agility, and dexterity*" (Vepa, 2009, pp. 25). In other words, biomimetic robots are built, using biological mechanisms as guidelines. Biological features of animals have been perfected by evolution, and therefore can serve as an example, for machine advancement in many fields, such as exploration of difficult terrains, environmental monitoring, or industrial automation (Abdulbaqi et al., 2023). The inspiration for more agile and natural robotic movements has been drawn from many diverse species, from fish, birds, or cheetah to reptiles such as gecko (Gao et al., 2019). It is important to note that not all biomimetic robots are designed for the purpose of interacting with animals. All robots for animal interaction, however, should be designed with the goal of creating a strong resemblance between the robot and animal. A robot that mimics behavioural and physical features of animals through biomimesis, can create natural interaction with these animals, because they would treat it as a member of the same species (Tamborini, 2023). Therefore, even though robots used in this thesis are not biomimetic, as robots for social interaction with animals generally are biomimetic, it is a relevant term in this thesis. Moreover, further

improvement of the robots could lead to development of biomimetic robots, that would be more fitting for the context of interacting with cats.

Animal-Robot Interaction (ARI) is an emerging field, which utilises robots for acquiring better understanding of animals and contributing to **ethology** – the study of animal behaviour and cognition (Schmickl & Romano, 2024; Abdai & Miklósi, 2024). In this approach, biological and technological background is combined, to design robots socially compatible with animals, and use them in the research of behavioural and cognitive capabilities of animals (Abdai et al., 2018). When robots are treated by the animals as one of their own species, it can be used to facilitate the interaction with one or more animals, and evoke specific behaviour, or test particular social scenarios (Romano & Stefanini, 2025).

Domestic cats (*felis catus*) are a small species within the feline family, including big cats, such as lions (Bradshaw et al., 2012). The predatory nature of cats makes them good hunters, who are motivated by prey (Cecchetti et al., 2021). As, domestic cats are the study participants and the main focus of this thesis research, the term **Cat-Robot Interaction**, or more broadly – feline interaction, has been specified, to explicitly describe the interaction between domestic cats and robots, in situations, where cats are the users of the technology. Considering the predatory nature of cats, instead of testing the interaction with the cat-like robot only, a bird-like robot has been utilised as well.

The term *perception* often refers to a cognitive state of subjective representation in humans (Burge, 2022, Chapter 2). However, it is also commonly used in animal research to describe the way animals register and react to their surroundings (McGrath et al., 2024). Therefore, animal perception refers more to physical and tangible way in which animals respond to stimuli, rather than the objective thoughts and feelings (Scanes, 2018). In this thesis, the term *perception* has been adapted to describe how cats react to the robots, based on the displayed behavioural cues.

Animal-Like Robots is a term, which has been developed for the purpose of this thesis, to represent robots, that are intended for interaction with animals and might not necessarily look like them, together with robots, that resemble animals but might not be suitable for animal users. Here, the word ‘like’ refers to both visual and behavioural resemblance, without specifically pointing towards one or the other. A pre-existing term has not been adapted from other academic sources, as they did not describe the types of robots that are relevant in this research. It was important to combine biomimetic robots for animal interaction, with robots

that can look similarly to animals but are not intended for animal users. In the context of this thesis, robots designed for humans, have been utilised for animal interaction, in effort to develop them further into biomimetic robots, suitable for interaction with domestic cats. The robots used in the study are **robotic pets** – companion robots that mimic domestic pets such as cats, to create similar interaction patterns to the ones humans have with these pets (Díaz-Boladeras, 2023).

The categorisation of Animal-Like Robots is essential to highlight the differences in terminology, referring to robots that resemble animals, whether it is visual or behavioural similarity. Different terms, such as Animatronic or Zoomorphic, are explained in the 2.1.2 Categorisation of Animal-Like Robots section of the following chapter, to provide a unified understanding for relative vocabulary, in this thesis and future studies of Animal-Robot Interaction.

The reason behind introducing robots in this research, is not the technological advancement, but learning more about the animals, by using technological means, that best reflect their needs. **User Experience (UX)** is a design field centred around the demands, preferences, and behaviours of users, who in the case of this study are cats (Norman et al., 1995). It can help to deepen the understanding, of what design implementations would improve the experience of animals, when interacting with a robot. Particularly, the **UX Goals** (Preece *et al*., 2002) framework can be adapted for animal users, to gain a better understanding, of how to develop design solutions for animal interaction in the future.

Animal-Centred Design (ACD) focuses on developing technological solutions, that would contribute to the wellbeing of animals. Since they are the users of the designed products, the UX Goals should be adapted to make sure that animals are included in the process, and the end-product meets animals' needs (Mancini & Nannoni, 2022). **Cat-Centred Design** is more specifically focused on design solutions for cat users. Based on the results of the study, carried out in this thesis, and a **Method for Evaluating Animal Usability (MEAU)**, created by Ruge and Mancini (2019), a UX Goals framework for Cat-Centred Design has been proposed in 5.2.2 Future Framework for Animal-Centric Design.

Despite animals' contribution to the development of new mechanisms, they are rarely the beneficiaries of those novel ideas. Robots have been successfully implemented in animal research, resulting in important discoveries of animal cognition and behaviour, however, this knowledge is not always used for animal welfare improvement. For instance, in order to

check the extent in which a mobile robotic rat can influence social behaviour of rats, the robot has been programmed to chase a rat and cause distress to it (Shi et al., 2013).

The field of Animal-Robot Interaction is a complex discipline. The wellbeing of an animals, who, in this case are the users of the design implementation, should always be a priority for the researchers. This is where the ethical consideration arises, prompting one to wonder, whether animal research is leading to actual improvements of their life quality, and if so, how such research should be conducted to cause minimal harm and distress to these beings. Moreover, what is the value of robots in animal studies, how and why should they be involved. The ethical considerations and approaches, adapted in this thesis, have been discussed further in the 3.1.4 Research Ethics section.

1.1.2 The Research Gap and Motivation

The existing research in Animal-Robot Interaction has been reviewed, as part of the background literature search process, that was done for this thesis. The review underlined a lack of studies featuring social interaction between cats and cat-like robots. Therefore, the value of this research stems from its novelty and the potential for improving the life of domestic cats. It can be achieved by creating Cat-Centred Design guidelines for future development of robots for feline interaction, based on the interaction cat participants had with the cat-like and bird-like robot. There have been studies of cat interaction with robotic toys, such as the Cat Royale – robotically-enhanced environment for cats (Schneiders et al., 2024) or the Autonomous Feline Entertainment Robot (AFER) designed and developed at the University of West Florida (Adams & Rahman, 2021). Pet caring robots (Kim et al., 2009) have also been frequently used in the Cat-Robot Interaction research, as documented by Indonesian scientists in a comprehensive literature review on this topic (Angela et al., 2024).

Cats and dogs are often portrayed collectively in ARI studies focused on domestic pets; however, the research gap becomes more significant, when considering feline and canine species together. The interaction of dogs and robots has been explored more thoroughly, likely due to the high level of trainability, leading to various ways, in which they assist humans, such as working as guide dogs, or serving in the law reinforcement. Some of the examples of Dog-Robot Interaction studies include dogs interacting with a simple commercial robotic-pet dog (Zamansky et al., 2018); dogs encountering delivery robots in natural settings – during walks with their owners (Väätäjä et al., 2023); or even dogs taking commands from Nao – a small humanoid robot (Qin et al., 2020). The research gap underlines the significance

of exploring interaction between cats and robots more thoroughly. Development of biomimetic robots for feline interaction can contribute to the knowledge of cat behaviour and socialisation. Moreover, it can improve the general development of biomimetic robots for animal interaction.

Robotic pets used in this study, have been designed for human users, who rely mostly on visual cues. However, because cats have sharper senses than humans (Sung, 2024), the features of the robot might be disturbing for them during direct interaction. Thus, the embodiment, autonomy and behavioural skills of the robots, should be analysed in the context of animals' cognitive skills, such as visual, auditory and olfactory processing (Abdai et al., 2018). Therefore, even if the robots utilised in this study, are not designed for cat perception, they can help to establishing guidelines for cat-centric design of future robots. Moreover, findings can contribute to the field of Animal-Robot Interaction as a whole.

1.2 Research Objectives and Research Questions

This thesis work aims to apply robotic pets, designed for humans, in the exploration of Cat-Robot Interaction potential. Despite the human-centric design of the robots, they have been utilised, due to their commercial availability. A cat-like robot, as well as bird-like robot are used in this study to determine, which animal-inspired robot will initiate more natural interaction with cat participants. The study is centred around indoor domestic cats, due to high availability of owners who volunteered their cats for participation. The possibility for conducting research in their natural environment – their owner's home, where they feel safe, is another advantage for choosing cats. The animals' comfort is one of the main objectives for this research. Moreover, bringing the robot into the owner's house offers an opportunity to involve the owner in the interaction, as well as to control the process and ensure the safety of all parties.

The research questions are presented in a causal order, meaning, that answering the first question will provide the basis for responding to the second question, and to entertain the third question, data from the foregoing two should be considered.

RQ1: How do cats perceive cat-like and bird-like robotic pets?

Introducing robotic pets that resemble two different species, can provide valuable knowledge in further studies of Cat-Robot Interaction. A robot resembling feline species, and a robot resembling potential prey, have been chosen to determine, which category of biomimetic

robots should be further developed in the future. It is possible, that more natural interaction can be achieved by implementing a different species in cat interactions, considering their predatory nature, however, studies on rat-robot interaction have shown that animals interact better with a robot representative of the same species (Shi et al., 2011). Consequently, the anticipated outcome of the study is to achieve social interaction between domestic cats and a cat-like robotic pet, which introduces the next research question.

RQ2: Can cat-like robot facilitate a natural social interaction with a domestic cat?

This research aims to explore the possibilities of implementing cat-like robots in studies of cat sociality. A bird-like robot has only been considered, due to the predatory nature of cats, and because they are often considered to be solitary species (Stella, 2021). More emphasis has been put on the cat-like robot, because usually robots for social interaction with animals resemble these animals in terms of physical features and behavioural cues (Landgraf et al., 2021). The cat-like robotic pet, used in this study, might not be ideal for initiating social interaction, similar to the one that would occur between the domestic cats. Therefore, the desired outcome of the study would be to achieve basic interaction between the cat-like robotic pet and domestic cats, which would contribute to the exploration of future robotic implementations, described in the following research question.

RQ3: What design improvements would benefit the future research of Cat-Robot Interaction?

Because robotic pets, used in this study, are very simple, they might not be able to have a natural interaction with cats. The probability, of the cat-like robot not being treated as a representative of the same species by the cats, seems to be quite high. Utilising robotic pets, designed for humans, can introduce the need for new features and improvements. Design implications sketches, for the robots used in this study are developed, to contribute to the further development of biomimetic robots for Cat-Robot Interaction. This can provide great opportunities for learning more about animals as the users and beneficiaries of technologies. Moreover, creating animal-centric, ethically considerate design solutions can improve the overall wellbeing of animals.

It is crucial to highlight, that this study prioritises animal welfare, and aims to contribute to the general progress in that field. Design implementations, for future development of biomimetic robots for feline interaction, are proposed to improve the living conditions of cats. The use of robots in animal research, allows to control the interaction process by

manipulating the robots' actions, to see how animals would respond. While research can be conducted in natural and comfortable conditions for animal participants, more data can be gathered with robots.

This thesis paper contributes to the field of User-Technology Interaction and therefore does not elaborate on the technical aspects of robots, focusing rather on the social interaction of domestic cat with two types of robotic pets. Technical difficulty of the project has been taken under consideration, due to limited movement range and primitive behavioural features of the robotic pets. As previously stated, the user, in this context a cat, is the primary focus of this study. It is aimed at exploring the possibility of robotic implementations, for future social research of feline species.

1.3 Structure of Thesis

The remainder of this thesis is organised as follows. Chapter 2 provides the theoretical background for this research by introducing the field of Animal-Robot Interaction and reviewing relevant studies. It presents the categorisation of Animal-Like Robots and existing research on Cat-Robot Interaction. Furthermore, the chapter discusses the social and predatory behaviour of cats.

Chapter 3 describes the research methodology. It outlines the methods used for data collection and analysis, as well as the planning and implementation of the study phases. The participant profile is presented, and the ethical considerations and participant rights relevant to the study are discussed.

Chapter 4 presents the findings of the study, while Chapter 5 discusses and analyses these findings. The results are presented separately for each robot, organised thematically, and compared at the end of the chapter. Design suggestions, sketches, and implications are also included. Chapter 5 answers the research questions by interpreting the findings in the context of existing research. Furthermore, it discusses ethical considerations, including research ethics and a future framework for Animal-Centric Design. Finally, methodological and technological limitations are addressed, and directions for future work are proposed.

Chapter 6 concludes the thesis by summarising its contributions and outlining opportunities for further research in the field of Animal-Robot Interaction, with particular focus on the feline species.

2. THEORETICAL BACKGROUND

This chapter introduces the theoretical framework for this thesis. The first section describes the significant historical moments in the development of Animal-Robot Interaction (ARI) and presents the experiments that are particularly important in the context of this research. Moreover, it provides a novel categorisation of Animal-Like Robots, developed for the purpose of this thesis. The next section focuses on cat behaviour, including the origins and nature of cat sociality, and differences between interacting amongst other cats and with humans, as well as the predatory behaviours of domestic cats. At the end of the chapter, a summary is provided to highlight the research gap that this study aims to fill.

2.1 Implementations for Animal-Robot Interaction

Firstly, this section explores historically relevant studies in the field of Animal-Robot Interaction, particularly the ones that fit within the context of this research. Secondly, it discusses two different types of robotic implementations for cats, which underline the research gap in Cat-Robot Interaction.

2.1.1 Historical Background

The scientific research of Animal-Robot Interaction (ARI) and Biomimetic Robotics are not novel fields in the academic world. It is believed that the first and most well-known, biologically inspired robots, have been made in the late 1940s by a neurophysiologist Gray Walter, who, as one of the first, has created robots for the sole purpose of behavioural research (Winfield, 2024). He designed two autonomous tortoises, which, despite bearing little resemblance to an actual turtle, were able to follow the light and avoid obstacles (Walter, 1950).

One of the first experiments, in which animal behaviour was studied in the presence of a robot, was conducted by Marc Böhlen. A simple mobile robot, in a cylindrical shape, was placed in a cage with three chickens, who, over the period of a sixty-day study, have stopped perceiving the robot as threatening, and were able to coexist with it (Böhlen, 2000). Despite the revolutionary value of this study in introducing Animal-Robot Interaction, it did not utilise a biomimetic robot, nor did it feature social interaction between animals and the robot, which is why the following study is of relevance to this historical background.

One of the first robots to interact with animals, was an autonomous, mobile, robotic cockroach in the study of animal decision making in social setting. The robots were designed to facilitate a natural social interaction with living participants. Not only were they of similar size to an adult cockroach, but also, they were conditioned with cockroach recognition pheromone, which allowed them to easily blend in with other roaches. The study has shown that the robots were able to influence the insects in the process of decision making, by increasing the likelihood of them choosing a shelter with intense lighting, as opposed to a darker one, which was originally preferred. (Halloy et al., 2007).

A group of scientists at Waseda University in Japan, have developed a biomimetic robotic rat for social interaction with laboratory rats. The robot was programmed to influence social behaviours of rats, so that it could provide more controlled settings in future experiments on laboratory rats. The WR-3 version of the robot was causing distress to one of the rats by constantly following it and expressing dominant behaviours. It continued throughout multiple interaction sessions, while other rats were observing. Over time, researchers noted, that the rat, who was subjected to bulling by the WR-3 robot, developed signs of depression. However, what was particularly interesting in this research, was that other rats started treating the distressed rat similarly to the robot. This study showed that a biomimetic robot, not only, can have a direct impact on an animals physical and emotional state, but also, it can influence a social dynamic in a group of animals. (Shi et al. 2010).

The next experiment conducted by these researchers involved an improved version of the mobile biomimetic rat robot – WR-4. This time the robot was positive and friendly towards the rats, who were showing signs of anxiety. Gradually, rats started behaving more friendly towards the robot and became less anxious. Moreover, these rats preferred the company of robot over other rodents. Conclusively, this example is an even stronger testimony to, how influential the interaction between an animal and biomimetic robot can be. A rat could be equally distressed by a robot, that resembles rat or looks completely different. However, for a rat to exhibit a friendly behaviour towards the robot, the biological resemblance in movement and physical analogy is curtail. (Shi et al., 2013).

2.1.2 Categorisation of Animal-Like Robots

The robots resembling animals have been categorised, to provide clarity on the types of robots used in this thesis, as well as similar robots, which could potentially cause confusion around

the topic. The following division has been created, based on extensive research of related literature. It does, however, include only the most relevant terms.

Table 1. *Categorisation of Animal-Like Robots*

	Category	Related Source	Definition
Robots that do not necessarily resemble animals, used mostly for research.	Biomimetic Robots	Vepa (2009)	Robots mimicking the biological features animals for better performance.
	Bionic Amphibious Robots	Ren & Yu (2021)	Biologically inspired robots, which are able to move on land and underwater.
	Soft Robots	López-González et al. (2023)	Robots inspired by animal morphology, where soft material is covering the mechanical "skeleton".
	Animats	Dean (1998)	Autonomous robots, simulating animal behaviour and able to survive in this animal's environment.
Robots resembling animals, designed for humans.	Animatronic Robots	Utture et al. (2017)	Main incentive for these robots is to look, sound and act as a real-life being, not all of them resemble animals; often used in the entertainment industry
	Zoomorphic Robots	Bradwell et al. (2021)	Robots closely resembling animals.
	Robotic Pets	Guerra et al. (2022)	Animal-shaped robots, that exhibit behaviour of domestic pets to serve as robotic companions for humans.

The table creates a distinction between robots, that are used for animal interaction, but do not necessarily resemble animals from a human point of view, and robots, that look like animals but might not be usable for social interaction with animals, as they are designed primarily for human users. Since Animal-Like Robots are a relatively new concept and there are few academic sources explaining the differences between them, this categorisation is very general. Hopefully, it can serve scholars in the future, to build a more extensive and technical division between these types of robots.

2.1.3 Robotic Implementations for Cats

The current research of Cat-Robot Interaction is centred around human user, rather than the animal (Kim et al., 2009). The existing robotic implementations for domestic cats can be divided into two categories: caregiving robots and robotic toys. The first category directly benefits cat owners by automatising feeding and cleaning or initiating those tasks when the owners are away. Whereas the second category is centred around stimulation and exercise of the pets.

While **robotic toys** directly interact with the animals, they still can be considered as more of a Human-Centred Design (HCD), since they help humans provide exercise to their pets and are commercially targeting customers by meeting their personal preferences. *"Historically, design for animals has been guided by the drive for efficiency, economic gain, the preferences and goals of human carers, and by tradition or common practice, rather than by understandings of animals' ancient evolutionary nature and welfare needs"* (Webber et al., 2022, pp. 2). Consequently, in some cases, it might be more important to attract buyers' attention, than to provide good entertainment for the pet. Some of the examples of non-commercial robotic toys, which have been described in academic sources, include an interactive set-up of different smart toys, which record cats' activity and optimise diversity of play (Han & Witzman, 2023); an Autonomous Feline Entertainment Robot (AFER) – smart toy that can be clipped to a shelf or a desk, equipped with different movement patterns and modes of play (Adams & Rahman, 2021); and a mobile-controlled, mouse-shaped autonomous robot, able to move around at a high speed, with obstacle avoidance and a laser tail, to make the cat entertainment more versatile (Ray, 2021).

Caregiving robots make the process of looking after a pet more flexible and automatic. Owners can leave their cats alone for longer periods of time, while being sure that their pets will get regular distributions of fresh water and food. Moreover, with the commercially

available technological solutions, they can even make the process of cleaning the litter box automated. Some of the examples of caregiving robots, which have been introduced in academic articles, include PURRtentio – litter box equipped with electromechanical biosensing, which enables the monitoring of sodium and glucose levels in cat urine, to provide constant veterinary monitoring (Sun & Vega, 2023); a pet care system, including a feeder, water dispenser and litter box, which collect data and can be supervised by owners through a mobile app (Chen & Elshakankiri, 2020); and the Puspin Smart Cat Litter Box System, which monitors cat's routine and cleans itself with an autonomous waste management (Rey & Rey, 2024).

It is important to remember, that cats, despite being often described as solitary animals, rely on their owners and require company (Ines et al., 2021). Therefore, it is essential to note that the caregiving robots, implemented into the daily care of domestic cats, can be a facilitation and not substitution for cat owners.

2.2 The Social and Predatory Behaviour of Domestic Cats

This section provides an overview of the social behaviour of cats, both between each other and with humans, to give basis for the characterisation of the behavioural traits indicating, that cats perceive the cat-like robotic pet as a representative of its' own species in the study phase. Moreover, it discusses the predatory behaviours of cats, so the interaction with the bird-like robot can be analysed accordingly. Therefore, the outline of three types of cat behaviour is be made – intraspecific (within species) social interaction, interspecific (between species) interaction with humans, and predatory behaviour (Oliveira & Bshary, 2021).

2.2.1 The Origins and Nature of Cat Sociality

The sociality of cats likely developed through the process of an early domestication, "*when otherwise solitary animals would have been drawn together towards human settlements*" due to favourable living conditions (Atkinson, 2018, pp. 42). As described by British scientist John W.S. Bradshaw, who specialises in the research of cat behaviour – "*cats exhibit a remarkable degree of flexibility in their social arrangements, apparently determined by the concentration of resources, particularly food and suitable denning sites*" (Bradshaw, 2015, pp. 115).

Consequently, cats have developed advanced communication with humans, which evolved from the within-species social behaviours. The social interaction of cats between each other

has been adapted to communicate with humans, and therefore the behaviours in both scenarios can be similar.

There are not many scientific sources analysing the socio-cognitive abilities of cats (Humphrey et al., 2020), which contributes to the complexity of categorising cat behaviour. Nevertheless, an attempt to describe the nuances of social approaches towards humans, cats and potential prey will be made, for the purpose of this thesis. The division of possible social approaches is important to determine, whether cats perceive the cat-like robot, used in the study, as a representative of the same species, or not. It is possible that cats will exhibit social behaviours towards owners, or the experimenter and they should not be mistakenly interpreted as interaction with the robot.

2.2.2 Characteristics of Feline Social Behaviours

The signals of social interactions between cats can be divided into antagonistic (unfriendly) behaviours and affiliative (friendly) behaviours. They might be misinterpreted, as fighting elements often occur during play, which is a bonding activity. Trudy Atkinson in her book on feline behaviour, explains, that hidden claws, lack of noises, forward body posture and returning to bonding behaviours after play, are the main signs that cats are not aggressive towards each other. Adequately, cats that behave aggressively towards each other are hissing or growling, they keep the head and body retrieved when attacking with front paws and extended claws, while moving their tails rapidly from side to side. (Atkinson, 2018).

Cats are more likely to exhibit affiliative behaviours, such as touching noses, allogrooming (licking each other), allorubbing (rubbing against each other), playing and resting together, towards their family members, as they favour relatedness to familiarity, however, these signs of affection occur also between cats who live together and are not related (Crowell-Davis, 2007). Cats greet each other by sniffing/touching noses while approaching with the tail lifted, which is also a behaviour they exhibit towards humans, when they return home (Atkinson, 2018).

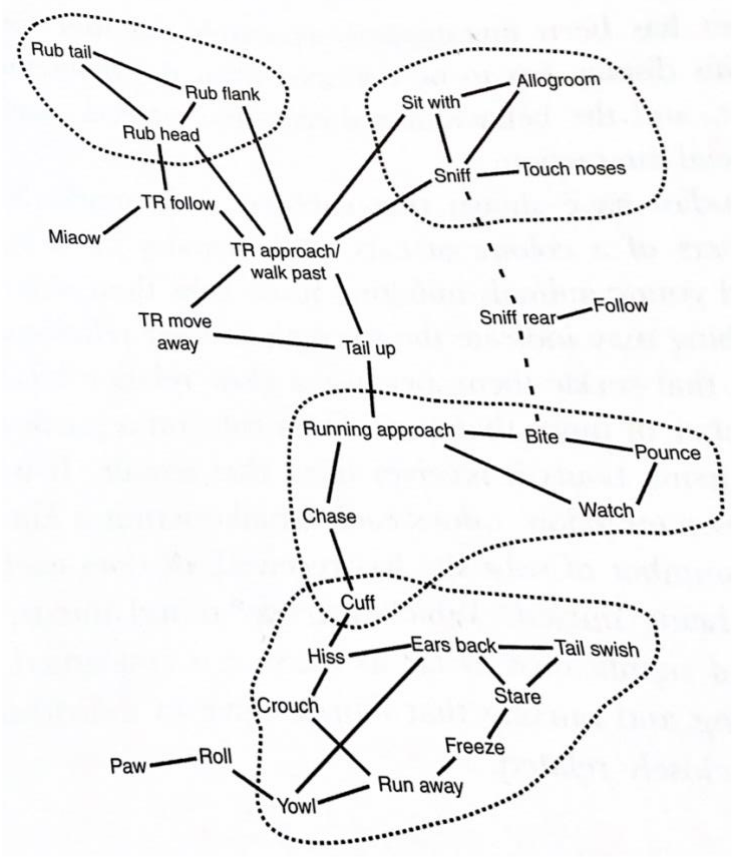


***Figure 1**. **A classification of social behaviour patterns performed by neutered cats** by Sarah Brown and Charlotte Cameron-Beaumont (Bradshaw et al., 2012, Chapter 8, pp. 153).*

The graph above provides a pattern of social behaviours, that can occur between cats. The amicable interactions, presented at the top, consist of two clusters – allorubbing (top left) and sniffing or grooming (top right). Friendly interactions are often initiated by the 'tail-up' signal (centre), where TR refers to a cat with a lifted tail in movement. The defensive interactions are presented in a cluster at the bottom, with cluster of aggressive behaviours above it. (Bradshaw et al., 2012, Chapter 8).

Domestic cats are particularly vocal animals, which can be attributed to domestication, especially since meowing is typically directed towards humans, rather than fellow cats. Purring, however, is not limited to human interaction. It also occurs during drowsy sleep, tactile stimulation, as well as while greeting or mutual grooming between two cats, and when cats find themselves in a warm and familiar environment. (Bradshaw et al., 2012, Chapter 5).

2.2.3 Social Interaction Between Cats and Humans

Cats have adapted many intraspecific social behaviours to interact with humans, which means that, if kittens have not been properly socialised within their own species, they might struggle with interspecies communication as well (Crowell-Davis, 2007). For this reason, feline

sociality towards humans bears similarities to how cats interact between each other, and it might be difficult to distinguish them.

As an answer to this complex problem, John Bradshaw (2015) proposes the following categorisation of social behaviours of pet cats towards their owners – **species-typical actions** adapted to interspecies communication by association, such as pawing objects or jumping on them to gain attention of the owner; **species-typical signals of kittens towards their mothers**, adapted in adult life to communicate with humans, such as kneading and meowing; **species-typical adult-to-adult signals**, that have been adapted for human interaction, but keep their original function, such as purring, allorubbing (e.g. rubbing head and chin on owners' body) and allogrooming (e.g. licking owners' fingers). (Bradshaw, 2015, pp. 120).

Cats' interaction with their owners can be influenced by how often humans initiate the interaction, meaning, that owners, who actively seek contact with their pets, might disregard cats' need for independence. Despite preferring frequent and short interaction pattern, similar to the one, that would occur within species, cats appreciate initiating interactions according to their preference and need (Wedl et al., 2011). As a result, owners, who are overly expressive towards their pets, might have a worse relationship with them.

British scientists examined the role of slow blinking in cat-human interaction and found out, that the exchange of slow blinking sequences with cats, whether performed by an unfamiliar stranger or the owner, created a positive emotional response in cats, and contributed to their more trusting and relaxed behaviour (Humphrey et al., 2020). The origin of this communication style in cats is unclear; however, it likely has been developed throughout the process of domestication. Nevertheless, the study shows the positive impact of eye narrowing expressions in the wellbeing and trust of cats towards humans.

2.2.4 Predatory Behaviours of Cats Towards Prey

For feline species, hunting is a survival mechanism. It is not solely motivated by hunger, since it might be too late to hunt the moment cats feels tired and hungry (Atkinson, 2018). Therefore, the hunting behaviour of cats, should be addressed and managed by their owners. Many cats, who are going outside, not only are contributing to endangering smaller wildlife, but also run the risk of becoming victims to road traffic, diseases, or larger animals (Cecchetti et al., 2021). However, even indoor-outdoor cats are hunting less, when provided with the right nutrition, playing activates, and access to litter boxes and hiding spots (Cecchetti et al., 2020).

It is a common misconception, that cats like to torture their prey before finally killing it. Instinctively, they exhaust the victim to minimise the risk of getting injured themselves, as well as to ensure that the prey is positioned correctly to be killed (Atkinson, 2018).

The second edition of The Behaviour of the Domestic Cat book provides a detailed description of the process of approaching and attacking prey by cats. It could be summarised as follows. Firstly, the cat locates the prey and approaches quickly in a crouching position. Cat will assume the watching posture by pressing body to the ground, positioning front paws underneath the shoulders, stretching the neck and pointing the ears forward. Cat prepares for attack by moving hind legs back, rising and lowering them in a treading movement to release tension from the muscles, tail twitching. If at this stage the prey is unattainable for some reason, cat makes a characteristic chattering sound with the teeth. Finally, cat makes a sprint with a short final spring to keep hind legs on the ground, while front paws attack, whiskers are directed forward to compensate cat's poor vision on a close distance. (Bradshaw et al., 2012, pp. 128-129).

2.4 Summary

The scientific knowledge of feline social and predatory behaviours is quite extensive, but more specific categorisations could be done with more research. Development and implementation of biomimetic robots for feline interaction could contribute by providing more data acquired in controlled, but comfortable, setting. This could allow scientists to utilise robots for more in-depth study of feline behaviour, and consequently improve, not only the lives of domestic cats, but also other felines, such as the endangered species or those living in captivity.

This research aims to explore the possibility of further design and development of robots for feline interaction, firstly, by establishing whether a prey-like or friend-like robot would be a better option in the context of domestic cats. Feedback, derived from observations of interactions between cats and cat-like robot, and owners' interpretations of the way their cats reacted to the robots, can be utilised in establishing design implications for the robots, and developing framework for other feline-centred design solutions.

3. RESEARCH METHODOLOGY

The research approaches, data collection and data analysis methods, applied in this master's thesis, have been presented in the following chapter. The main stages of the research, including design, testing and conducting the study, have been reported. Participant profile was specified to provide insight to the research and those who took part in it.

3.1 Research Design and Implementation

This thesis utilises the Animal-Centric Approach in the field of Animal-Robot Interaction. The main incentive of this approach is to adjust to animals' needs and capabilities, to create technology, which can contribute to their welfare (Mancini, 2017). By adaption of the Human-Centred Design method for animals' benefit, design improvements can be implemented and enhance the usability for both sides. This can result in ethically responsible testing and improvement of robotic pets primarily designed for humans and enable them to serve animals as well.

The stages of thesis research have been presented in this section, with particular focus on the study part, including the design and testing phase, as well as the ethical aspects.

3.1.1 Research Platforms

Three robotic pets have been tested with a cat tester, to determine which should be used in the study. Aside from the cat-like robotic pet, bird-like and guinea pig-like robots went through short, under fifteen-minute, interaction sessions with the cat tester – a mixed-breed rescue male who is estimated to be 6 years old. He was recruited based on convenience and availability, since he belongs to the author, and could be around the robots for an extended period of two days. Despite a potential bias in running the trial test with a cat, staying in close relation to the experimenter, having a deeper knowledge of cat's individual character, as well as robots' specifications, has been advantageous in trial testing.

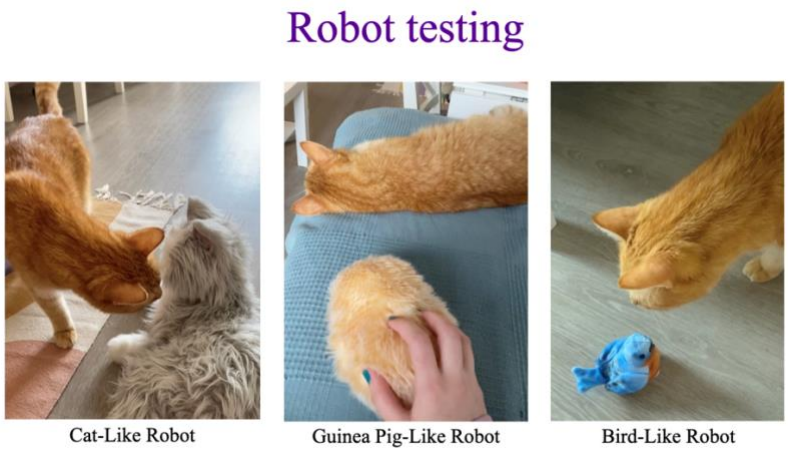


Figure 2. Robot testing *(photos taken by the author during the interaction between the three robotic pets and the cat tester).*

The guinea pig-like robot has been the least interesting for the cat tester and therefore was excluded from the study. As illustrated by Figure 2, during the interaction cat fell asleep, which proves that neither the shape, nor the sounds or movement were exciting enough to facilitate interaction and encourage cats to respond with predatory behaviour.



Figure 3. Research Platforms – the cat-like and bird-like robots *(photo taken by the author).*

The study used the cat-like robot and bird-like robotic pet manufactured by **Joy for All**. These robots have been chosen due to their commercial availability and comparatively low prices, despite being originally designed for elderly human users. The cat-like robot produces sounds like meowing and purring, with limited movement in the head and front paw, and the bird-like robot or the Walker Squawker, designed to accompany elderly people on walks, sings single notes and longer songs, with movement in the beak and the head (Ageless Innovation, n.d.). The design features of the robots have been evaluated in the 4.3 Design Suggestions chapter.

3.1.2 Pilot Testing and Study Setup

A pilot study has been carried out, to test the planned format of the interaction sessions. Owners of two female cats have volunteered to participate in the pilot test. Despite potential bias in choosing owners and cats familiar to the experimenter, it has proven to be beneficial at this stage of testing, because cats were less intimidated to interact with the cat-like and bird-like robot in the presence of a person they already knew, and their owners felt comfortable with expressing their opinions about potential improvements for the study. During the pilot test, cat owners were asked open-ended interview questions, before and after their cats interacted with the robots (Appendix 1). The interview was audio recorded and transcribed for data analysis. The interaction between cats and robots was video recorded and shared with the owners afterwards.

After running the pilot test, the following changes were made to the original study setup. Firstly, a question prompting owners to describe the individual experience of their cats was added, along with introducing a scale, on which owners could evaluate whether their cats seemed to be interacting with a machine, rather than an animal, to get a better understanding of the perceived liveliness of the robots. Another change to the interaction process, that has been made after the pilot test, was asking the owners to describe their cats' reactions with an adaptation of the **think-aloud method**, which originally has been developed for users to talk about their actions, while testing a design in experimental settings (Ericsson & Simon, 1990). Because the owners know their cats the best, they can also provide most accurate interpretation of how their pets are perceiving the robots. Moreover, second study session was initiated by asking the owners if they had any thoughts or anything to add, after the initial interaction session, a week prior. Finally, plural forms for cat participants have been implemented, since no one-cat household has been chosen to partake in the study (Appendix 2).

3.1.3 Research Process

The main tasks performed throughout this thesis work, as well as the results of these tasks, have been reported in the table below. Important steps in the research process and thesis work timeline, aim to visualise the workload and provide insight into, what has been done to write this thesis, and run the study.

Table 2. *Research process*

Step	Tasks	Results	Time
Literature Review	Thematic search of publications	Academic articles related to ARI, biomimetic robotics, feline behaviour and ethology	March-August 2025
	Selecting more relevant sources	Articles closely related to topics discussed in the thesis	
	Formulating title and research questions	Narrowing down the research topic and structure	
	Reading publications and deeper thematic search	Writing Introduction and Theoretical Background chapters, developing framework	
Study Preparation	Creating the study plan	Timeline and steps to follow	September-October 2025
	Developing documents for the study	Informed consent form, information sheet and interview script	
	Online sign-up form	Participant recruitment and background data collected	
	Testing robots for the study	Selection of 2 out of 3 robots based on cat-tester interactions	
	Running the pilot study	Testing and improving experiment set-up and data collection methods	
The Study	Running the 1st week of the study	Documenting initial reactions of the cats to the robots, recording owner insights	November-December 2025
	Adjusting the structure of the experiment	Adding interactions with the other robot, due to high interest, developing the additional interview script	
	Running the 2nd week of the study	Documenting second interaction session and initial reactions to the other robot	
	Data processing	Anonymisation of the data, affinity diagram creation	
	Debrief and reflection	Writing the third chapter – Research Methodology and Materials	
Data Analysis	Data analysis and debrief	Reporting findings, design implementations, thematic categorisation and presentation of data	January-March 2026
	Creating visual representations	Thesis presentation	
	Learnings and insights from the research process	Writing the Discussion and Conclusions chapters	

3.1.4 Research Ethics

This research followed ethical principles, that emphasise conducting studies *for* animals rather than *on* them. The welfare of the cat participants was prioritised throughout the research

process, in line with the principle of **equal consideration of similar interests**, which argues, that harm directed at animals should be regarded with the same seriousness, as harm directed at humans (Singer, 2022). The study also aligns with the **Three Rs** – Replacement, Reduction and Refinement, formulated by Russell and Burch and later updated by Balls (2009). Although, the Three Rs originate in laboratory research contexts, their underlying aim of minimising animal involvement, and preventing unnecessary distress, is relevant to interaction studies involving domestic animals. Biomimetic robots can contribute to these goals, by enabling controlled and repeatable research scenarios, with fewer animal participants, and less intrusive methods (Bierbach et al., 2021).

Beyond the Three Rs, the study followed broader ethical guidance for technology-mediated animal interaction research. Väätäjä (2014) argues that animal welfare should be a central design objective, emphasising the need to understand species-specific behaviour, conduct risk assessments, and account for individual variation in animals' reactions to technology. With this in mind, this study was conducted at cats' own homes, in the presence of their owners. Cats were interacting with the robots freely, so that they could comfortably approach them at their own speed.

Because animals cannot give informed consent, participation decisions must be mediated by a responsible human, who prioritises the animal's wellbeing (Mancini, 2017). Cat owners, therefore, provided informed consent on behalf of their pets, and were encouraged to monitor their behaviour during the interaction sessions. Owners were instructed to stop the session, if their cats showed signs of distress. All interactions were designed to be short, non-invasive, and adaptable to the cats' comfort levels.

These ethical considerations guided the design and implementation of the study to ensure, that the research respected the welfare, autonomy, and individual needs of the cat participants. It could contribute to the advancement of ethically responsible Animal-Robot Interaction research.

3.2 Participants

Since cats are the main focus of this study, they are referred to as participants. Four households (H1, H2, H3 and H4), with one male and one female cat, have taken part in this study. During the first week, cats interacted with one of the robots. In the second week, they had another interaction with the same robot, and additional interaction session with the second

robot, since it was requested by the owners. The sessions were planned this way to see, if cats' approach towards the same robot changes, when the robot is already familiar.

All the cats participating in this study were kept indoor and vaccinated, to ensure their safety. Moreover, the robots have been disinfected between each interaction session with a pet and child friendly anti-bacterial spray. Only neutered cats have been chosen, to minimise the possibility of the hormones influencing their behaviour. The youngest participant was one and a half years old, and the oldest was between five and seven years of age. More precise calculation of the older cat's age was not possible, since she was a rescue cat.

3.2.1 Data Protection and Participants Rights

Human owners were crucial part of the research, since they could provide information about their cats, and consent to the participation in the study, with the best interest of their pets in mind. No personal information of the owners was collected, as they were not the focus of this research. Email and phone numbers served as means of communication between cat owners and the experimenter. Owners also provided their house addresses, since the study was conducted at their homes, for participant comfort. The wellbeing of participants was ensured, and any potential stress of taking part in the study, was minimised.

Upon signing up for the study, owners were informed about data protection and their rights. On top of agreeing for voluntary participation, with the use of online form, owners were asked to sign an informed consent sheet (Appendix 3) before the first interaction session. With that, owners agreed for the study to be conducted at their homes, for the interaction between their pets and robots to be video recorded, and to partake in a semi-structured interview, which would be documented by voice recording. The collected data was stored until 19th of December 2025 online and in physical form and was accessed solely by the experimenter and securely destroyed afterwards. Owners were informed, that they are entitled to resign from the study, request the data to be deleted and withdrawn from data analysis process, without providing any justification.

3.3 Data Collection Methods

The research was carried out in Tampere, during the second and third week of October 2025. The mixed methods of data collection have been used by combining the use of online questionnaire, for quantitative data collection, as well as semi-structured interview and observation, for qualitative results (Tian et al., 2025).

3.3.1 Participants Recruitment

The recruitment of participants was carried out by **convenience sampling method**, which is a technique utilising resources easily accessible to the researcher (MacNealy, 1998). Cat owners, willing to volunteer their cats for the study, have been recruited through Tampere University forum for staff and students on Microsoft Engage platform. Owners have been asked to fill out an online Microsoft Form (Appendix 4), which was tested by the author and two friends, fellow cat owners, before publication. Recipients have been informed about the study and data processing methods, followed by request for initial participation consent. Moreover, owners were asked to provide background information about their cats, including health and vaccination data, to ensure the safety of all participants. They have also been asked to estimate the typical time for cat activity, and whether an interaction session can be arranged within that time; not only to avoid disrupting the daily cycle of cats' rest and play time, but also to make the tests as efficient as possible.

Next, cat owners had a task of rating statements (Appendix 5) regarding social and predatory behaviours of their cats on a five-point **Likert scale**, from *strongly disagree* to *strongly agree* (Rosa et al., 2022).

Finally, owners described the temperament of their cats by selecting one of the personality types from chapter nine of the Behaviour of Domestic Cat 2nd Edition book, where type A has been outlined as *sociable, confident and trusting*, type B as *timid and nervous*, and type C as *active and rather aggressive* (Bradshaw et al., 2012, pp. 171).

3.3.2 Semi-Structured Interview

Semi-structured interview method enables an adjustable setup for data gathering, where interviewer asks pre-defined questions, but can add follow-up questions, to gain an in-depth understanding of each participant individually (Adeoye-Olatunde & Olenik, 2021). This qualitative method of data collection was used in order to understand the unique approaches of cats towards the robots.

Cat owners were asked a series of questions, prior to each interaction session, where they described the current mood and state of their cats, as well as shared predictions about the session. Afterwards, they were asked to evaluate the interaction, by estimating the individual approaches of the cats towards the robot, describing their behaviour and suggesting potential design improvements, that would make the interaction more enjoyable for their pets. Originally, a script for first and second interaction session was developed, however, interview

script for additional interaction session with the other robot was created for the second week of the study, due to owners' interest in the other robot (Appendix 2).

3.3.3 Observation

This method of data collection is particularly useful, when the study subjects cannot provide verbal reports, which is the case in this study (Mazhar et al., 2021). Interactions between cats and robots were video recorded, with the use of a handheld iPhone 11 Pro smartphone, which allowed detail documentation of participants behaviour, by a quick change of camera angle and distance. Video recording was focused on cats and not their owners or households, to ensure anonymity and comfort.

Owners were asked to interpret the behaviour of their cats in real time. A **think aloud method of usability testing**, which normally involves the user describing their thought process while testing a product, has been adapted to provide better insight into cats' reactions to the robot (Nielsen, 2012, Jan 15). It provided a valuable commentary to the video recordings, since the behavioural cues of cats are very subtle. Utilising the knowledge owners have about their cats' individual personalities, contributed to more thorough and accurate analysis of cat behaviours towards the robots, by providing more context.

3.4 Data Analysis Methods

Methods of data analysis, implemented in this research, have been presented below. The following methods have been chosen, to best represent the collected data, and highlight the most crucial aspects of the findings. Data from the interviews has been analysed using affinity diagram and categorised by thematic coding. The behavioural responses of participants have been explored with methodological triangulation, where video recordings, owner interpretations, and ethogram of cat behaviour were confronted. The MEAU framework has been used to gain a better understanding of animals as users in design processes.

3.4.1 Analysis of the Interview Data

Affinity diagramming (Scupin, 1997) serves in organising qualitative data into hierarchical representation, which can be helpful in contextual analysis of interview data, at the starting point of the design process (Lucero, 2015). In this study, the method was implemented, by organising full quotes of owners' answers under the questions that were asked. Since each cat

had a name starting with a different letter, they were used for participant coding, to anonymise the analysed data.

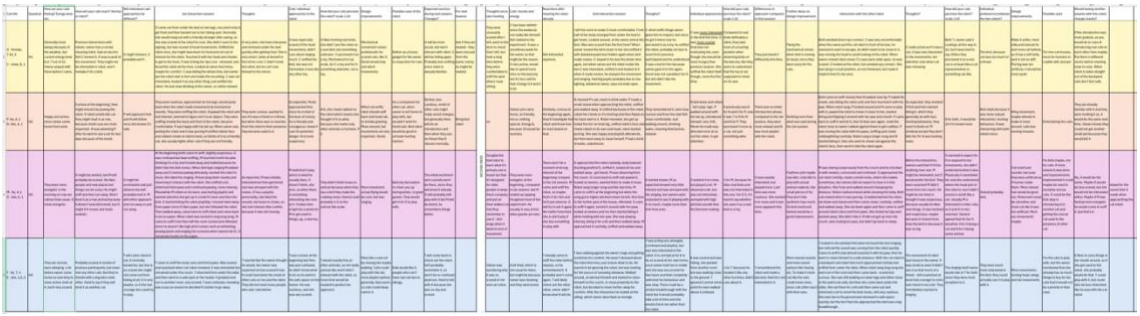


Figure 4. Visualisation of the affinity diagram created for data analysis in this thesis.

In the above affinity diagram (Appendix 6), different colours represent each of the four households (H1, H2, H3, H4), taking part in the study, with one male and one female cat per household. The columns correspond to the main incentive of the questions, which were answered by cat owners, and are provided in full quotation. Due to the interview format being semi-structured, the answers might be a result of a follow-up question. Therefore, instead of providing the full question for each column, only the topic was displayed.

Comparing the answers from different interviews was the first step in discovering, what themes appeared across the study, and allowed for more in-depth data analysis. **Thematic coding** (Holton, 1973), is simply labelling information on the same subject, which enables clear delivery of qualitative findings (Mortelmans, 2025). The following main themes emerged during the data analysis:

Design implications – possible future improvements for each of the robots; ·

State – emotional state of the cats during the interaction; ·

Behaviour – how the cats behaved towards the robots; ·

Perception – how the robots were perceived as by the cats. ·

3.4.2 Analysis of the Behavioural Data

Data triangulation (Denzin, 1970) increases the credibility of findings, by integrating multiple methods or data sources (Meydan & Akkas, 2024). In this research, three types of data sources were incorporated, to create a comprehensive analysis. First, the video recordings of cats interacting with the robots were compared with interpretations of their behaviour, provided by the owners. Then, findings were confronted with an ethogram of cat behaviour

and emotions, created for the purpose of this study, to validate cat responses observed by the experimenter and the owners.

Ethogram (Van Abeelen, 1963) – categorisation of behaviours, displayed by the animal in specific situations (Abdai et al., 2018). A categorisation of behaviours alone, would not have been sufficient for the study, since more context was needed, for understanding cats' approach towards the tested robots. Therefore, the ethogram (Appendix 7) is a categorisation of cat emotions, which can be read based on certain behavioural traits, exhibited by the cats. Visualisations of some of the behavioural cues have been incorporated, to simplify the process of detecting cats' emotions, during the interaction sessions with the robots. It is important to note, that the scientific knowledge and categorisation of cat sociality and behaviour, especially when it comes to emotional responses, is limited, and therefore the accuracy of this ethogram should undergo further testing (Nicholson & O'Carroll, 2021).

The use of ethogram in data analysis, can be helpful for more structured recording of the behaviour, which has occurred during the study (Casarrubea, 2024). In this research, it has been used as a guideline in the analysis of video recordings and owners' interpretations, of the behaviours displayed by their cats, during the interaction sessions. Data from video recordings and interviews, has been confronted with the behavioural categories, described in the ethogram. Not only, did it provide a clear structure for data analysis and presentation of findings, but also validated the observations made by cat owners and the experimenter.

The **Method for Evaluating Animal Usability (MEAU)**, developed by Ruge and Mancini (2019), is a framework designed to assess how effectively animals interact with technology. In this thesis, it has been used in the development of Animal-Centred Design guidelines, which prioritise users' needs and welfare, especially concerning feline species. The MEAU method adapts established UX Goals to account for the sensory, cognitive, and physical characteristics of non-human users. It follows a structured seven-stage process, including understanding the user, the activity and interaction, interpreting interaction design principles from the animal's perspective, identifying relevant usability goals, and using behavioural measures to evaluate usability and create design improvements (Ruge & Mancini, 2019).

4. FINDINGS

This chapter presents the results of the study, categorised thematically by the main topics, emerged from the collected data – approach towards the robots, as well as behavioural and emotional cues, indicating the approach and perception of the robots by cat participants. Design suggestions have also been presented in this chapter. The findings regarding bird-like robot and cat-like robot have been presented separately, and combined towards the end of the chapter, in the Comparison Between Robots section.

4.1 Interaction with Bird-Like Robot

The bird-like robot has been used for two sessions, in two of the households (H1 and H3). O – female, aged between seven and ten years old, and C – 6-year-old male, were the cats living in the H1. In H3 there was a five-year-old female – G, and a four-year-old male – M. The bird-like robot has also been introduced during the second interaction session to cats in H2 and H4, who therefore met the robot only once. Participants in H2 were siblings at four years of age, P – male, and N – female. Finally, in H4 lived T and K – seven years old male, and a one-and-a-half-year-old female.

4.1.1 Approach Towards the Robot

The owner in H1 described O as timid and nervous (type B) and C as sociable, confident and trusting (type A). Despite owner's assessment of the participants' temperaments, C was hiding in a cat house throughout the interaction sessions and did not approach the robot on his own, whereas O made few attempts of getting closer to the bird-like robot. Despite being too scared to leave his hiding spot in the presence of the experimenter, when owner brought the bird-like robot closer to him, C appeared to be unaffected by it. *"He actually didn't pay any special attention to the toy"*.

The cats in the H2, were both assessed by their owner to have type A personality. They seemed comfortable to in the presence of the experimenter, and they approached both robots quite confidently. They were social with the cat-like robot, but the owner expressed a preference with the bird-like robot by saying: *"It was more natural with the bird than with the cat"*.

M and G in H3 also had type A personality, but they approached the robot very differently, as anticipated by the owner – *"G will hunt it, I'm pretty sure. M, he's a bit of a wuss, so I think he might have a look at it and take off, runaway"*. They both approached the robot at the beginning to sniff it. After the initial introduction, M kept his distance, while G played with the robot.

In H4, K – a young female, had type B personality and T – male aged seven, had type A personality, according to the owner assessment. Owner thought the cats were more willing to interact with the bird-like robot – *"Both of them were more interested in the bird robot"*.

4.1.2 Behavioural and Emotional Cues Indicating Cats' Reactions

O came close to the robot to get treats, but was visibly scared of it, facing it all the time and licking her lips nervously. *"O was very alert… She had the very low pose and she quite quickly escaped… back under the bed, even though she sniffed the toy and pushed it with the head when she was eating the kibbles"*. Owner believed that O was scared of the robot moving, more than singing – *"moving of the head is what scares her a lot"*. When the cats met the bird-like robot for the second time, C was more interested in it by smelling it, but O seemed to be more scared. Despite owner's expectations of O's behaviour during the second session – *"O will be more warmer, less alert, she might come to sit with us"*, O did not approach the robot until the experimenter left the room, and was not brave enough to eat the treats, this time around.

Both cats in H2 were cheek-rubbing against the bird-like robot and smelling it. P and N were moving the robot around with their paws and biting it, which are typical hunting and playful behaviours.

The female participant in H3, was playing with the robot, while the male was observing. *"He likes to watch G play… He doesn't really play that much by himself"*. However, he was disturbed by high pitched sounds that the robot made and he left the room. *"He doesn't like singing or whistling or any kind of noises like that"*. G was pawing and biting the robot playfully. Owner noticed that she would like the robot to move around more. *"She definitely thought that this is a toy and it's making noises and it's fun… but I think in the end, she also lost interest because it wasn't actually moving"*.

In H4, K was very shy in the presence of the experimenter and only entered the room during the second study session, interested in the bird-like robot. *"K had enough courage to go and, like, at least check it out a little bit, and T even did some movement with his paw for the first*

time". T played with the robot a little bit, by pawing it. Both cats showed more interest in bird-like robot and were braver in interacting with it.

4.1.3 Perception of the Robot

Owner of participants in H1 was sceptical about them perceiving the robot as a real bird – *"I don't believe they will mistake it to be true bird"*. The first interaction sessions confirmed the owner's expectations. "*C thought it was totally a toy and O thought it was not exactly a toy, but something unknown… neither one thought it was living at all"*. After the second interaction session owner reflected that *"O perceived it more like a robot, something was wrong. She really seems to understand that the toy wasn't supposed to move on itself"*, whereas C viewed it as a toy.

In H2, the owner evaluated the cats' perception of the robot at 8 points, where 1 was *a robot* and 10 was *an animal – "Both of them see it as an object to hunt, a bird"*.

Comparing participants' interaction with real birds and the bird-like robot, owner in H3 thought, that cats treated the robot more as a toy, not a real bird. *"They look at the birds when they're hanging out on the balcony. So, their behaviour was nothing like that when they see real birds. They do that generic clicking sound"*. Cats' perception of the robot on the scale was evaluated at 2.

In H4, the owner evaluated solely the singing of the bird-like robot, and gave it 7 points on the realness scale, reflecting, that it was the most important factor for the cats. *"I think that the sound was, the one that worked, not really how the bird is, because it doesn't move"*.

4.2 Interaction with Cat-Like Robot

Robots have been assigned to households randomly and rotated between the interaction sessions, in a way that ensured safety and sanitation, before being introduced to each of the households. Therefore, following the order, in which bird-like robot has interacted with cats in H1 and H3 twice, and with cats in H2 and H4 only during the second week of conducting the study; the cat-like robot visited H2 and H4 twice and H1 and H3 only for one interaction session.

4.2.1 Approach Towards the Robot

In H1, participants were more scared of the cat-like robot then the bird-like robot. They avoided the robot and did not want to approach it.

Cats in the H2, were friendly towards the robot. *"At the beginning, as I have expected, they were cautious… Then they tried to smell around… to see if it was a threat or a friend"*. They approached the robot quite confidently – *"N is more suspicious, P is generally friendly and courageous, so he goes toward the object and doesn't care if he is dangerous or not"*.

To the surprise of owner in H3, M did not move from the couch at all and paid very little attention in the robot – *"whatever the new thing is, a toy or just an object or whatever, he is usually interested enough to go and sniff it at least once"*. G approached the robot carefully, walking around it and keeping her distance. To summarise the experience, owner said: *"If you brought a real cat to our house, and I think G would approach it in a similar manner… but M would approach it immediately"*.

In H4, K was so scared of the robot, that she escaped the room, but T was curious and approached the robot a couple of times. *"I think that T reacted like I thought he would, but I'm a little bit surprised that K was so scared. I don't understand why… She was scared, even before you took the robot cat out"*.

4.2.2 Behavioural and Emotional Cues Indicating Cats' Reactions

When the owner in H1 moved the robot closer to C, he was visibly uncomfortable. *"He really avoided the direct eye contact, and he spun his head around so that he wouldn't look at it. When I tried to put the toy* (cat-like robot) *a bit closer to him, he started to look for an escape route"*. O looked at the robot but avoided direct eye contact. She was uncomfortable but not threatened, lying in a loaf position in her hiding spot under the bed. *"Her attention rose when the cat moved and made the meowing* (noise)*"*.

Participants in H2 exhibited social behaviour towards the robot and treated it as another cat in some ways. They both sniffed mostly the back end of the robot and the head area, which indicates, that they seemed to understand the shape and physical features of the robot. *"He went around and smelled with the tail up, which means he wanted to introduce himself in the cat language"*. When owner petted the cat-like robot and it started purring, N came to sniff its' head and rubbed her cheek against the robot's face. *"She generally marks* (cheek-rubs) *animals and humans, so probably she sees it* (the robot) *as something alive"*. During the second interaction, N exhibited even more social behaviour. *"N was more friendly because she lied down and then rolled. And this is a sign that 'let's play' in the cat language"*.

In H3, M observed the robot from his safe spot on the couch, close to the owners, and napped a little in a loaf position, after seeing no particular threat from the robot. When the robot was

purring, G approached carefully and sniffed the back of the robot and then came to sniff around its' head and front paws. She was very cautious around the cat-like robot – *"She was very suspicious of it and very hesitant to approach… it may have been the fact that it moved a lot more than the bird or because of the size"*. After the initial introduction, G walked away and licked her lips, as a sign of discomfort. *"She looked a bit like she was worried that the robot would smack her… or make a sudden movement. I think she was expecting it to respond to her movements"*.

In H4, K initially was hiding under the couch, but soon left the room in a low position, moving quickly by the wall, which signified avoidance and stress. *"She is very scared. She's going so low and it's also not typical for her to be that scared, not at home at least"*. T was braver in his attempts to approach the cat-like robot. First, he came to sniff the front of the robot but was surprised and scared by the robot's movement. He observed the robot from under the table close by but soon retrieved to his safe spot on the heater, further away. During the second interaction session, T was more playful and, as owner said, behaved strangely looking up towards the ceiling, but still did not pay much attention to the robot. *"Well, I have to say that he doesn't seem to be very interested in it, but then again, now he is acting really weirdly… Is he hallucinating or something because it looks like he's seeing something that we are not seeing… Maybe playful, but yeah. Not typical behaviour"*. Neither of the participants was interested in interacting with the cat-like robot, during both interaction study sessions, they were, however, interested in the bird-like robot, the one time, that they saw it.

4.2.3 Perception of the Robot

Owner in H1 expressed ambivalent opinions on the cats' perception of the robot. When it comes to O, the owner said, that when the robot made meowing noises and moved, she considered it to be a real cat but also expressed that: *"She would have defended her area, if that was real cat… not threatened, but was making it implicit that this is her area"*. Owner was also unsure of how C perceived the robot saying: *"It's hard to tell if he thinks it's a real cat, or just something that represents a cat, that is tough and scary"*. The owner was also sceptical about future interactions between the cats and the robot – *"I can't see that thing being their friend"*. Nevertheless, the owner rated participants' perception of the robot at 7 points on the realness scale.

At first, the owner in H2 evaluated the cats' perception of the robot at 6 points for N and at 5 for P. After the second interaction session, however, the rating went higher to 8 points for N and 6 for P.

In H3, the perception of the robot was evaluated at 1 for M and 6 for G, although owner brought to attention an interesting aspect: *"If there is a distinction between cat or no cat, I would say it was for 4 for G, and if alive and not alive, I'd say 6"*. Owner summarised participants' impressions on the robot, by saying: *"M did not think it was real, but I think G might have thought that it was real"*.

After the second interaction session, the owner in H4 expressed, that T perceived the robot at 1 point on the scale, by saying: *"I don't know, maybe then it would be something like 1 because he's really not paying attention towards it. It's like a furniture or something like that"*. The owner was unable to evaluate how K perceived the robot, because she was not present during the sessions, too scared to be in the same room as the robot.

4.3 Design Suggestions

As the context in which robotic pets were used in this study, differs from the original purpose, potential design improvements have been developed, to make the robots more suitable for interaction with domestic cats. The functionality of the robotic pets has been analysed, based on observations of cats interacting with robots, made throughout the study, as well as feedback and ideas provided by the owners.

4.3.1 The Design Improvements of the Cat-Like Robot

Possible design improvements for the cat-like robot, have been developed based on the feedback, provided by the owners, who shared their ideas, with their pets' best interests in mind, after observing how the cats interacted with the robot. Some implications have been proposed by the experimenter, through combining owners' feedback, conclusions drawn from the interactions, and knowledge of robotic design, as well as insight into cats' behaviour and characteristics.

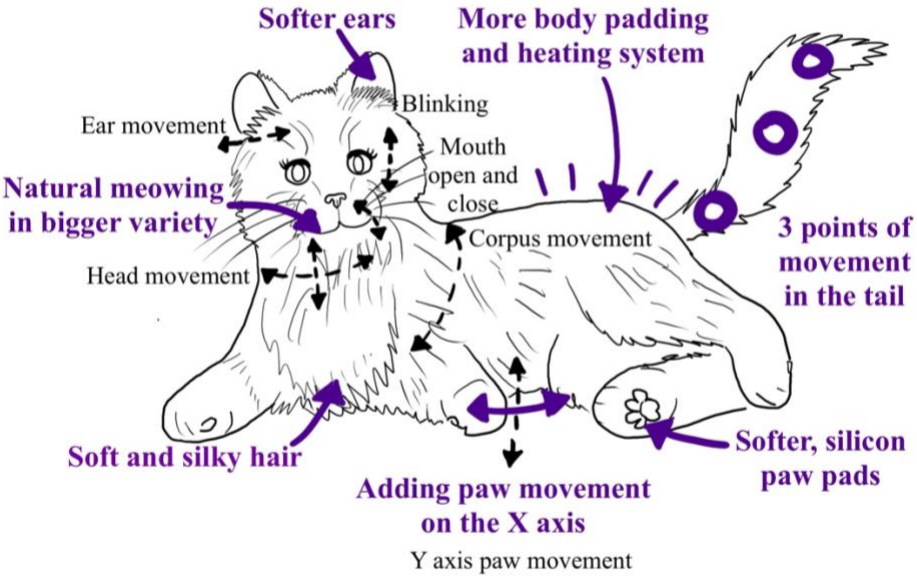


Figure 5. Design suggestions for the cat-like robot *sketched by the author (possible improvements presented in bold text).*

A common design suggestion has been the implementing **more natural sounds** of the cat robot, proposed by three (H1, H3 and H4) out of four owners, who noticed, how unnatural and artificial the sounds were. Owner in H1 made a remark on the purring sounds of the robot, by saying: *"Some cats purr loud, but maybe a bit less loud purring would be more what I expect"*. Owner in H3 suggested using real cat noises, since they seemed synthetic – *"The meows were very artificial and sounded like a human had made them. I would include actual cat sounds"*. Another owner (H4) paid attention to how limited the sounds were. *"I don't know if it would be possible to make the noises to be a little bit more natural… there was meowing and purring, but the cats they could also hiss…"*.

Another common theme was the **overall movement** of the cat-like robot, suggested by the owners in H2, H3 and H4. Owner in H2 said that **mirroring cats' behaviour** by the robot, would create a more natural interaction – *"When the cat smells, it smells back. And then give a sign, like if it* (the cat) *likes it, he* (the robot) *can try to put his head towards the body because that's generally* (how) *cats greet each other"*. Another owner in H3 noticed that the movements were very artificial – *"The amount of movement was good, but it was really artificial. At some point it looked like a cat was malfunctioning"*.

The **tail movement** and the **ear movement** is an important feature in social communications for cats and therefore design improvement suggestions were made in that context. *"The tail is important… like tail up, down, puffed... is showing their mood in general"* (H2). Owners,

rightfully remarked, that improvements in this matter would be very beneficial, for how cats interact with the cat-like robot. *"I was thinking about the ears, because cats react with their ears. Maybe it would then be more, you know, cat-like"* said the owner in H4. Whereas the robot did not have any tail movement programmed in the original settings, there has been some ear movement, but, as the owner in H3 noticed, it was not very natural – *"It was very, like, twitchy movements of the ears. It should be smoother, so it would look more natural to the cats"*.

When it comes to the body of the robot, owner in H4 suggested adding a heating system for **warmth**, so cats could sleep next to the robot in the winter – *"My cats really like the warmness. They would enjoy it if the cat would be warm, so they would sleep next to it"*. Half of the owners (H1 and H3) paid attention to how unnatural robot's **fur texture** felt – *"...I think the fur texture could also be more cat-like and not synthetic"* shared the owner in H3.

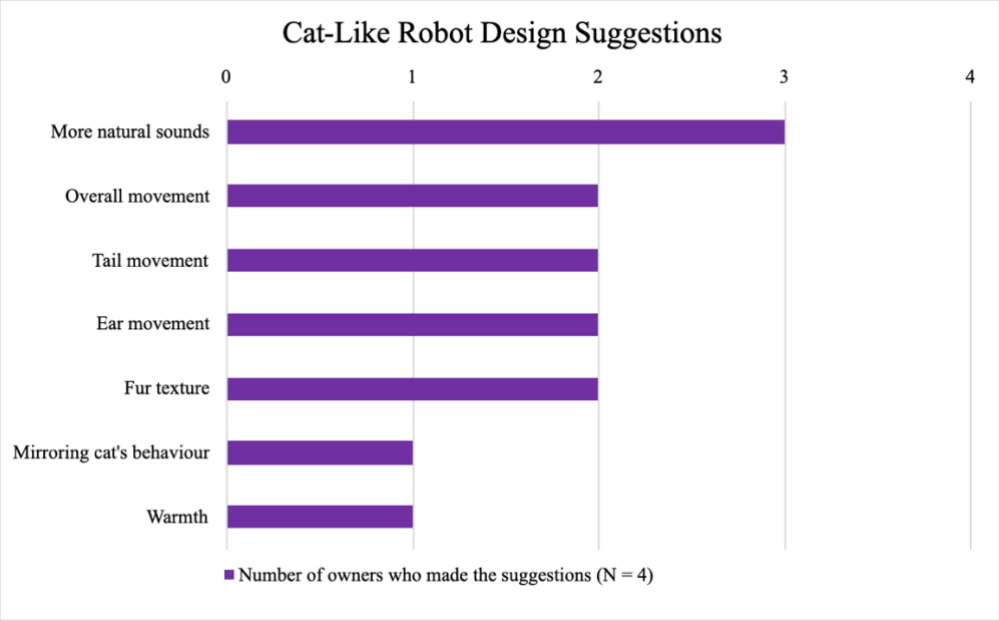


Figure 6. Bar chart with owner suggestions for cat-like robot design improvements.

Owner in H1 suggested improving the fur texture and contributed to the suggestions on more natural sounds of the cat-like robot. The owner in H2 made an interesting suggestion of implementing a mirroring feature into the robot, so that it would respond to the movements and behaviours of the cats during the interaction. That owner also mentioned the importance of the tail movement and said that the robot could generally move around more. Owner in H3 contributed by suggesting more smooth movements, which can count as an overall movement suggestion, ear movement and fur texture improvements, as well as implementing actual cat sounds. In H4, the owner mentioned more natural ear movement and cat sounds, together with

more movement and tail movement. Owner also made a suggestion of implementing a heating system for cats to enjoy sleeping next to the robot in winter.

4.3.2 The Design Improvements of the Bird-Like Robot

The design improvements, presented in the following illustration, are a result of the interactions between cat participants and the bird-like robot. After the interaction sessions, owners, who knew their cats best, provided suggestions, which have been later summarised and analysed by the experimenter, who combined them with own observations.

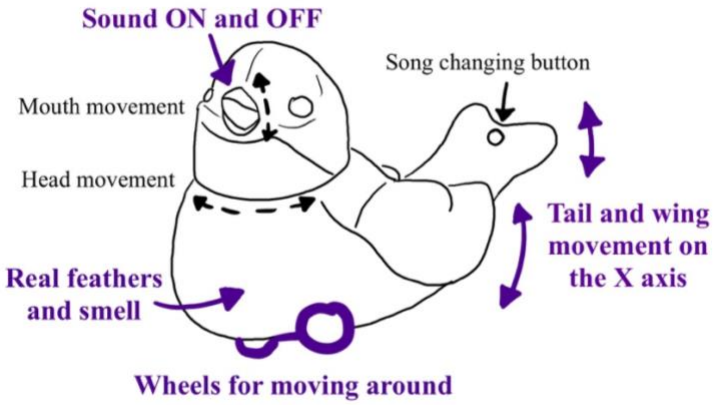


Figure 7. Design suggestions for the bird-like robot *sketched by the author (possible improvements presented in bold text).*

The most common suggestion has been to implement **more movement** in the robot, to make it more exciting for the cats – *"It would be good for G if it had more movement, just as a toy"* said owner in H3. Three out of four owners (H2, H3 and H4) mentioned that their cats would be more interested in playing with the robot if it was moving around, so they could chase it. Owner in H2 proposed adding **wheels**: *"It could have, instead of feet, wheels for easier implementation"*. Two owners, in H2 and H4, added that especially **wing movement** would improve the design, and one of them also mentioned implementing some **tail movement** and overall movement of the robot. *"Maybe, if it's possible to have movements in the wings and tail of the bird and maybe turning the head or something like that"* (H4).

Improving the robot, so that it would make **less mechanical sound** during movement, was brought up by the owner in H1. *"There was that mechanical sound which might be problematic for scared cats… It isn't loud but it's still very unusual"*.

All four owners mentioned that smell is an important factor for their cats, and half of them proposed adding bird **smell** to the robot would be beneficial for making the interaction more

natural – *"the smell cue is very important"* (H2). Three owners, in H2, H3 and H4, suggested adding real **feathers** to the robot's surface, since cats seem to like playing with them and it would also make the robot seem more real to the cats. *"Maybe some feathers would make it definitely more interesting… If it were possible to implement actual animal material into the bird's, you know, surface"* (H3).

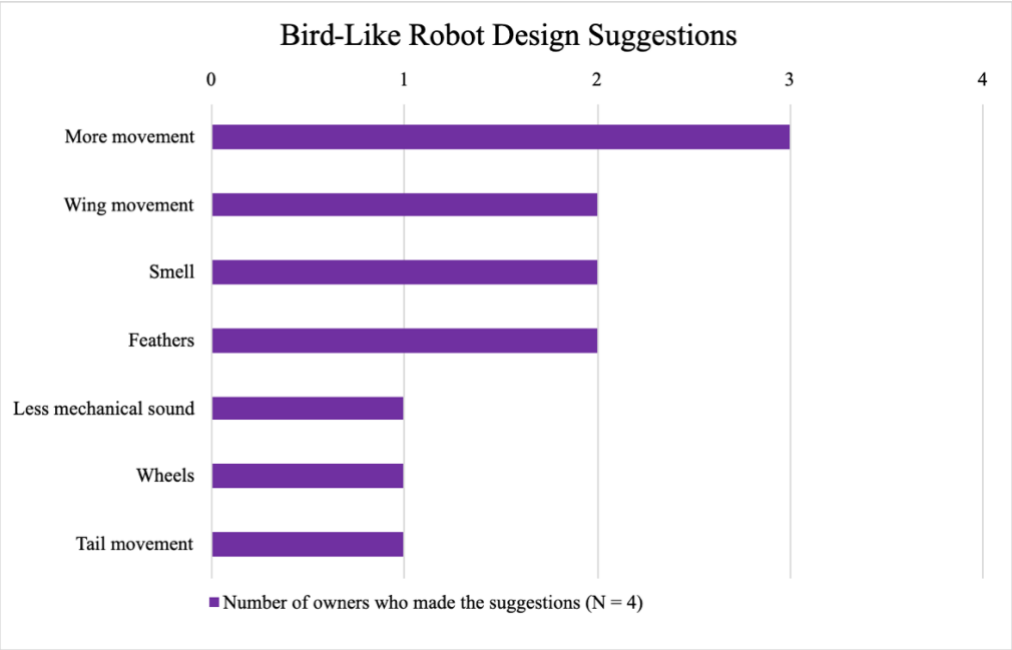


Figure 8. Bar chart with owner suggestions for bird-like robot design improvements.

Owner in H1 made the suggestion of improving the mechanical sound that bird-like robot made while moving and implementing smell of a real bird for cats to perceive it more as an animal. Owner in H2 contributed to the suggestions of more movement, wing movement and wheels, by saying that implementation of wheels would allow the robot to move around more, and wing movement would make it more exciting too. In H3, owner suggested more movement on top of adding feathers to robot's surface and the smell of an actual bird. Owner in H4 apart from suggesting feather implementations, focused on the overall movement, mentioning the tail and wing movement as well.

4.4 Comparison Between the Robots

Across all four households, the bird-like robot has been received more positively than the cat-like robot. Owners in all households explicitly said, that the participants preferred interacting with the bird-like robot over the cat-like robot. *"I think if they had to choose between the bird and cat, they would choose the bird because… cat robot was too* (much of a) *threat"* summarised the owner of C and O in H1. The bird-like robot commonly elicited play and

hunting behaviours, whereas the cat-like robot was more frequently approached as a potential social partner or threat.

Cats assessed as having Type A personalities were generally more likely to interact with both robots than Type B cats, although notable individual differences existed. While owner-assessed personality, appeared to influence interaction willingness, individual behavioural tendencies and situational factors also played an important role. C in H1, for example, has been assessed as type A personality, but did not approach the robots and was not interested in interacting with either of the robots.

Four out of six cats, which have been assessed by the owners to have personality type A were willing to interact with the robot; cats with type B personality were not willing to interact with the robots. In this context the willingness to interact is seen, as showing interest in the robot, and exhibiting some type of social behaviours or hunting behaviours, other than sniffing. In the case of this group of participants, age was not considered to be an influential factor, however, gender has been taken into account. Three out of four females took more initiative when interacting with the robot. Two out of four male cats were significantly less interested in the robot and only in H4, the male participant took more initiative in interacting with the robots.

In conclusion, each robot elicited different behaviour; cats had slightly more social approach towards the cat-like robot and exhibited hunting behaviour towards the bird-like robot. Considering the current stage of design of the robots, as well as the fact that they originally have been created for human users, bird-like robot was preferred by all participants. However, it should be noted that social behaviours of cats are complex, and therefore the mechanisms of the cat-like robot need more careful and detailed revision.

5. DISCUSSION

This chapter discusses the findings of the study, in relation to previous research on Animal-Robot Interaction, feline behaviour, and Animal-Centred Design. The results are interpreted in the context of the research questions, focusing on cats' perception of the robotic pets, the potential of the cat-like robot to facilitate social interaction, and the design implications for future robots. The chapter also examines ethical considerations, arising from the findings, and concludes with the limitations of the study and directions for future research.

5.1 Interpretation of Findings

The following section answers the research questions with a summary of the most important findings from this study, by providing an interpretation of the collected data, and confronting it with the pre-existing body of research in the field of ARI and the behaviour of domestic cats.

5.1.1 How Do Cats Perceive Cat-Like and Bird-Like Robotic Pets? (RQ1)

The findings demonstrate that cats responded differently to the two robotic pets, indicating, that cats distinguished between them, based on the shape, movement patterns, sounds, and species-specific behavioural cues. The bird-like robot consistently attracted more immediate attention from all cat participants, shown by focused staring, ear-flicking, a lowered body posture, and cautious approaching, during the initial interaction. These behaviours were accompanied by widened pupils and tail movements, which can be interpreted as excitement (Kappel et al., 2024). Cats were pawing and biting the bird-like robot in a playful manner; therefore, they could see the robot more as an inanimate object, such as a toy than a real bird. Owner in H1 expressed that *"When they are watching real birds their eyes and ears are pointed towards the bird"*. None of the cats approached the robot in a hunting manner, meaning, there was no pouncing, sneaking or attacking (Bradshaw et al., 2012). *"He likes real birds, likes to watch them, wants to hunt them and showed no interest in this"* said the owner in H3. Moreover, participants did not make a chattering sound, which owners described as a common reaction to birds on TV or observed from a window – *"they do that generic clicking sound"* noticed owner of cats in H3. That sound, however, is made, when prey is out of reach (Bradshaw et al., 2012), so it does not necessarily mean, that cats did not

perceive robot as a prey, especially, because biting and pawing are behaviours exhibited when hunting as much as in playing (Atkinson, 2018). It is very difficult to distinguish between these two, particularly, because study was run on domestic indoor cats, and most of them have never interacted with real prey, making use of their hunting instinct in playing instead. Cats' general perception of the bird-like robot can be summarised followingly: out of 8 cat participants 2 perceived the robot as a bird or prey, 3 as a toy and 3 as an inanimate object. This prediction can be drawn from owners' interpretations, as well as the observations and data analysis made by the experimenter.

In contrast, the cat-like robot elicited slower and more hesitant responses. Cats approached it with caution and tended to maintain a greater physical distance during the early stages of the interaction. Out of the two households (H2 and H4), where two interaction sessions with the cat-like robot were carried out, one became increasingly more comfortable in the presence of the cat-like robot, whereas the other one exhibited similar behaviour during both interactions.

In two of the households with more timid cats (H1 and H4), owners noticed that their pets did not behave typically to meeting another living pet. *"She would have defended her area, if that was real cat"* (H1), and *"I don't think that T was thinking of it as an animal. Because I have seen him behaving with other animals and he is usually doing this hissing and that kind of things"* (H4). The cats nonetheless demonstrated investigative behaviours, such as sniffing different parts of the robot, usually initiating with the back end of the robot, walking around it, and occasionally making brief physical contact. Two cats in H2 rubbed their cheek around the robot's head and one of them, the female, showed her belly to the robot in a playful manner, which is a type of behaviour attributed to social play (Kappel et al., 2024). *"She generally marks* (cheek-rubs) *animals and humans, so probably she sees it as something alive"*. Considering, that cats sniffed the robot around its' back and the face, as well as rubbed their cheeks around robot's face, suggests, that at least the shape of the robot was perceived as cat-like. This behaviour is consistent with feline social interactions described by Trudy Atkinson (2018), as greeting. Out of the 8 cat participants, half perceived the robot as a living cat or a cat-like being, whereas the other half viewed it more as an inanimate or unknown object, according to owners' interpretations.

In conclusion, both robots can facilitate a very basic interaction with the cats at this stage. Further technological improvement and adaptation for cat users can benefit the research of feline behaviour. The bird-like robot can be developed to stimulate hunting behaviour in domestic cats, and the cat-like robot can be adapted for research of social behaviour. The

initial assumption, that one robot would prove to be a better solution for feline interaction was inaccurate, because both robots can be of use in different scenarios.

5.1.2 Can Cat-Like Robot Facilitate a Natural Social Interaction with a Domestic Cat? (RQ2)

The data gathered for this study indicates, that the cat-like robot was able to facilitate interaction with cat participants. At the current stage of technical development and design, fifty percent of the participants displayed small signs of social behaviour towards the robot, such as allorubbing, tail-up greeting, sniffing and invitation to playing (Bradshaw, 2015). It is difficult to confirm, whether those participants considered the robot to necessarily be a living cat, or just some creature vaguely resembling a cat, however, they seemed to understand the physical features of the cat, rubbing their cheeks and sniffing around robot's face, as well as, sniffing back end of the robot. In H3, owner had the following reflection on the interaction between G and the cat-like robot: *"She saw a thing resembling a being like herself, but not the other sensory things like smell and sound"*. Therefore, one of the most prominent findings relates to the absence of subtle social cues, like tail movement and bodily features, such as smell, which are important in feline intra-species communication.

The fact, that robot did not respond or mirror behaviour displayed by the cats, was the main reason for the loss of interest and reservation in exhibiting more social behaviours, since cats often mirror the behaviour of each other in social settings (Martvel et al., 2024). *"When they see no specific reaction to their presence, they see it as an object"* said the owner in H2. The mechanical movements and rigid body, lack of responsiveness from the cat-like robot, as well as its' artificial vocalisations, seemed to be confusing for the cats. They appeared to be unable to interpret the robot's presence in the framework of their usual social behaviour, instead, treating it as an unfamiliar animate object, especially, when it comes to the participants, who were more careful and timider. *"Probably he was thinking that that is something weird but not a real animal"* shared the owner in H4 after observing T interacting with the cat-like robot.

The most reasonable conclusion, considering the variety of approaches displayed by the cats towards the robot, would be that, at this stage of development, the robot can facilitate brief and basic social interaction with more outgoing and friendly cats. That is why further design implications should be considered.

5.1.3 What Design Improvements Would Benefit the Future Research of Cat-Robot Interaction? (RQ3)

The study identified several areas, in which the design of biomimetic robotic pets could be improved, to better support meaningful interaction between cats and robots. The insights were drawn from owner observations, as well as the video-recorded reactions of the cats.

One of the most frequently mentioned aspects, was the embodiment of the cat-like robot, as well as the behavioural realism. Owners felt that its rigid structure and robotic noises contributed to the cats' hesitation. Softening the robot's body, by incorporating fur-like materials and making its movements smoother and flexible, could help create a more realistic appearance. Especially the tail movements, were identified as a potentially valuable adjustment, as it is an important communicative tool in feline social interaction.

Cats were most hesitant when robot's movements were sudden or accompanied by motoric noise. Improvements to movement fluidity, reductions in mechanical sound, and more natural timing of pauses and direction changes would likely support more naturalistic engagement. Owners also expressed the view that, adding species-appropriate vocalisations, could help the robot appear more lifelike. Even though cats rarely use voice to communicate with each other, owners noticed, that their cats reacted to sounds from cat videos but not to the limited vocabulary and artificial sound of robot's meowing.

A further design priority, identified in this study, relates to interaction control. Both the experimenter and the owners noted that having the ability to guide the robot's behaviour in real time, would improve the quality of the interaction. Such control could allow the robot to adapt to the cat's emotional state and behavioural cues, especially during initial encounters, when cats are more sensitive to unexpected stimuli.

The design implications for both cat-like and bird-like robotic pets have been presented in a table format as components of the proposed Cat-Centred Design framework. The table provides additional context for these design aspects and highlights how they contribute to the development of robotic pets that better meet feline users' needs. Each design implication is accompanied by an explanation of its positive impact on cat-robot interaction, demonstrating its contribution to a more Cat-Centred Design.

Table 3. *Cat-like robot design implications*

Design aspect	Design implication	Expected benefit
Vocalisations	Use more natural and varied cat sounds	Increases perceived realism and social engagement
Movement	Implement smoother, less mechanical movements	Reduces hesitation and uncertainty
Social responsiveness	Enable behaviour mirroring and adaptive reactions	Supports reciprocal interaction
Tail and ears	Add realistic tail and ear communication signals	Improves feline-to-robot communication
Fur and warmth	Use more realistic fur and incorporate heating	Encourages proximity and physical comfort
Multisensory cues	Introduce species-appropriate scent cues	Supports within-specific smell recognition and bonding
Real-time control	Adapt robot's behaviour to the individual needs of cat users	Creates safer and more comfortable interaction conditions

This table provides a summary of the design suggestions made in context of the cat-like robot, by synthesising all the data related to the design of this robot. The suggestions made by the owners, based on the interaction between cats and robots, have been analysed and outlined to create a better visualisation of the design contribution. For the same reason, the design suggestions of the bird-like robot, have been presented in the following table.

Table 4. *Bird-like robot design implications*

Design aspect	Design implication	Expected benefit
Locomotion	Enable autonomous movement around the environment	Sustains play and hunting interest
Bird-like behaviour	Add wing, tail, and head movements	Improves behavioural realism
Mechanical noise	Reduce motor sounds	Minimises avoidance and distraction
Surface materials	Incorporate feathers or feather-like textures	Increases attractiveness as a play target
Olfactory cues	Add bird-related scent cues	Enhances prey-related investigation
Multisensory stimulation	Combine movement, sound, texture, and scent	Better supports predatory engagement
Control and customisation	Add real-time control and adaptable features, like sound	Meets the individual needs of cat users

Finally, considerations of animal welfare played a central role in the findings. Cats benefited from a gradual introduction process in which the robot could be approached on the cats' own terms. Providing cats with the possibility of familiarising themselves with the scent of the robots in repeated interaction, as well as minimising the sensory stimulation by conducting research in environment, that is safe and familiar for cat participants, proved to be important in animal research that is ethical and prioritises the welfare of the participants. These findings highlight the need for robotic implementations, that are tailored to the sensory capabilities, behavioural expectations, and emotional needs of feline users.

5.2 Ethical Considerations

This section provides an insight into the ethical aspects of this research, and how the collected findings can contribute to ethical awareness of animal studies, involving domestic cats and biomimetic robots. It also focuses on introducing a potential framework for Cat-Centred Design, which would make the process more ethically responsible and user oriented.

5.2.1 Research Ethics

Research involving animals, should always prioritise their wellbeing and safety. If animal welfare is compromised over the need for data collection, even if the outcomes of the research would contribute to animal welfare, it is not justifiable, to sacrifice the wellbeing of animal participants, in order to gain more knowledge (Mancini & Nannoni, 2022). Therefore, even though an ideal outcome of this research would be, to contribute to the field of animal welfare, by learning more about feline behaviour mechanisms, the wellbeing of the participants remained the main priority.

The study has been conducted in home settings, to provide most natural and safe conditions, as well as, to minimise stress factors for the participants. This method has proven to be a very good solution, and should be commonly adapted, when conducting research on domestic cats. Running the study in participants' homes, proved to be an ethically beneficial approach, as it allowed cats to remain in a familiar environment, and reduced the likelihood of stress associated with transportation or unknown surroundings. However, the findings also demonstrated, that the presence of the experimenter, influenced the behaviour of some participants, making them hesitant or avoiding interaction while an unfamiliar person was present. This highlights the ethical importance of minimising human-related stressors when conducting Animal-Robot Interaction research.

An important finding of this study was the considerable variation in responses between participants. While some cats displayed affiliative or playful behaviours towards the robots, others remained hesitant or avoided interaction altogether. This highlights the ethical importance of recognising individual differences among animals, rather than assuming that a technological solution will be equally suitable for all users. In some cases, the cat-like robot appeared to create uncertainty rather than familiarity, indicating that poorly adapted biomimetic designs, may unintentionally increase stress. Robots allow researchers to create controlled and repeatable situations; however, the findings suggest that increasing

experimental control, should not come at the expense of animal comfort. Participants engaged most naturally when they were free to approach, ignore, or withdraw from the interaction.

Overall, the findings reinforce the view, that ethical Animal-Robot Interaction research must extend beyond preventing physical harm. Cats responded, not only to the physical presence of the robots, but also to subtle behavioural and sensory characteristics. Therefore, future developments should consider emotional comfort, predictability of interaction, and respect for individual differences, as central ethical design requirements. This approach may contribute to the development of robotic systems, that support both scientific inquiry and animal welfare.

5.2.2 Future Framework for Animal-Centric Design

The findings indicate that future designs should prioritise the sensory and behavioural needs of animal users, rather than merely replicating visual appearance. Several of the issues identified by cat owners, including unnatural sounds, rigid movement patterns, and the absence of species-specific social cues, point toward the need for a more comprehensive Animal-Centred Design framework. Because this thesis studies cat users, the following preliminary framework will be adapted to cat users specifically, making it an outline of Cat-Centred Design.

Ruge and Mancini (2019) developed a **Method for Evaluating Animal Usability (MEAU)**, to make sure that design process is prioritising animals' needs, and can be tailored specifically for animal users. The following adaptation of UX Goals has been created to evaluate the interaction between cats and robots and understand, what design improvements should be made in the future.

- **Effectiveness** – robot, that mimics behaviour and features of cats closely enough for them, to consider it as a member of the same species. Are the cats behaving as if they are interacting with another cat?
- **Efficiency** – the resources used for organising the study are distributed efficiently, and participating in the experiment does not require the cat participants and their owners, to put in a lot of time and effort, or change their daily routine. How to compromise between minimising resources and maximising results?
- **Safety** – minimising the stressful factors, by reducing noises of robotic movement and providing gradual introduction, supported by friendly and welcoming behaviours

of the robot upon the first encounter. What part of the experiment or the robot itself cause stress and discomfort to cat participants? How can they be minimised?

- **Utility** – creating a control device, that enables the person overlooking the interaction, to adjust robot's behaviour accordingly to the users' needs, which would make the interaction flow more natural. Would real time control of robot's actions improve the interaction?

- **Learnability** – simplifying the set-up and control of the robot, by providing clear guidelines and intuitive interface, which would allow the owners to introduce the robot to their cats and provide a natural and stressless environment for the users. How can the test be carried out in home setting, without experimenter's presence?

- **Memorability** – experiment can be repeated and replicated easily, with the use of guidelines and documentations. How to ensure that interaction structure is unified, so that its' outcomes can be clearly documented, statistically valid and replicable?

- **Satisfaction** – creating an interaction experiment, that prioritises personal needs of the users, is easy and enjoyable for both the cats and their owners, so that their engagement contributes to the research of cat sociality and the interaction between the feline species and robots. Does the experiment prioritise cats' needs and welfare, while being easy and enjoyable?

It is important to note, that this is a preliminary framework of Cat-Centred Design, and it has not been tested. Implementation of this framework could improve the design process for animal users, by ensuring that their needs are prioritised, and animal welfare is the primary concern of the research. This way animals can be involved in the design process, only at the necessary stages, in order to minimise stressful factors.

5.3 Limitations and Future Work

Due to this research being carried out independently and individually, as a part of master's thesis, the time and resources available have not been extensive. This section addresses the methodological and technical limitations of this study, and how they could be improved in the future, to provide groundwork for the field of a Cat-Robot Interaction.

5.3.1 Methodological Limitations

Participant research was carried out by convenience sampling and therefore involved only eight participants in Tampere city. Even though it was a substantial amount of data collected for this study, expanding the research to more homes, and getting more cats to interact with the robots, would not only provide more quantitative data, but also give more insightful qualitative findings.

In two households (H1 and H4), where one of the cats had a type B personality, owners admitted, that having more time to gradually introduce the robots to participants, would have been beneficial for the cats, who typically took time to get used to new circumstances. The fact that only two out of eight participants were assigned type B personality, and there were no representatives with type C personality, generated unbalanced data, which shows, that more versatile personalities of participants, would be useful in future research. The personality assessment itself could have been carried out by an independent observer. It was assumed, that owners would be most suitable for describing the personality of their cats, since they knew them the best, however, the objectivity has been compromised because of that. Owners knew their cats in the specific context of their everyday life together and did not have much comparison to other cats and their personalities, which could have caused bias.

Lastly, more structured behavioural coding would be beneficial for the validation and standardisation of the findings. The ethograms of cat behaviours and emotions should be developed further, to allow for a better categorisation, of the way in which cats are interacting with the robots. This would also provide a framework for cat-like robot machine learning, to contribute towards more natural movements and adaptable social behaviours of the robot.

5.3.2 Technological Limitations

The robots used in this study were commercially available robotic pets, designed for human users rather than for Animal-Robot Interaction research. As a result, their behaviour did not fully correspond to the sensory and social needs of cats. The cat-like robot displayed limited behavioural responses and was unable to adapt its' actions based on the cats' reactions, which reduced the natural flow of the interaction.

Both robots also lacked several species-specific features that are important in feline communication and perception. The cat-like robot did not provide realistic social cues such as natural vocalisations, tail signalling, scent, or responsive behaviour. Similarly, the bird-like robot was unable to move independently through the environment, limiting opportunities for

more natural hunting behaviours. These limitations likely influenced how the cats perceived and interacted with the robots. Therefore, the findings should be interpreted in the context of the technological capabilities of the specific robots used in this study.

5.3.3 Future Work

Continuing and improving this research, would, first of all, require the consideration of the design implications, suggested in the previous chapter, and adaptation of existing robots for animal users. By integrating smell stimuli, which is a very important cue in feline social interaction and introducing machine learning mechanisms, behaviour-mirroring techniques, as well as developing the robotic movement further, more natural interaction between cats and robots could be achieved.

For better validation of research, a bigger research group should be considered, consisting of cats at different stages of life with wide variety of personality types. Introducing the robots to participants over an extended period of time, could also improve the quality of the findings. By instructing owners, how to independently facilitate interactions between cats and robots, the interfering variable in the form of experimenter's presence could be eliminated. Moreover, more timid cats would have time to gradually get used to the robot, and consequently, an unnecessary stress would be decreased. More detailed analysis and categorisation of cat behaviour, could be later established, based on video recordings and journal entries, provided by the owners.

6. CONCLUSIONS

Despite initial assumptions, that either cat-like or prey-like robot would be more suitable for interacting with domestic cats, this research shown that both robots can be adapted for feline interactions, depending on what behaviour is researched. Participants' approach towards the cat-like robot was more social, than towards the bird-like robot, which was treated more as a toy. After implementing proposed design implications, cat-like robot could be used in the research of feline sociality and bird-like robot could be utilised in the studies of hunting behaviours.

Building on previous research, this thesis established an ethogram of feline behaviours and emotions for the purposes of the study, proposed a categorisation of Animal-Like Robots, and developed a preliminary Cat-Centred Design framework based on the findings. Design implications sketches, for the robotic pets, have been made, to propose future improvements for more cat-centric design. Findings from the study can support more ethical research of animals and utilise technology to gain a better understanding of their needs.

This thesis contributed to establishing groundwork for further Cat-Robot Interaction research, by proposing design suggestions for the robotic pets, used in the study, and introducing a design framework adapted to cat users. Biomimetic robots for feline interactions could be developed, to gain more data on cat sociality and hunting behaviours, which could provide better care for domestic cats and other feline species in captivity. Moreover, including cats as users in design processes and adapting UX Goals to their needs, will help facilitate the development of technologies, that can really improve the life of domestic cats and their owners, whether it is robotic toys, caregiving robots or biomimetic robots for interaction research.

More studies of domestic cats should be done. Continuing the research, can really improve the wellbeing of feline species by learning more about their behaviour and sociality to provide better care for them. Cats are severely understudied, compared to other domestic pets, such as dogs. The research of domestic cats can be done in a safe and comfortable environment of their homes, so that the knowledge and awareness of cat behaviours and sociality is growing. As humans, it is our responsibility to use the technological advancements, to take care of beings that are dependent on us and provide the best living conditions to our pets.

REFERENCES

Adams, C., Rahman, M. (2021) Design and Development of an Autonomous Feline Entertainment Robot (AFER) for Studying Animal-Robot Interactions. *SoutheastCon 2021*, Atlanta, GA, USA, 2021, pp. 1-8. https://doi.org/10.1109/SoutheastCon45413.2021.9401864

Adeoye-Olatunde, O. A., Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. *Journal of American College of Clinical Pharmacy*. 2021; 4: 1358-1367. https://doi.org/10.1002/jac5.1441

Abdai, J., Miklósi, Á. (2024) Ethology: The Science of Animal Behaviour. *An Introduction to Ethorobotics*, Taylor & Francis Group, pp. 3–92. https://doi.org/10.4324/9781003182931-2

Abdai, J., Korcsok, B., Korondi, P. & Miklósi, Á. (2018). Methodological challenges of the use of robots in ethological research. *Animal Behavior and Cognition, 5*(4), pp. 326-340. https://doi.org/10.26451/abc.05.04.02.2018

Abdulbaqi, A. S., Panessai, Y., Abed, T. H., Mohameed, O. J., Shawqui, O. S., Sulaiman, B. H., Mohammed, M. K., Jassim, A. S., Jabur, Y. K., Abd alla I. H., Nejrs, S. M., Alsultan Q. H. & Khalaf, H. A. (2023). Design and fabrication of bio-inspired robotic systems for developed mobility and functionality in unstructured environments. *KHWARIZMIA*, pp. 46-62. https://doi.org/10.70470/KHWARIZMIA/2023/005

Ageless Innovation, (n.d.). Lifelike Robotic Pets for Seniors. https://joyforall.com/?srsltid=AU7gw4WF1bjP24EEXd-CdIJDVa10yj-rILkHbXF_yXa1mMzUeLC2yF4V

Angela, S., Tiomar, J., Sudijanto, J. A. & Widianto, M. H. (2024). IoT-Enabled Systems for Automated Cat Care: A Comprehensive Literature Review. *6th International Conference on Cybernetics and Intelligent System (ICORIS) IEEE*., pp. 1-6. https://doi.org/10.1109/ICORIS63540.2024.10903944

Atkinson, T. (2018). Social, Feeding and Behaviour in: Practical Feline Behaviour. Understanding Cat Behaviour and Improving Welfare, pp. 42-51. *Clinical Animal Behaviourist*, ISBN: 978-1-78064-783-8, UK. https://doi.org/10.1079/9781780647838.0042

Balls, M. (2009). The Sources, Incidence, and Removal of Inhumanity. In: The Three Rs and the Humanity Criterion. An abridged version of The Principles of Humane Experimental Technique by W.M.S. Russell and R.L. Burch. *Fund for the Replacement of Animals in Medical Experiments*. https://doi.org/10.14573/altex.2010.2.144

Bierbach, D., Francisco, F., Lukas, J., Landgarf, T., Maxeiner, M., Romanczuk, P., Musiolek, L., Hafner, V. V. & Krause, J. (2021). Biomimetic robots promote the 3Rs Principle in animal testing. *The 2021 Conference on Artificial Life*, pp. 36-38. https://doi.org/10.1162/isal_a_00375

Böhlen, M. (2000). More Robots in Cages: Exploring Interactions Between Animals and Robots. *Robotics 2000*. https://doi.org/10.1061/40476(299)26

Bradshaw, J., Casey, R. & Brown, S. (2012). The Behaviour of Domestic Cat 2nd Edition. *CABI*, ISBN: 978-1-84593-992-2.

Bradshaw, J. (2015). Sociality in cats: A comparative review. *Journal of Veterinary Behavior: Clinical Applications and Research* 11, pp. 113-124. https://doi.org/10.1016/j.jveb.2015.09.004

Bradwell, H. L., Winnington, R., Thill, S. & Jones, R. B. (2021). Morphology of socially assistive robots for health and social care: A reflection on 24 months of research with anthropomorphic, zoomorphic and mechanomorphic devices. In *2021 30th IEEE International Conference on Robot & Human Interactive Communication*, pp. 376-383. https://doi.org/10.1109/RO-MAN50785.2021.9515446

Burge, T. (2022) Perception: First Form of Mind. *Oxford University Press*. https://doi.org/10.1093/oso/9780198871002.001.0001

Casarrubea, M. (2024). Physiology, patterns and behavior. *Physiology & Behavior* 285, 114655. https://doi.org/10.1016/j.physbeh.2024.114655

Cecchetti, M., Crowley, S. L. & Macdonald, R. (2020). Drivers and facilitators of hunting behaviour in domestic cats and options for management. *Mammal Review* 51(3), pp. 307-322. https://doi.org/10.1111/mam.12230

Cecchetti, M., Crowley, S. L., Wilson-Aggarwal, J., Nelli, L. & Macdonald, R. (2021). Spatial behavior of domestic cats and the effects of outdoor access restrictions and interventions to reduce predation of wildlife. *Conservation Science and Practice*, 4(2). https://doi.org/10.1111/csp2.597

Chen, Y. & Elshakankiri, M. (2020). Implementation of an IoT based Pet Care System. *The Fifth International Conference on Fog and Mobile Edge Computing (FMEC)*, pp. 256-262. https://doi.org/10.1109/FMEC49853.2020.9144910

Crowell-Davis, S. L., (2007). Cat Behaviour: Social Organization, Communication and Development. In I., Rochlitz (Eds.) *The Welfare Of Cats. Animal Welfare*, Vol. 3. Springer. https://doi.org/10.1007/978-1-4020-3227-1_1

Dean, J. (1998). Animats and what they can tell us. *Trends in Cognitive Sciences*, Vol. 2, Issue 2, pp. 60-67, ISSN 1364-6613. https://doi.org/10.1016/S1364-6613(98)01120-6

Denzin, N. K. (1970). The research act: a theoretical introduction to sociological methods. *Aldine Publishing Company*, ISBN: 0-202-30121-4.

Díaz-Boladeras, M. (2023). Bond formation with pet-robots: An integrative approach. *Current Psychology* 42, 2591–2608. https://doi.org/10.1007/s12144-022-03792-7

Romano, D. & Stefanini, C. (2025). Animal–robot interaction induces local enhancement in the Mediterranean fruit fly Ceratitis capitata Wiedemann. *Bioinspiration & Biomimetics*, 20(3). https://doi.org/10.1088/1748-3190/adbb42

Ericsson, K. A. & Simon, H. A. (1990). Verbal Reports as Data. *Psychological Review*, Vol. 87, No. 3, pp. 215-251. https://doi.org/10.1037/0033-295X.87.3.215

Gao, Z., Shi, Q., Fukuda, T., Li, C. & Huang, Q. (2019). An overview of biomimetic robots with animal behaviors. *Neurocomputing* 332, pp. 339-350. https://doi.org/10.1016/j.neucom.2018.12.071

Guerra, S., Rosa, C., Sousa, L., Neves, A., Pestana, G., Hernández, M. J., Losada, R., Pires, S. & Ribeiro, O. (2022). The Use of Robotic Pets by Community-Dwelling Older Adults: A Scoping Review. *International Journal of Social Robotics*, 14:1481–1492. https://doi.org/10.1007/s12369-022-00892-z

Halloy, J., Sempo, G., Caprari, G., Rivault, C., Asadpour, M., Tâche, F., Said, I., Durier, V., Canonge, S., Amé, J. M., Detrain, C., Correll, N., Martinoli, A., Mondada, F., Siegwart, R. & Deneubourg, J.L. (2007). Social Integration of Robots into Groups of Cockroaches to Control Self-Organized Choices. *Science* 318, 1155-8. https://doi.org/10.1126/science.1144259

Han, I. & Witzman, S. (2023). Internet of Robotic Cat Toys to Deepen Bond and Elevate Mood. *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI '23 Companion)*, pp.791-794. https://doi.org/10.1145/3568294.3580183

Holton, G. (1973). Thematic Origins of Scientific Thought. Kepler to Einstein. *Harvard University Press*, ISBN: 0-674-87746-2.

Humphrey, T., Proops, L., Forman, J., Spooner, R. & McComb, K. (2020). The role of cat eye narrowing movements in cat–human communication. *Scientific Reports* 10, 16503. https://doi.org/10.1038/s41598-020-73426-0

Ines, M., Ricci-Bonot, C. & Mills, D. S. (2021). My Cat and Me—A Study of Cat Owner Perceptions of Their Bond and Relationship. *Animals*, *11*(6), 1601. https://doi.org/10.3390/ani11061601

Kim, J. H., Choi, S. H., Kim, D., Kim, J. & Cho, M. (2009). Animal-Robot Interaction for pet caring. *2009 IEEE International Symposium on Computational Intelligence in Robotics and Automation - (CIRA)*, Daejeon, Korea (South), pp. 159-164. https://doi.org/10.1109/CIRA.2009.5423214

Landgraf, T., Gebhardt, G. H. W. & Bierbach, D. (2021). Animal-in-the-Loop: Using Interactive Robotic Conspecifics to Study Social Behavior in Animal Groups. *Annual Review of Control, Robotics, and Autonomous Systems* 4:487-507. https://doi.org/10.1146/annurev-control-061920-103228

López-González, A., Tejada, J. C. & López-Romero, J. (2023) Review and Proposal for a Classification System of Soft Robots Inspired by Animal Morphology. *Biomimetics*, 8, 192. https://doi.org/10.3390/biomimetics8020192

Lucero, A. (2015). Using Affinity Diagrams to Evaluate Interactive Prototypes. In J., Abascal, et al. (Eds.) *Human-Computer Interaction. INTERACT 2015*. Vol. 9297. Springer. https://doi-org.libproxy.tuni.fi/10.1007/978-3-319-22668-2_19

MacNealy, M. S. (1998). Strategies for Empirical Research in Writing. *Pearson*, ISBN 9780205272532.

Mancini, C. (2017). Towards an animal-centred ethics for Animal–Computer Interaction. *International Journal of Human-Computer Studies*, Vol. 98, pp. 221-233. https://doi.org/10.1016/j.ijhcs.2016.04.008

Mancini, C. & Nannoni, E. (2022). Relevance, Impartiality, Welfare and Consent: Principles of an Animal-Centered Research Ethics. *Frontiers in Animal Science*, Vol. 3. https://doi.org/10.3389/fanim.2022.800186

Martvel, G., Scott, L., Florkiewicz, B., Zamansky, A., Shimshoni, I. & Lazebnik, T. (2024). Computational investigation of the social function of domestic cat facial signals. *Scientific Reports* 14, 27533. https://doi.org/10.1038/s41598-024-79216-2

Mazhar, S. A., Anjum, R., Anwar A. I. & Khan, A. A. (2021). Methods of Data Collection: A Fundamental Tool of Research. *Journal of Integrated Community Health*, 10(1), pp. 6-10. https://doi.org/10.24321/2319.9113.202101

McGrath, A. P., Horschler, D. J., & Hancock, L. (2024). Feline Cognition and the Role of Nutrition: An Evolutionary Perspective and Historical Review. *Animals*, *14*(13). https://doi.org/10.3390/ani14131967

Meydan, C. H. & Akkas, H. (2024). The Role of Triangulation in Qualitative Research: Converging Perspectives. In A., Elhami, A., Roshan, H., Chandan (Eds.) *Principles of Conducting Qualitative Research in Multicultural Settings, IGI Global*, pp. 101-132. https://doi.org/10.4018/979-8-3693-3306-8.ch006

Mortelmans, D. (2025). Thematic Coding. In: *Doing Qualitative Data Analysis with NVivo. Springer Texts in Social Sciences. Springer, Cham*. https://doi.org/10.1007/978-3-031-66014-6_8

Nielsen, J. (2012, Jan 15). Thinking Aloud: The #1 Usability Tool. *Nielsen Norman Group*. https://www.nngroup.com/articles/thinking-aloud-the-1-usability-tool/ (accessed: Oct 15, 2025)

Norman, D., Miller, J. & Henderson, A. (1995). What You See, Some of What's in the Future, And How WeGo About Doing It: HI at Apple Computer. In *Conference Companion on Human Factors in Computing Systems* (CHI '95). https://doi.org/10.1145/223355.223477

Oliveira, R. F., Bshary, R. (2021). Expanding the concept of social behavior to interspecific interactions. *Ethology, 127*(10), 758–773. https://doi.org/10.1111/eth.13194

Preece, J., Rogers, Y. & Sharp, H. (2002). Interaction Design: Beyond Human-Computer Interaction. *John Wiley & Sons, Inc*., ISBN: 0-471-49278-7.

Qin, M., Huang, Y., Stumph, E., Santos, L. & Scassellati (2020). Dog Sit! Domestic Dogs (Canis familiaris) Follow a Robot's Sit Commands. *ACM/IEEE International Conference on Human-Robot Interaction*, pp. 16-24. https://doi.org/10.1145/3371382.3380734

Ray, L. C. (2021). KOMI: smart toy for feline pets. *ACM Interaction Design and Children Conference*. https://hdl.handle.net/2031/8c8df898-9151-44fb-8982-82bc6bec96cc

Rey, W. P. & Rey, K. W. J. D. (2024). PUSPIN: Redefining Cat Care with an IoT-Enabled Smart Cat Litter Box Management System. In *2024 4th International Conference on Computer Communication and Information Systems (CCCIS)*, pp. 22-27. https://doi.org/10.1109/CCCIS63483.2024.00012

Rosa, L., Manaces, E. & Luis, F. (2022). Indeterminate Likert Scale in Social Sciences Research. *International Journal of Neutrosphic Science*, Vol. 19, Issue 1. https://doi.org/10.54216/IJNS.190125

Ruge, L. & Mancini, C. (2019). A method for evaluating animal usability (MEAU). In Proceedings of the *Sixth International Conference on Animal-Computer Interaction*, pp. 1-12. https://doi.org/10.1145/3371049.3371060

Scanes, C. G. (2018). Animal Perception Including Differences with Humans. In C. G., Scanes & S. R., Toukhsati (Eds.) Animals and Human Society. *Academic Press*, pp. 1-11. https://doi.org/10.1016/B978-0-12-805247-1.00001-0

Schmickl, T. & Romano, D. (2024). Robots and animals teaming up in the wild to tackle ecosystem challenges. *Science Robotics*, 9(96). https://doi.org/10.1126/scirobotics.ado5566

Schneiders, E., Benford, S., Chamberlain, A., Mancini, C., Castle-Green, S., Ngo, V., Farr, J. R., Adams, M., Tandavanitj, N. & Fisher, J. (2024). Designing Multispecies Worlds for Robots, Cats, and Humans. *Proceedings of the CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3613904.3642115

Scupin. R. (1997). The KJ Method: A Technique for Analyzing Data Derived from Japanese Ethnology. Human Organization 56(2), pp. 233-237. https://doi.org/10.17730/humo.56.2.x335923511444655

Shi, Q., Ishii, H., Miyagishima, S., Konno, S., Fumino, S., Takanishi, A., Okabayashi, S., Iida, N. & Kimura, H. (2010). Development of the hybrid wheel-legged mobile robot WR-3 designed to interact with rats. *2010 3rd IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechatronics, BioRob 2010*, pp. 887–892. https://doi.org/10.1109/BIOROB.2010.5627719

Shi, Q., Ishii, H., Miyagishima, S., Konno, S., Fumino, S., Takanishi, A., Okabayashi, S., Iida, N. & Kimura, H. (2011). Development of a Hybrid Wheel-Legged Mobile Robot WR-3 Designed for the Behavior Analysis of Rats. *Advanced Robotics*, No. 25, pp. 2255–2272. https://doi.org/10.1163/016918611X603819

Shi, Q., Ishii, H., Kinoshita, S., Konno, S., Fumino, S., Takanishi, A., Okabayashi, S., Iida, N. & Kimura, H. (2013). A rat-like robot for interacting with real rats. *Robotica, 31*. https://doi.org/10.1017/S0263574713000568

Singer, P. & Tse, Y. F. (2022). AI ethics: The case for including animals. *AI and Ethics* 3, pp. 539-551. https://doi.org/10.1007/s43681-022-00187-z

Stella, J. (2021). Behavioural Biology of the Domestic Cat. In K., Coleman, S., J., Schapiro (Eds.), *Behavioural Biology of Laboratory Animals* (1st ed., pp. 223-241), CRC Press. https://doi.org/10.1201/9780429019517

Sun, S. & Vega, K. (2023). cirCAT: Cat Centered Smart Home System and Veterinary Complementary Devices. In *The Tenth International Conference on Animal-Computer Interaction (ACI '23)*. https://doi.org/10.1145/3637882.3637901

Sung, W. (2024) Senses and communication. In *Feline Behavior and Welfare*, pp. 3-19. https://doi.org/10.1016/B978-0-323-99868-0.00021-2

Tamborini, M. (2023). The elephant in the room: The biomimetic principle in bio-robotics and embodied AI. *Studies in History and Philosophy of Science*, Vol. 97, pp. 13-19. https://doi.org/10.1016/j.shpsa.2022.11.007

Tian, L., Wu, T. L. Y., Robinson, N., Carreno, P., Chan, W. P., Sakr, M., Abdi, E., Croft, E. A. & Kulic, D. (2025). Qualitative and Mixed-Methods Evaluation for HRI. In *Experimental Methodology for Human-Robot Interaction* (1st ed., Vol. 1, pp. 133–148). CRC Press. https://doi.org/10.1201/9781032693682-13

Utture, O., Mane, N. S., Varute, S. S. & Waingade, A. B. (2017). Multidisciplinary Technology of Animatronics: A Review. *Asian Review of Mechanical Engineering*, *6*(2), 4–7. https://doi.org/10.51983/arme-2017.6.2.2435

Väätäjä, H., Tapio, S. & Häkkilä, J. (2023). Exploring Dogs' Reactions when Encountering Delivery Robots in Urban Environment. *26th International Academic Mindtrek Conference (Mindtrek '23)*, Tampere, Finland. ACM, New York, NY, USA. https://doi.org/10.1145/3616961.3617805

Väätäjä, H. (2014). Animal Welfare as a Design Goal in Technology Mediated Human-Animal Interaction. *Workshops on Advances in Computer Entertainment Conference*. Association for Computing Machinery, New York, USA, Article 6, pp. 1–8. https://doi.org/10.1145/2693787.2693797

Vepa, R. (2009). Biomimetic Robotics, *Cambridge University Press*. https://doi.org/10.13140/2.1.1570.8484

Walter, W. G. (1950). An Imitation of Life. *Scientific American*, Vol. 182, No. 5, pp. 42–45. https://doi.org/10.1038/scientificamerican0550-42

Webber, S., Cobb, M. L. & Coe, J. (2022). Welfare Through Competence: A Framework for Animal-Centric Technology Design. *Frontiers in Veterinary Science*, 9:885973. https://doi.org/10.3389/fvets.2022.885973

Winfield, A. (2024). Evolutionary robotics as a modelling tool in evolutionary biology. *Frontiers in Robotics and AI*, 11:1278983. https://doi.org/10.3389/frobt.2024.1278983

Zamansky, A., Bleuer-Elsner, S., Masson, S., Amir, S. & Magen, O. (2018). Effects of anxiety on canine movement in dog-robot interactions. *Animal Behaviour and Cognition*, 5(4), pp. 380-387. https://doi.org/10.26451/abc.05.04.05.2018.

APPENDICES

Appendix 1: The first stage of the interview questions.

Appendix 2: Final interview script.

Appendix 3: Informed consent form.

Appendix 4: Microsoft Form.

Appendix 5: Scale on social and predatory behaviours of cat participants.

Appendix 6: Affinity Diagram.

Appendix 7: Ethogram.