URBAN ECHOES

FOSTERING ENGAGEMENT WITH URBAN AVIAN WILDLIFE THROUGH AESTHETIC EXPERIENCE

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MASTER'S THESIS

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ABSTRACT

Urbanisation continues to distance people from nature, reducing everyday encounters with wildlife and weakening ecological awareness.

This thesis investigates how a mobile application, *Urban Echoes*, can foster engagement with urban avian wildlife through aesthetic, multisensory interaction. Birds were chosen as the focal point for the application due to their abundance in urban environments and their rich vocalisations. The application was developed to deliver a location-based auditory map of bird sounds. The app was tested over one week with 11 participants in urban and suburban environments.

The application demonstrated a strong impact on participants' sonic and visual awareness of birds, enhancing their knowledge of bird species, calls, names, and appearances. Several participants also began identifying where certain birds were typically found.

Beyond individual engagement, the project uncovered broader design implications for location-based audio applications. Notably, it highlighted the importance of alignment between the auditory and visual environment; when these elements were not in harmony, users experienced a sense of dissonance. This finding underlines the value of designing for a cohesive, multisensory experience.

Additionally, the study revealed implications related to the public acceptability of speech interfaces. Many users reported discomfort when using the speech interface in public spaces, expressing that it drew unwanted attention and made them feel self-conscious.

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LISTINGS

ACRONYMS

HCI	Human Computer Interaction
SHCI	Sustainable Human-Computer Interaction
SID	Sustainable Interaction Design
SDG	Sustainable Development Goals
UML	Unified Modelling Language
RtD	Research trough Design
ACI	Animal Computer Interaction
AAR	Augmented Acoustic Reality
TTS	Text-to-speech
UML	Unified Modeling Language

0 FOREWORD

0.1 GENERATIVE AI DECLARATION

For this thesis, I have used generative AI as a programming aid. The models used, in order of magnitude, are Claude 3.7 Sonnet, GPT-3 and GPT-4 in the form of GitHub Copilot, and ChatGPT-4. All three were used to provide suggestions and improvements to the codebase, as well as for code generation and completion. ChatGPT was additionally used for grammar checking and creating BibTeX citations for websites, using prompts similar to the following: *https://www.inaturalist.org/ Can you create a BibTeX citation for this website?*. Lastly, I used ChatGPT to translate Danish evaluation responses. After translation, I reviewed the resulting text to ensure accuracy. Both the original and translated versions can be found in Appendix C.1.

0.2 ADDITIONAL TOOLS

The report is written in LaTeX using the Overleaf service. Furthermore, I used Writefull and Grammarly for grammatical suggestions, both on free trial versions. For coding, I used the Visual Studio Code editor along with extensions for Flutter development, PgAdmin4 as a graphical management tool for PostgreSQL, and the Android APK from Android Studio was used to run emulators during parts of development. My private GitHub account was used for source control, as it provided better integration with Microsoft Azure than my AU GitLab account. Lastly, the PlantUML Visual Studio Code extension[73] was used for creating the UML diagrams.

0.3 ACKNOWLEDGMENTS

I would like to thank my supervisor, Peter Gall Krogh, for his guidance throughout the project. His suggestions, advice, and enthusiasm have been invaluable during the development and creation of this master's thesis. I am also grateful to all those who participated in the evaluations. Additionally, I would like to thank Morten S. Riis and Marie Højlund for taking the time to meet with me and share their insights on the sonic aspects of the project. Lastly, I want to thank Magnus Lasse Lund Bentsen, with whom I conducted the initial project work that laid the foundation for this thesis.

1 INTRODUCTION

1.1 URBAN ECHOES: AN AUDITORY MAP EXPERIENCE FOR AVIAN ENGAGEMENT

In this thesis, I explore *Urban Echoes*, an auditory map designed to engage users with their local avian wildlife through aesthetic interaction. I detail the application's creation, design decisions, and technical implementation, while situating it within existing research. Finally, I present an evaluation of the system and its outcomes and discuss potential directions for future work.

The *Urban Echoes* application is a continuation of a previous concept developed in a 10 ECTS project on more than human-centred design [22] that I conducted together with Magnus Lasse Lund Bentsen, a fellow IT product development master's student, last semester. The 10 ECTS project ended with a report and a rough prototype serving as a very first iteration of *Urban Echoes*, which can be found in Appendix A.1 and Appendix A.2, respectively. However, the continuation into a master's thesis has seen many alterations in the concept of *Urban Echoes*; as such, the original work is not required to understand the concept. None of the code from the 10 etc project was used for this master thesis project.

1.1.1 Application overview and design

Urban Echoes is an Android application developed in *Flutter* [32] that consists of two primary activities: the *Observer* and the *Listener*. These are designed to function independently, allowing users to choose whether they want to use one, the other, or both simultaneously at any given time. The visual interface is intentionally kept minimal to encourage users to focus on their surroundings rather than on their phone screens.

To help understand how the application works, I will first present the two activities. Users can make sightings or observations by seeing or hearing birds in their immediate environment. The user records an observation by clicking the microphone button in the application, as seen in Figure 1.1a, and speaking the name of the observed bird. This prompts the application to respond by asking for confirmation, presenting a confirmation card (Figure 1.1b) along with an audio prompt asking the user whether this was the bird the user saw.

If the user responds "ja" (yes), the observation is saved and uploaded to a central database. A confirmation card is then displayed (Figure 1.1c), and a recorded message informs the user that the observation was successfully uploaded. Each observation includes the common and scientific names of the birds, as well as the geospatial location, date, and time of day.

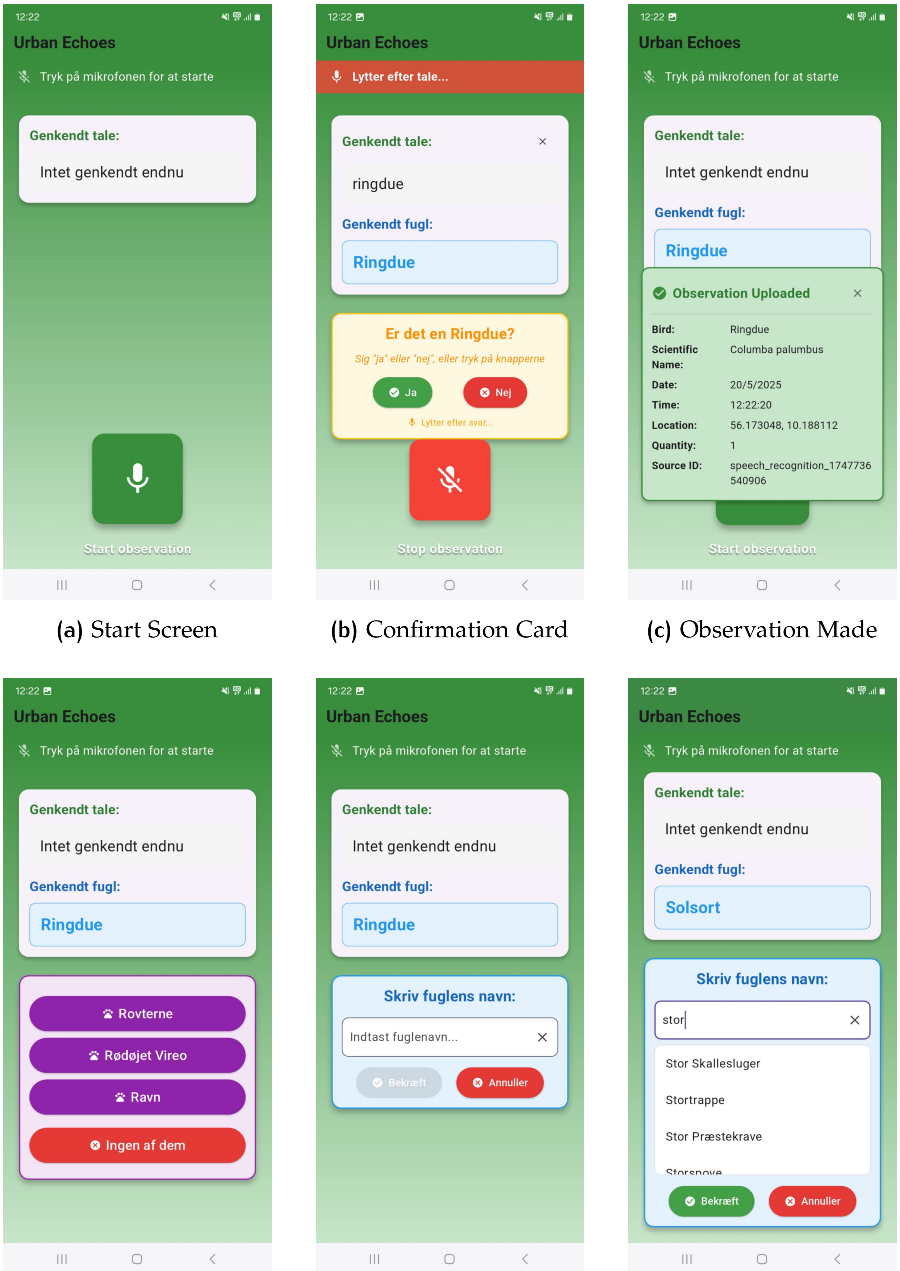
If the application recognises a different bird than the one the user said, the user can respond with "nej" (no). The application will then ask if the user meant one of the following birds, presenting the most likely alternatives based on what it heard, as illustrated in Figure 1.1d. If the correct bird is not among the suggested options, the user can click "ingen af dem" (none of them). This will open a search bar where the user can manually enter the name of the observed bird, as shown in Figure 1.1e. This is considered a last resort, as the application is primarily designed for voice-based interaction.

The *Listener* activity allows users to explore the auditory map created from uploaded observations. Except for those the user has already loaded, all observations are fetched from the database at startup. Each observation is represented by a point on the map, located at the position where it was recorded. Each point has a radius of 50 meters, and the audio associated with it increases in volume as the user approaches the centre of the observation.

This functionality is achieved using the phone's GPS. If the user has moved more than 2 meters and the last update was more than 3 seconds ago, the app updates the location. It then checks whether the user is within the radius of one or more observation points and plays the corresponding sound files. These are spatialized to the left or right ear, depending on the user's position relative to the observation point.

Observation points can overlap, and the system supports the simultaneous playback of up to five observations. This allows users to move through the city and experience a layered soundscape composed of bird observations made by themselves and other users. The design process of the application, as well as the design choices and changes, will be discussed in Chapter 3.

Used together simultaneously, the two activities encourage users to rely more on visual observations, as their auditory channel is occupied by the sounds heard through their headphones. Alternatively, users can choose to wear headphones on only one ear, allowing them to hear both the real and virtual bird sounds.



(a) Start Screen **(b)** Confirmation Card **(c)** Observation Made

(d) "Was it one of these?" **(e)** Search Bar **(f)** Search Results

Figure 1.1: Screenshots from the Urban Echoes application.

1.2 AESTHETIC AUDITORY EXPERIENCES

The design seeks to deepen the appreciation of nature by creating an aesthetic experience with avian wildlife as the focus. The idea of using experiences to foster an environmental connection was inspired by Chawla et al. [18], who found that our experiences with and connection to nature significantly shape our willingness to act on climate change. Specifically, they found that formative experiences with nature are crucial in developing environmental sensitivity, which they define as the motivation to learn about, care for, and feel concern for the environment [18].

To create such experiences, the design of *Urban Echoes* is conceptually informed by the aesthetics of interaction, as described by Petersen et al.[55]. In this framework, aesthetics are considered in terms of both context and use. This perspective recognises that while a design may have aesthetic potential in itself, the aesthetics of use emerge through the user's process of sense-making and the personal meanings they derive from the interaction.

To illustrate how this view can be used to analyse academic work that seeks to engage people with local nature, we can look at Gaver et al.'s *Naturewatch Camera* [35]. *Naturewatch* is a citizen science project in which users construct DIY wildlife cameras that autonomously capture images of wildlife when animals enter the frame. The aesthetics of use and context are evident in how users evaluate the cameras, with sense-making and meaning becoming central to the user experience. Users note how the cameras allow them to observe the lives of animals in their gardens without the animals detecting their presence—something they were previously unable to do [35]. The community aspect and the sharing of images also contribute to the aesthetic experience, as these elements are important to the context and meaning the users derive from participation.

For *Urban Echoes*, birds have been chosen as the subject of the application due to their global prevalence—even in urban environments—their species diversity, and the perceived pleasant qualities of their vocalisations, particularly within a soundscape. Sounds associated with avian activity have even been found to aid in stress reduction and attention recovery [57], highlighting the positive effects their presence can have on humans. It is important to note that the types of sounds that produce these effects often depend on personal preferences and individual experiences [57].

Importantly for *Urban Echoes*, digitised bird vocalisations have been explored by Lawton et al. [43], who investigated the use of speakers in a forested area to play bird calls. They found that natural soundscapes had numerous beneficial effects, even when digitised. These included increased attention to visual surroundings, enhanced perceived enjoyment, and greater reflection on the loss of nature [43]. This suggests that heightened sonic awareness may also promote visual awareness—something that was also commonly observed in *Urban Echoes*.

The *Urban Echoes* application is specifically geared towards urban dwellers, as urban soundscapes experience significantly more noise pollution than rural and suburban areas [56]. Areas with less noise pollution generally offer a richer soundscape, thereby reducing the need for such an application. The aesthetics of use are intended to emerge as users begin to attune themselves to the visual and auditory environments around them. To expand on this further, I want to discuss the term *noticing*.

1.3 NOTICING AS A DESIGN TOOL AND NATURE APPRECIATION

The act of *noticing* [67] as introduced by anthropologist Anna Tsing has gained traction within the Sustainable Human-Computer Interaction (SHCI) community[44]. In this context, *noticing* extends to more than perceiving what is in front of us, but noticing the complex relationships surrounding our object of notice. This includes considering how economic, social, environmental, and other contextual factors shape and transform what is observed. It calls for a heightened curiosity and a sensitivity on the part of the observer—and openness to perceiving more than what is readily apparent.

As designers, we can ask ourselves how the act of noticing can be used to inform more-than-human-centred design. As previously discussed in Chapter 1.1, this project originally began as a 10 *ETCs* exploration of the more-than-human-centred design space. Although we were unaware of the concept of *noticing* during that project, we inadvertently engaged in it to some degree during our attempts to understand city pigeons—the focus of the study at the time.

I began my master's thesis with the knowledge and newfound appreciation for pigeons acquired during that project. As the thesis progressed, my interest in pigeons expanded to birds more broadly, and I found myself noticing the birds in the city in ways I never had before. I started perceiving them more consciously and began to notice which birds appeared in which environments.

This raises the question of how the concept of noticing can be applied in design practice. Noticing, as a means to enhance the designer's ability to decentre the human, has been explored in the literature—particularly in the design text *Watching Myself Watching Birds: Abjection, Ecological Thinking, and Posthuman Design* [10] by Biggs et al., where the lead author conducted an autoethnographic study on how noticing the birds of Indiana changed her perceptions and led to personal and professional growth.

In the paper, the author describes developing feelings of *abjection*—a simultaneous sense of fascination and repulsion—toward the birds as a result of her engagement with them. In contrast, I did not share this experience. From the beginning of my process of recognising birds and perceiving them more attentively, I felt a sense of appreciation and excitement. That said, my increasing focus on sonic environments did lead to a heightened awareness of other urban sounds. For instance, I now find the sound of cars unpleasant, whereas previously I would have dismissed it as mere background noise.

I want to emphasise that, although my experiences and feelings differ from Biggs', neither is inherently more correct than the other.

The SHCI community can provide tools through interactive systems that help people *notice* in new ways—by giving us more senses, different perspectives, and more. Rosén et al. present three design concepts that exemplify different ways of *noticing* within a city gardening community [59]. The first is a control-oriented approach, which focuses on monitoring measurable factors such as soil pH levels, moisture, and similar parameters. The second is a sensibility-oriented approach, which emphasises the development of tacit knowledge over time. Lastly, they present an appreciation-oriented approach, which is centred on sensory engagement and exploratory experiences without a specific practical goal [59].

1.3.1 Ontological design and Futuring

Design theorist Tony Fry presents the concept of *futuring* [34]—the act of preserving or creating the conditions for a viable future. It stands in opposition to the current trend of *defuturing* [34], which either actively or inadvertently hinders the viability of a livable future. Fry argues for a shift from sustainability to sustainment in design thinking. This more holistic understanding calls for system-level transformation rather than simply patching flaws in existing systems. He urges designers to think critically about what they create, as they directly shaping the future through their designs.

Fry's work resonates with Arturo Escobar's theory of ontological design, which posits that all acts of design are interventions in ways of being: we design the world, and in doing so, the world designs us [29]. Ontological design is rooted in an onto-epistemic view, in which a reciprocal relationship exists between being and knowing—our ways of being shape our ways of knowing, and vice versa.

Given that the literature [10, 44, 52, 59] suggests that the act of noticing is a powerful tool for fostering more than human-centred thinking, what does this tell us about the relationship between noticing, futuring, and ontological design? Tsing's concept of "noticing," in this light, becomes an exercise in uncovering the ontology of the object or phenomenon being noticed. By attuning us to more-than-human relations, the act of noticing offers new ways of knowing and being, supporting ecological awareness and ethical responsiveness. As previously discussed, research suggests that such perceptual shifts contribute to increased environmental sensitivity [18], thereby laying the groundwork for more livable futures.

When viewed through the lens of ontological design, *Urban Echoes* can be understood as a springboard for *noticing* birds in the urban environment. The aesthetic experience is intended to attune users to birds and act as a catalyst for *noticing* them. The chosen evaluation method—diary studies in which users write down their thoughts—also supports this, effectively encouraging *noticing* as part of the reflective process of writing your thoughts down.

Urban Echoes aligns closely with appreciation-oriented *noticing* by allowing users to hear bird sounds in relative isolation, especially when using noise-cancelling headphones. While the app does not explicitly advocate for systemic change, it gently encourages a deeper appreciation of urban nature—representing a small but meaningful shift toward sustainment. The ideal scenario involves users *noticing* the birds and having an aesthetic experience through the act of *noticing*.

1.4 PROJECT TIMELINE

The idea and concept were expanded from the 10 ECTS project during the first weeks of the project. Development of the application took place from the end of January to early May 2025, with report writing occurring in parallel with coding, starting in mid-February and continuing until the delivery date in mid-June. The evaluations were conducted in May, starting on either the 12th or 14th of May; each evaluation was conducted over a week.

2 RELATED WORK

In this section, I present related work that has either inspired or parallels my project. I also discuss comparable commercial and scientific applications, highlighting their contributions and examining how *Urban Echoes* differs from them.

2.1 RESEARCH THROUGH DESIGN AND DRIFTING

The work in this thesis falls under the domain of Research trough Design (RtD), meaning that the findings and insights emerge as a result of conducting design experiments. A defining feature of RtD is its embrace of *emergence* [36]—the capacity to respond to opportunities that arise during the design process, rather than adhering strictly to a predetermined preregistration [36].

The emergent nature of RtD is further elaborated through the concept of *drifting* [40], as introduced by Krogh et al. They describe how design experiments evolve as contextual knowledge from previous experiments accumulates. Five distinct forms of drifting are identified [40] in their work, two of which have been used in the development of *Urban Echoes*.

The design experiments conducted during the previous 10 ETC project were characterised by *expansive* drifting [40], as the field of more-than-human computer interaction and Animal Computer Interaction (ACI) [45] was explored. The authors expanded their knowledge, and each design experiment informed the next, without a clearly defined boundary between them.

In contrast, the further development of *Urban Echoes* into a master's thesis project has followed a pattern of *serial drifting* [40], where individual design experiments, such as the vertical slice discussed in section 3.5, formed the foundation for subsequent iterations linearly.

2.2 SUSTAINABLE HUMAN COMPUTER INTERACTION

The call for climate action and nature conservation has in recent years gained more attention, and rightly so. With the global community behind on 41 out of 42 indicators to achieve the 2030 goals of the Paris Agreement[13], the prospects of achieving these goals become more and more difficult.

Within Human-Computer Interaction Human Computer Interaction (HCI), the challenge of addressing climate action has led to the emergence of SHCI and Sustainable Interaction Design (SID), with roots in two influential papers by Eli Blevis [11, 46]. These new fields focused on using technology to promote sustainability in the user's life across many sectors, such as the environment, social justice, public health, and other areas concerning building a sustainable future.

A literature review by Hansson et al. surveyed the field of SHCI and found that research has addressed a wide range of the United Nations Sustainable Development Goals (SDG), with published work mapped to 6 of the 17 goals. This highlights the interdisciplinary and far-reaching nature of the field [37]. Much of the research focuses on the direct application of technology to address specific sustainability challenges. For example, Hansson et al. [37] report that of the 26 studies associated with SDG Goal 12.2—"By 2030, achieve sustainable management and efficient use of natural resources"—the majority (18 articles) explored eco-feedback or eco-visualisation systems. These systems aim to make resource consumption more visible and comprehensible, thereby promoting sustainable behaviour.

A more recent and extensive literature review by Besana et al. expanded the conceptual framework of how interaction design can support sustainability. Earlier work had identified two primary approaches within SHCI: *sustainability through design* and *sustainability in design*. Besana et al. rephrased the latter as *sustainability by design* and introduced a third approach: *sustainability in design* [9]. These approaches encapsulate different but not mutually exclusive ways of engaging with SID. *Sustainability through design* aims to promote behavioural change at individual, communal, or societal levels, even if the artefact itself is not inherently sustainable. *Sustainability by design* embeds sustainability into the product's very design, aiming to reduce its environmental footprint. *Sustainability in design* shifts the focus to the design process itself, critically examining whether the methods and practices employed are sustainable.

Urban Echoes aligns most closely with the *sustainability through design* approach, as it seeks to foster environmental awareness and attentiveness to urban birdlife. However, since the application is not currently optimised for energy efficiency, it does not meet the criteria for *sustainability by design*. Additionally, the use of generative AI tools throughout the development process, in my view, limits their alignment with *sustainability in design*.

The paper *"Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape"* by Bremer et al. presents another perspective of SHCI as being ill-suited to create large-scale change across complex problem areas involving various disciplines through the direct application of technology. Instead, they argue that SHCI researchers should seek to incorporate *green policy informatics* [15] into their projects. Green policy informatics is the idea that technology should help promote climate action by providing tools for transparency and supporting complex decision-making. Beyond that, it should encourage communities and support the push for green policies.

I believe both *green policy informatics* and more direct approaches have their merits. My project aligns more closely with the direct application school of thought within SHCI, as it does not provide clear pathways to influence policy or form communities. Instead, it focuses on sparking individual interest in local wildlife. This emphasis stems from a focus on personal interests and emotional experiences, rather than actively promoting radical change or community formation.

This distinction is important and is exemplified by the way the prototype facilitates the creation of a collective artefact in the form of an auditory map. However, the emphasis lies on the observations themselves and the experience of hearing them, rather than on the individuals who recorded them. I will discuss the design choices behind this approach in more detail in Chapter 4.

To justify my decision to prioritise individual emotional experiences over community-building and to focus primarily on urban residents, I refer to the global trend of increasing urbanisation. According to UN projections, 68% of the world's population is projected to live in urban areas by 2050 [68]. Since wild nature is scarcer in cities than in rural areas, encountering wildlife increasingly becomes something that must be actively sought out rather than passively experienced.

This scarcity is exacerbated by the poor reputations of many urban-dwelling animals, such as pigeons, seagulls, raccoons, and rats. These animals are often met with indifference or aversion, leading to negative or neutral encounters between residents and local wildlife [27].

Although many birds are generally viewed positively, *Urban Echoes* aims to foster meaningful experiences with all birds, including commonly unpopular species like seagulls and pigeons.

2.3 ENGAGING WITH NATURE THROUGH AUDIO CONTENT

Audio-based technologies show promise in fostering connections between humans, animals, and the environment. Several studies demonstrate how soundscapes and audio-augmented experiences can engage participants while raising awareness about ecological systems.

2.3.1 Nature Soundscapes: An Audio Augmented Reality Experience

Lawton et al. demonstrate how Augmented Acoustic Reality (AAR) has the potential to highlight the loss of nature [43] and encourage reflection. Participants in Lawton et al.'s project became more aware of environmental degradation, with the added benefit of the soundscapes also fostering a sense of calm and encouraging engagement with the local surroundings.

Lawton et al.'s project used speakers placed in the real environment to implement their soundscape experiences. While they mention binaural audio through headphone playback as an area of interest, it also presents certain limitations. As noted by Lawton et al., "binaural audio, via headphone reproduction, detaches the listener from the real-world sounds in the environment" [43]—something which the evaluation of *Urban Echoes* in Chapter 6 underscored as having both positive and negative effects.

For any similar project to *Urban Echoes*, maintaining a connection to the immediate natural environment is critical to the AAR experience. Encouraging participants to pay greater attention to their surroundings aligns with the objectives of *Urban Echoes*; however, in this project, the playback audio is fully detached from the present physical environment and instead represents a recorded event. This decision partly stems from a desire to balance design goals with ecological and practical considerations.

There has been very little research into the effects of using playback audio of bird sounds in communal spaces, such as cities. However, one study by Harris et al. investigated the effects of playback audio on two tropical bird species and found that it had multiple adverse effects, including exposing the birds to danger and increasing their stress levels [38]. Additionally, several major birding organisations—such as the American Birding Association, the Rochester Birding Association, and others—advise against the use of playback, citing concerns such as disrupted nesting, breeding interference, and impacts on the birds' ability to raise their young [5, 6, 61, 62].

This project, therefore, focuses on individual immersive experiences rather than communal sound installations. The design seeks to minimise ecological disturbance while allowing participants to concentrate on the presented audio content, albeit at the cost of full immersion in their immediate auditory surroundings. To address this, the inclusion of an observer role is intended to encourage users to engage with the real-world soundscape and make observations in content-less areas. The underlying hypothesis is that cultivating sonic awareness through *noticing* can also heighten visual awareness of the nature around them.

2.3.2 Audio-enabled locative media

Urban Echoes also draws inspiration from audio-enabled locative media, such as audio walks. The first audio walks were developed somewhat serendipitously by Janet Cardiff in 1991 [16]. This initial work inspired her entire career, which has featured the creation of numerous acclaimed pieces. Her most famous audio walk, *Her Long Black Hair* [17], guides listeners through Central Park South using photographs in combination with audio and location-specific cues to craft a layered experience. A common feature of audio walks is their emphasis on geographical context, active participation through movement, and a narrative structure.

Other examples of audio-enabled locative media can be found in *Placed Sounds* [8] and *Situated Sound* [30], both of which describe techniques for positioning sounds or music in physical space. *Situated Sound* typically refers to experiences in which, for example, a user entering a church might first hear music followed by context-specific information about the location. *Placed Sound*, on the other hand, places greater emphasis on the listener's engagement and how they remix the experience through movement. A notable example is an album by BLUEBRAIN, which employed *placed sound* throughout the National Mall in Washington, D.C. [12]. Rather than listening to the album linearly, the user explores the space, with the music dynamically tailored to the visual environment—for instance, ascending harp tones while climbing the steps of the Lincoln Memorial.

As *Urban Echoes* is based on user-generated observations, the placed sound is less curated. As will be demonstrated in the evaluation section 6, the interaction between the visual environment and the placed sounds—namely, the user observations—played a significant role in shaping the overall user experience.

2.4 APPLICATIONS FOR ENGAGEMENT WITH BIRDS

There are many free applications available for the identification of and participation in local wildlife. The following is not an exhaustive list, but rather an exemplar-based overview of the field. The most prominent app is *Merlin ID* [53], developed by the Cornell Lab of Ornithology. The app allows users to identify birds based on their calls and songs. Furthermore, users can take images or describe the bird using pre-defined cues, and then receive suggestions based on their input. An examination of the app's description makes it clear that its goal is to engage people in birdwatching and to make the hobby more accessible to both enthusiasts and casual users. To ensure accuracy, *Merlin ID* suggestions are based on regional sightings submitted to eBird [64], one of the largest citizen science platforms [39], where birders can upload observations.

Compared to *Urban Echoes*, *Merlin ID* places a stronger emphasis on education and learning, particularly in helping users learn to recognise birds and deepen their understanding. Moreover, *Merlin ID* encourages users to heighten their sonic awareness and actively listen for birds in their immediate environment. In contrast, *Urban Echoes* is less focused on users learning about birds and the existing soundscape; instead, it presents an exaggerated, soundscape to its users and seeks to create an aesthetic experience.

Personal reflections from using both applications revealed distinct strengths in each. With *Urban Echoes*, the immediate visual surroundings became a frame for imagining where the bird might be located, prompting reflections on which habitats certain birds are typically found in. I also found myself actively searching for the birds I was hearing. *Merlin ID*, on the other hand, encouraged a different kind of engagement—one centred on gaining knowledge about species, vocalisations, and migratory patterns. Once a sound was identified, I was more inclined to search for the bird visually, with the knowledge that the species was present at that moment. In this case, the recognition that the bird was "here and now" motivated further observation.

Both applications could benefit significantly from being used in tandem, or potentially being integrated—an idea I will return to in Chapter 7.3. Another key difference lies in how the apps support citizen science. *Urban Echoes* was originally envisioned as a citizen science project, but as the project evolved, the focus shifted towards providing a more aesthetically engaging experience. In contrast, *Merlin ID* remains a robust tool for birders to verify their observations before contributing them to citizen science initiatives.

2.4.1 Citizen Science and Bird Observation

Citizen science enables members of the public to contribute to scientific research by collecting data at a scale that would otherwise be unattainable for scientists alone [20]. The adoption of citizen science within the bird observation community has significantly enhanced researchers' understanding of bird migration patterns and population trends. Since eBird operates globally, it provides a broader dataset than regional observation platforms such as the Danish DOFbasen [24].

iNaturalist [72] is another citizen science application, accompanied by a website, which focuses on documenting wildlife, plants, and fungi, thereby covering a wider scope than eBird. To foster continued engagement, iNaturalist promotes sharing and discussion, creating a more communal experience than the more individually focused eBird and Merlin ID.

An examination of the real-time eBird map reveals a noticeable overrepresentation of the Global North compared to the Global South, indicating an uneven distribution of data, as shown in Figure 2.1. The light grey dots indicate a recorded observation.

Figure 2.1: A screenshot of the eBird live map, 31-03-2025 [71]

This highlights a key challenge of digital citizen science: the disparity in digital access and wealth between the Global North and South, which leads to unequal representation in data collection.

An alternative model of citizen science can be found in regional bioblitz events, where scientists and members of the public engage in intensive field surveys to systematically document local biodiversity. A research project aiming to develop an app for locating a rare cicada was tested during such an event. The researchers encountered considerable reluctance towards digital tools among both professional and amateur naturalists, who overwhelmingly preferred traditional methods such as pen and paper [48]. When asked why, participants cited that digital technologies detracted from their experience of the surrounding natural environment [48].

As previously mentioned, *Urban Echoes* was originally conceived with citizen science components. However, given the existence of well-established tools for bird-related citizen science, introducing an additional platform could potentially fragment the user base and detract from existing initiatives. Moreover, users who actively contribute to such projects are often deeply invested in their local environments and may perceive the use of technology as detracting from their experience of nature.

Furthermore, the substantial effort required to establish and maintain a reliable and scientifically trustworthy database was deemed beyond the scope and priorities of this project. Instead, *Urban Echoes* integrates sightings from eBird to populate its map, supplemented by user-generated observations within the app. Although the number of eBird observations in Aarhus is limited, the few that do exist, particularly of rarer species, may nonetheless engage and excite users when encountered through the app.

2.5 DIGITAL STORYTELLING

With *Urban Echoes*, I intend for users to co-create a collaborative narrative with the local environment, where birds act as participants in the story. Digital storytelling offers a compelling way to provide context and meaning to aesthetic experiences. One example is audio walks, in which a geographical location provides the context for audio content, forming a coherent and situated experience.

The use of geographic position for narrative context is not unique to audio walks. Various forms of digital storytelling—such as videos and other multimedia experiences—have explored this concept. A relevant example is *Seven Stories* [51], a research project by Nisi et al., where location-specific visual narratives were used to tell local stories on Madeira through videos. They found that users experienced difficulties with orientation and GPS reliability, which negatively affected the experience, as users focused more on their devices than on their surroundings. In response, the researchers adopted a marker-based solution instead [51].

While *Urban Echoes* relies entirely on GPS, it does not require the same level of positional fidelity as *Seven Stories*. Therefore, the risk of detachment from the environment is reduced, allowing users to remain more attuned to their surroundings.

It is common for audio walks to include a map displaying the user's position and nearby points of interest. However, as noted in the work of Nisi et al. [51], this reliance on visual feedback can lead to frustration if GPS fidelity is low but critical to the experience. In contrast, Pedersen et al. [54] found that an audio guide using only auditory media—without any visual map—increased observational engagement and decreased screen time. Inspired by these findings, I chose to exclude visual elements entirely from *Urban Echoes*, encouraging users to remain visually attuned to their environment.

The audio content in *Urban Echoes*, though location- and context-specific, is meant to be discovered by walking—without visual guidance from the application. Areas without sound also convey meaning: they suggest either a lack of bird activity or a gap in the dataset. In such areas, users are encouraged to walk without headphones or with only one earbud to attend to the live soundscape and, potentially, contribute new observations if they hear bird calls.

This design approach transforms each session into a dynamic story: a narrative of which birds were present, where, and when—or conversely, a story of absence. An imagined scenario might involve a user entering a silent forest, having removed their headphones to listen directly to the environment. Alternatively, a winter walk through the same forest could present a different experience—hearing birds recorded the previous spring while the live environment remains quiet. In either case, the user participates in a narrative about the local birds.

3 DESIGN ANALYSIS

In this section, I will analyse the design and describe the design decisions and experiments made throughout the development process. The subsections are presented in chronological order, reflecting how the project evolved throughout the thesis.

3.1 INITIAL VISION: A USER-CONTRIBUTED DATASET FOR BIRD RECOGNITION

The original vision of the application differed significantly from its final form, particularly in the design of the observation mechanic, while the core listening experience remained relatively consistent. Initially, the observation system was envisioned to operate through AI-based bird recognition using sound and images, similar to *MerlinID*. The app aimed to distinguish itself through its citizen science component, incorporating elements inspired by *iNaturalist* [72], where users actively contribute to datasets for visual recognition.

In this model, users would take a photo of a bird—or a group of birds—and annotate the image by drawing bounding boxes around each subject and labelling them, as illustrated in Figure 3.1. Once uploaded, the annotated image would be added to a growing object detection dataset. As a form of positive reinforcement, the user would then also make an "observation" entry as a reward for their contribution. The listening activity would function in the same way as in the final prototype.

I wanted to create a user-maintained dataset because, as with other citizen science projects, this approach enables scalability far beyond what traditional methods can achieve. Moreover, there is a notable lack of high-quality avian datasets for object detection tasks [69]. Visual recognition is highly dependent on the quality of the training data—the adage “garbage in, garbage out” illustrates this well. A large, high-quality, and well-labelled dataset could make a significant contribution to the field of avian object detection.

As the project progressed, I experienced an increasing disconnect between the dataset creation and observation method, and the intended aesthetic experience: These elements began to feel at odds. Ultimately,

Figure 3.1: Annotated image from the system description document for the initial idea

I decided that the project should focus on one of these aspects. I chose to prioritise the aesthetic experience and nature appreciation over the citizen science and AI dataset components, leading to the removal of these features in favour of a simpler observation approach: writing down the kinds of birds observed.

3.2 SOUNDSCAPES AND ACOUSTIC ECOLOGY

As an audio-based application, high-quality sound design is essential to the user experience of *Urban Echoes*. During the first stage of the project, I had meetings with experts in sound studies and sound aesthetics at Aarhus University. These conversations introduced me to the concepts of *soundscapes* [60] and *acoustic ecology* [60, 70].

Soundscapes and acoustic ecology emphasise the interplay between sounds and how they shape our perception of an environment, much like how each instrument in an orchestra contributes to a coherent listening experience. In a forest, for example, we might hear the wind rustling through the trees, a nearby stream, the movement of animals in the underbrush, and the crunch of our boots on the ground. These sounds are not heard in isolation, but form a unified auditory scene.

Transposing a recorded soundscape to a different time and place may create a sense of dissonance between the playback and the current environment. This dissonance arises when the original acoustic ecology of the sound does not align with the listener's visual or contextual environment, especially if the listener is familiar with one or both contexts. For instance, imagine walking down a street in a European city while a recording of the Common Swift plays. Although the call of the bird may be familiar, if the recording contains the acoustic backdrop of a rainforest, the result is a perceptual mismatch. The listener recognises that the soundscape does not belong to their present surroundings.

Since the goal of *Urban Echoes* is to foster a sense of connection with local nature through sound, the auditory environment must align with what the user expects to hear. This insight reinforces the importance of curating soundscapes that not only feature the correct species but also harmonise with the broader environmental context in which they are played.

3.2.1 The Challenge of Aligning the Acoustic Ecology with the Visual Environments

To ensure alignment between the visual environment and the soundscape I sought to isolate bird vocalisations from their ecological background so that users could either immerse themselves purely in these vocalisations or, by enabling transparency mode on their devices, allow the real-world soundscape to blend naturally with the playback audio.

I initially experimented with a simple noise gate to isolate bird vocalisations and filter out most of the ecological background. Unfortunately, this approach was ineffective due to the dynamic range of the bird calls, which led to parts of the calls being inadvertently cut off. I then considered limiting playback to sound files from the user's country. However, this would significantly reduce the applicability of the app in countries with limited available recordings.

I also explored the use of AI-generated audio via the ElevenLabs text-to-sound effects (SFX) feature [28]. Despite being promising in theory, the resulting bird calls lacked realism at best and, at worst, sounded downright unnatural. Ultimately, I reverted to using high-quality category A recordings from the *Xeno-Canto* database, selected at random. Although not perfect, this method provided the most consistent and natural listening experience. A final option considered was training an AI model capable of recognising and removing background noise. While potentially effective, this approach was deemed too time-consuming for the current project. However, implementing such a filter remains a compelling direction for future work.

The implementation I ended up using—selecting recordings based on high-quality ratings on *Xeno-Canto*—gave me little control over the acoustic ecology. One example of the dissonance that arose from this choice was a recording that featured a dog barking in the background, which a user noticed and mentioned in their evaluation response.

3.2.2 Evaluating the sonic aesthetics

To evaluate the Sonic aesthetics, I used a framework by Cunningham et al.[23]. In their view, sonic aesthetics can be evaluated using the following criteria *intensity, pitch, timing, spatial, fidelity, context, originality, and expectation*[23]. The definitions of these dimensions can be seen in the figure 3.2 taken from their paper *Towards a Framework of Aesthetics in Sonic Interaction*[23]

Dimension	Description
Intensity	The perception of loudness of the sound.
Pitch	The fundamental frequency, or musical note, dominant in the sound.
Timbre	The character of the sound and complexity of its frequency spectrum.
Spatial	The position of the sound relative to the listener's position.

(a) Dimensions: Intensity, Pitch, Timbre, Spatial

Fidelity	The production quality of the sound. Considers the clarity of the sound and its intention, including the presence of noise and other artefacts and the discernibility between signal and noise.
Context	The relationship between the sound, interaction task, and any other sensory stimulations (e.g., touch, visual, olfaction). Context may not always be known to the designer (such as for mobile applications).
Originality and Expectation	The level of predictability and familiarity in terms of the overall context of use, as well as in general experience.

(b) Dimensions: Fidelity, Context, Originality, and Expectation

Figure 3.2: Definitions of the aesthetic dimensions from the paper *Towards a Framework of Aesthetics in Sonic Interaction*. The screenshots are taken directly from the original table in the paper [23].

Looking at this framework, *Urban Echoes* fulfils most of the criteria for aesthetic sonic design, with a few exceptions. By selecting only high-quality recordings from *Xeno-Canto*—specifically those rated with the highest quality—and due to the inherently melodic qualities of bird songs and calls, most sounds in the application exhibit pleasing timbre and pitch. The intensity is generally appropriate; however, variations in loudness between different recordings can affect the aesthetic experience, as some may be too loud while others are too quiet. Originally used informally during the design process to review the audio, these aesthetic parameters were later adopted as part of the formal evaluation criteria.

For the vertical slice of the prototype discussed in Chapter 3.5, I selected specific sound files that contained as little background ecology as possible to facilitate transposition. However, for the final prototype, I opted to select files at random, as the manual approach of hand-picking recordings proved too time-consuming.

3.3 DESIGNING THE LISTENER ROLE

The application's listening experience lets users explore an auditory map. This map is navigated by walking. Location tracking works in conjunction with the audio playback system to play bird observations associated with the user's current location. During the design of the listening experience, I reflected on what maps communicate and how we interpret and use them.

3.3.1 Mapping the world

When creating a map, we must understand the information being represented and how the readers will interpret it. Questions such as: What are the intentions behind the creation of the map? What kind of world does the map depict?—are essential to consider. Take, for example, the most classic map projection: the Mercator projection. It preserves angles, making it useful for nautical navigation, but it does so at the cost of distorting the relative size of landmasses—enlarging those closer to the poles and shrinking those near the equator. Its widespread use has led to critiques that it inflates Europe and North America in a colonialist manner [47].

Bearing these questions in mind helped me to consider the kind of world the mapping in *Urban Echoes* reflects. Since the app is designed primarily for use in urban settings, it does not show where the highest bird populations are found. Instead, it visualises where users choose to engage with the app. As a result, cities may be overrepresented compared to rural areas, which may have fewer users but potentially more bird activity.

Another important consideration is the app's reliance on a stable internet connection. Areas without connectivity cannot be explored or used for observations through the application. This limitation may lead to a misleading impression if it is not made clear that the map produced by the app is not a direct representation of local bird populations, but rather a reflection of user activity.

This view of interaction as something that extends beyond the user and the application, encompassing the broader context in which the design is situated, is also reflected in the literature. For example, Alex Taylor's concept of "after interaction" [65] explores how systems leave traces beyond their direct use—such as how rental bike usage creates a unique, emergent map of activity.

In a similar way to how the Mercator projection serves nautical navigation, I wanted to explore the kind of activity and mapping that *Urban Echoes* would generate. As a listening experience, the map is intended to encourage people to engage with their visual surroundings while immersing themselves in the sonic environment. The goal is to allow users to experience the presence of a bird at the location where it was observed—even if it is no longer physically there. In places without observations, the absence of sound may act as an invitation, prompting users to search for birds and contribute new sightings.

3.3.1.1 Mapping Sounds

The question of how to map sounds in a meaningful way brings us to the concept of *Cartophony*, a term that merges cartographic and sonic practices. Cartophony has been explored in depth by Thulin, who developed a typology to categorise different approaches to sonic mapping [66]

A *sound in map* describes embedding sound into a more traditional visual map and one example can be found in the work of Laakso et al., who explored how sound can enhance traditional map experiences [41]. In their system, a digital hiking map was augmented with sound files linked to specific areas—such as forests or lakes. When users hovered their cursor over these zones, the corresponding sounds would play. This approach not only enriched the user experience but also made the maps more accessible to visually impaired users.

Another of Thulin's categories, *sound as map*, describes an approach in which sound itself serves as the primary spatial reference. In this mode, the listener navigates a space through auditory cues, using sound to orient themselves [66]. This is precisely the approach utilised by *Urban Echoes*, where sound becomes a navigational tool. Users follow sonic cues—such as the loudness of sounds and the ear in which the sound is heard—to locate the original sites of bird observations, effectively using auditory information to explore their environment.

One of the more critical design decisions related to mapping sound in *Urban Echoes* involved determining the appropriate discovery radius for observations. After experimenting with different values, I settled on a 50-meter radius. In my opinion, this distance struck the best balance between realism and usability, offering a meaningful duration of audio playback while allowing multiple observations to overlap.

3.4 ADDING TEMPORAL ASPECTS: SEASONS AND TIME OF DAY

I wanted to incorporate temporal aspects into the application, specifically the time of day and season, as these elements are important in understanding bird behaviour and could be used to teach users more about birds. There is a strong connection between bird vocal activity and breeding cycles [63]. In Europe, birds typically breed when food is most abundant for their offspring [42], which is usually in late spring or early summer in northern regions. Additionally, many birds migrate seasonally, which also influences the frequency and types of bird vocalizations.

To reflect this, I designed the app so users can choose which season they want to listen to, with the current season being the default. This allows a user, for example, to hear how a location might sound in spring—even during early December. While this feature was implemented, it did not significantly influence the prototype testing, as seasonal patterns would only become noticeable over longer-term use. As such, these features were turned off for the evaluation despite having been coded in the application.

I also considered incorporating the time of day, since birds are generally most active at and around sunrise [58], with lower activity during the night and a dip at midday. However, I chose not to include this in the prototype. The reason was to maximise the chances that evaluators would encounter one another's observations. Restricting playback to specific times of day would reduce the chance for users to encounter each other's observations. In a more complete version of the application, the time of day would influence playback, and users could even choose to explore how an area sounds at different times.

3.5 VERTICAL SLICE OF THE PROTOTYPE

A notable design experiment around mid-March was the creation of a straightforward small-scale implementation version capable of playing the observations to create a listener experience. At this point, the idea had been mostly refined into what would become the final iteration, but before fully committing, it was decided to test this small-scale implementation first

This version of the application represents a vertical slice of the final product, encompassing all features related to the audio walk component. However, it lacks functionality related to bird observations, such as creating and uploading observations to the database. At this stage, the application was not intended to include an auditory interface; instead, a search bar was used to facilitate observations.

Since it was not yet possible to make observations directly within the app, I manually inserted data into the database using SQL commands in PgAdmin4 [74]. To determine which bird species to include in the vertical slice prototype, I walked around the area and listened to the bird sounds. Table 3.1 lists the species identified during this walk. I found that the villa neighbourhood, with its large gardens and abundant trees, supported a significantly greater variety of birdlife.

During this walk, I noticed a substantial increase in awareness and attentiveness compared to a regular walk. The role of the observer encourages a heightened sensitivity to the soundscape, allowing for the identification of more birds than one might normally notice. I also observed that the birds were often silent for long periods—something I initially considered emulating in the prototype. However, I eventually opted for a more exaggerated and active sound design to enhance the user experience.

The birds I encountered during my short walk can be seen in Table 3.1

Species (English)	**Scientific Name**	**Danish Name**
Eurasian Blackbird	*Turdus merula*	Solsort
European Herring Gull	*Larus argentatus*	Sølvmåge
Common Wood Pigeon	*Columba palumbus*	Ringdue
Eurasian Blue Tit	*Cyanistes caeruleus*	Blåmejse
Rook	*Corvus frugilegus*	Råge
Common Gull	*Larus canus*	Stormmåge
Eurasian Tree Sparrow	*Passer montanus*	Skovspurv
European Greenfinch	*Chloris chloris*	Grønirisk

Table 3.1: Bird species encountered during the vertical slice walk, including Danish names

These were inserted as points into the database with the relevant coordinates and timestamps. A visual interface was implemented for debugging purposes, allowing me to identify issues with the prototype more efficiently. Figure 3.3 shows a view of this visual interface.

The main menu, shown in Figure 3.3a, featured three buttons: one for observations, one for creating tours, and one for accessing the user profile. However, only the observation button led to a functional interface; the other buttons directed users to Flutter placeholder pages.

On the observation page, users could use a search bar to enter the name of a bird. After selecting the number of birds observed, they could submit the observation. However, at this stage, the observation was not yet uploaded to the database, as the methods for uploading had not yet been implemented.

Using the bottom navigation bar, users could switch between the observation view (Home) and the map view. The map view displayed the observations and allowed users to switch between seasons, enabling them to hear how the same area might sound differently depending on the chosen season.

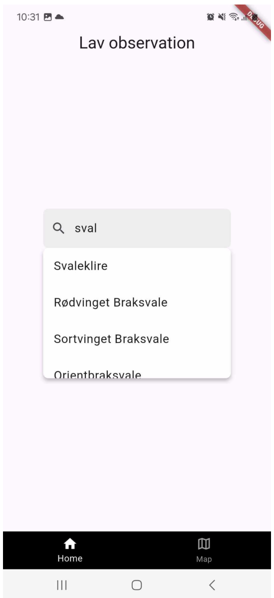
I tested the vertical slice prototype first with my advisor and later with a fellow IT Product Development Master's student. A bug related to the GPS functionality somewhat hindered the evaluation of the prototype, as the GPS updated infrequently. This caused certain observations to play for an extended period, while others failed to play at all. Despite this issue, both tests provided valuable opportunities for reflection on the strengths of the prototype and areas requiring improvement.

One notable insight concerned the exaggerated nature of the bird calls in the application. Compared to real-life encounters, the audio recordings were both louder and more intense than the actual bird calls and songs.

The GPS issue stemmed from the phone entering screen timeout mode after a short period of inactivity. I initially attempted to resolve this by enabling both audio playback and GPS tracking to continue running in the background. While I successfully configured the audio player to function as a background service, the GPS continued to cause problems. Ultimately, I chose to prevent the phone from entering screen timeout mode while the app is in the foreground.

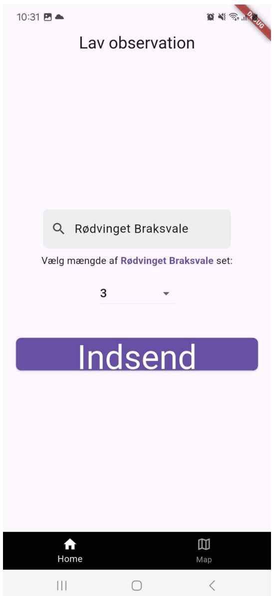
Although this approach significantly increases battery consumption, particularly problematic in an already battery-intensive application, I considered it a necessary compromise to focus on progressing with other aspects of development.

(a) Main menu



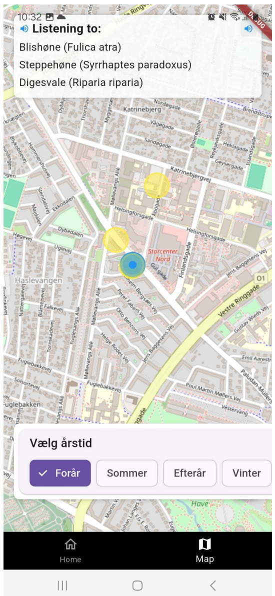
(b) Observation page

(c) Choose amount



(d) Send in the recording

(e) Sending the recoding



(f) The listener view

Figure 3.3: The visuals for the vertical slice

3.6 CHOOSING BETWEEN PROFILE AND WALKS OR AUDITORY INTERFACE

At this point, I faced a significant design decision during the development of the vertical prototype: whether to simplify the visual interface in favour of a more auditory-focused experience, using speech recognition and audio playback as the primary mode of interaction. However, pursuing this auditory interface would have left insufficient time to implement features such as the profile system and the ability to record walks.

The profile feature was intended to let users view their submitted observations and replay previously recorded walks. It also aimed to support the sharing of these walks with others by exporting them as MP3 files. Users would have been able to record their walks and the observations they encountered, and send these walks to others.

In the end, I decided to prioritise the auditory interface over the profile and sharing features, as it aligned more closely with the core vision of encouraging users to engage with their environment through sound.

3.7 CHANGING THE INTERFACE TOWARDS MINIMAL VISUAL INTERACTION

This constituted the last major design change made before evaluation. It was decided to implement voice recognition through a speech-to-text system. Text-to-speech (TTS) was tested but did not perform well in Danish and was therefore not included in the prototype. Instead, a playback solution was implemented using pre-recorded messages that could be combined into different sentences.

4 DESIGN AND EVALUATION OF SYSTEM ARCHITECTURE

4.1 LANGUAGE AND FRAMEWORK CHOICE

The application is primally written in Dart, a language designed for mobile and web development with C-like syntax. The decision to use Dart stemmed from a desire to work with Flutter [32], a multiplatform open-source framework developed and maintained by Google. I chose a multi-platform framework so that the application could run on Android, iOS, and the web from a single codebase. However, I later decided not to develop a web version. There was no specific reason for selecting Flutter over other frameworks like React Native, aside from a personal interest in learning a new language and framework.

Android was chosen as the main development platform, and the app was primarily implemented and tested on Android devices. This decision was influenced by the more lenient deployment policies on Android compared to iOS and the fact that I own several Android devices but no iOS devices.

4.2 GENERAL SYSTEM ARCHITECTURE

A UML class diagram showcasing the general system architecture can be found in Appendix B. For readability, the diagram presents only the structural overview—most classes are shown as stubs. The app follows the provider pattern, where functionality is composed of modular services, some of which are further grouped into higher-level managers. The main class, `MyApp`, acts as a `MultiProvider`, injecting services and state managers such as `ObservationUploader`, `SpeechCoordinator`, and `PageStateManager`. The `InitialScreen` is responsible for early lifecycle management and for initialising core services like `LocationService` and `AppStartupService`, before displaying either the intro screen (shown on first-time use) or the main UI. Implementation details will be discussed further in Chapter 5.

4.3 SPEECH RECOGNITION, TEXT-TO-SPEECH AND RECORDINGS

By clicking the microphone icon at the bottom of the screen, users trigger the applications speech recognition, as shown in Figure 4.1b.The application listens for the user's input, the application takes the user's speech as input and uses the Flutter package *speech_to_text* v7.0.0 [21] to convert it into text. The text is then matched against a species list, and if a match is found, the system proceeds by prompting the user with the confirmation card, as seen in Figure 1.1b.

Special words such as seasons, *ja* (yes), *nej* (no), and other confirmation terms are also checked for matches. Depending on the match, the application can transition to different stages—for example, entering the confirmation stage after the user says *ja* (yes) to having observed a bird.

The list of birds is sourced from the species database at netfugl.dk [49], ensuring that all species found in Denmark are included in the application. The app is intended for a Danish audience, so both the speech recognition and audio playback are in Danish.

4.3.1 Text to speech

I implemented TTS functionality in the application to announce bird names and play a few voice lines, such as "Have you observed a (bird name)"[1] and "Observation for (bird name) has been created."[2]. The text-to-speech was implemented using a library called *flutter_tts* v4.2.2 [26]. This approach used pre-written text fragments, which were spoken aloud when certain conditions were met. I initially preferred this solution over using pre-recorded audio, as it would allow faster scaling to include more bird species and additional languages. After testing the library's Danish capabilities, I found that it struggled with pronunciation to the point of becoming almost unintelligible. I therefore opted for an audio playback solution instead, recording the voice lines manually.

4.3.2 Playback solution

I recorded the bird names individually, enabling them to be inserted into various sentence structures. This made it possible to dynamically generate phrases such as (translated into English; the app uses Danish): "Did you see a..." followed by a recording of the bird's name,

1 Actual sentence in the application spoken in Danish: *Har du observeret en (fuglens navn)*
2 Actual sentence in the application spoken in Danish: *Observation for (fuglens navn) er oprettet*

resulting in complete sentences like "Have you seen a blackbird?", albeit with a slight delay between segments.

This solution also came with limitations: the application does not include voice lines for every bird species found in Denmark, as the recording process was highly time-consuming. However, I managed to record 53 of the most common bird species out of the approximately 300 present in Denmark.

To test these new functionalities, I created a debug interface, as shown in Figure 4.1. These visuals eventually formed the basis for the prototype's final design, shown in Figure 1.1.

4.4 BACKEND

The backend is built using *Python and FastAPI* and is hosted on *Microsoft Azure*. Microsoft Azure was selected over other cloud hosting services for several reasons. It scales effectively and offers all the necessary features for the backend, including *web hosting*, *PostgreSQL database support*, and *blob storage*. Additionally, students receive 100 USD worth of credit through the GitHub Student Developer Pack, which allows me to use the hosting service without incurring personal expenses. The choice to use a *FastAPI* backend was primarily based on my prior experience and familiarity with it from previous projects.

4.4.1 Database

The PostgreSQL database consists of two tables: `bird_observation_table`, shown in Table 4.1, and `birds`, shown in Table 4.2.

In addition, an Azure Blob Storage container holds sound files for all birds found in Denmark. Each bird is associated with 20 sound files, downloaded from *Xeno-Canto*. These files are organised in directories, and their paths are linked to entries in the application's database. When an observation is active, the application streams and plays a sound file via the corresponding blob storage link.
For a less data-intensive solution, the app could include sound files for regional birds bundled with the app or offer them as optional downloads. Although the app would still require an internet connection to access observation points, these could be cached locally to further reduce data usage.

Field	Type	Description
id	INT	Unique identifier for each observation
bird_name	VARCHAR	Common name of the bird
scientific_name	VARCHAR	Scientific name (e.g., *Corvus corax*)
sound_directory	TEXT	Path to the associated sound file
latitude	NUMERIC	Latitude of the observation point
longitude	NUMERIC	Longitude of the observation point
observation_date	DATE	Date of the observation
observation_time	TIME	Time of the observation
observer_id	INT	Reference to the observer
quantity	INT	Number of birds observed
is_test_data	BOOLEAN	Flag indicating whether the data is test or real
test_batch_id	VARCHAR	ID of the test batch (if applicable)
source_id	TEXT	ID from eBird for imported eBird observations

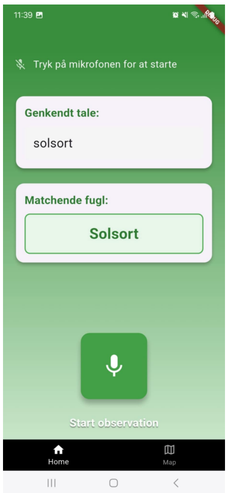
Table 4.1: Schema for the `bird_observations` table

Field	Type	Description
id	INT	Unique identifier for the bird
common_name	VARCHAR	Common name of the bird
scientific_name	VARCHAR	Scientific name (e.g., *Turdus merula*)
danish_name	VARCHAR	Bird's name in Danish
region	VARCHAR	Region where the bird is typically observed
lastobserved	TIMESTAMP WITHOUT TIME ZONE	Date the bird was last observed
is_common	BOOLEAN	Indicates whether the bird is commonly found

Table 4.2: Schema for the `birds` table

(a) Listening is triggered by clicking the large green button.

(b) The app is listening and has matched the spoken word with "solsort" (Blackbird).



(c) The recognised speech and matched word are displayed.

(d) The user says "ja" (yes) to confirm the observation, prompting the system to save it in the database.

Figure 4.1: Screenshots illustrating the speech recognition debug visuals in the application.

5 IMPLEMENTATION

In this section, I will go more in-depth with the implementation of the different components of the final prototype. All the code can be found on GitHub following the link in Appendix D.1 and UML diagrams can be found in Appendix B. The application's general architecture follows the Provider pattern to establish a hierarchical dependency injection system. Listing 5.1 illustrates how various provider types manage service dependencies, ranging from basic stateless services to complex coordinating services that orchestrate multiple components. The full setup is provided in Appendix E. A provider pattern was chosen due to the separation of logic through dependency injection, making the system more manageable, modular and understandable.

```
MultiProvider(
  providers: [
    // Core state managers
    ChangeNotifierProvider<PageStateManager>(create: (context) =>
         PageStateManager()),

    // Basic services
    Provider<DatabaseService>(create: (context) =>
        DatabaseService(), lazy: false),

    // Services with dependencies
    ListenableProvider<ObservationUploader>(
      create: (context) => ObservationUploader(
        databaseService: Provider.of<DatabaseService>(context,
            listen: false),
        // Other dependencies...
      ),
    ),

    // Complex coordinating service with multiple dependencies
    //Speech coordinator
    ChangeNotifierProxyProvider4<...>(...),
  ],
  child: MaterialApp(...),
)
```

Listing 5.1: MultiProvider setup in Flutter

5.1 AUDITORY MAP (LOCATION SERVICE)

The auditory map is created and managed by a class called `location_service`, with the following dependencies:

- `bird_sound_player`
- `azure_storage_service`
- `background_audio_service`
- `season_service`
- `location_manager`

Before delving into how it works, I will describe the dependencies to provide a greater understanding of the system.

5.1.1 bird_sound_player

This module initialises a pool of five audio players (the exact number is set in the `service_config` file), manages which players are available, and handles the playback of bird sounds using the available players. The audio players used are from the Flutter library `audioplayers` version 6.2.0 [50].

5.1.2 background_audio_service

This class ensures that sounds keep playing even when the application is minimised or the screen is turned off. Unfortunately, sounds will not change while the app runs in the background, as I was not able to get location tracking working as a background service.

5.1.3 season_service

A simple class for tracking the seasons. This includes keeping track of the current season as well as determining the season for other observations based on their dates. I initially designed the application to allow users to change seasons and hear only observations made in that season. However, the class is not used in the prototype, as I removed the feature to switch between seasons due to the limited number of bird observations and because all participants in the evaluation would be using the application during the same season.

5.1.4 azure_storage_service

This class followed a singleton pattern and has two responsibilities. Firstly, it should initialise the connection to the Azure storage blob holding all the sound files.

```
Future initialize() async {
  try {
    if (_initialized && _storage != null) return true;

    _storageAccountName = dotenv.env['AZURE_STORAGE_ACCOUNT_NAME'] ?? '';
    final connectionString =
        dotenv.env['AZURE_STORAGE_CONNECTION_STRING'] ?? '';

    if (_storageAccountName!.isEmpty || connectionString.isEmpty) {
      debugPrint('Azure Storage credentials are missing');
      return false;
    }

    _storage = AzureStorage.parse(connectionString);

    _initialized = true;
    debugPrint('Azure Storage Service initialized successfully');
    return true;
  } catch (e) {
    debugPrint('Error initializing Azure Storage Service: $e');
    _initialized = false;
    return false;
  }
}
```

Listing 5.2: Azure Storage Service Initialization Method

Its second responsibility is to list all the files in a certain folder of the blob storage. This is used as the bird sound plays a random sound file from a certain folder when playing a bird sound.

5.1.5 location_manager

The LocationManager class is responsible for tracking the user's location. It uses the LocationRepositoryInterface as an abstraction layer over the Flutter package geolocator[7].

```
void _handlePositionUpdate(Position position) {
  _currentPosition = position;

  // Skip processing if not enough time has elapsed
  final now = DateTime.now();
  if (now.difference(_lastPositionUpdate).inMilliseconds < 500) {
    return;
  }
  _lastPositionUpdate = now;

  if (_config.debugMode) {
    debugPrint('[LocationManager] Position update: ${position.
        latitude}, ${position.longitude}');
  }

  // Skip if position hasn't changed significantly
  if (_lastProcessedPosition != null) {
    final distance = _locationRepository.distanceBetween(
      _lastProcessedPosition!.latitude,
      _lastProcessedPosition!.longitude,
      position.latitude,
      position.longitude
    );

    if (distance < _config.distanceFilter / 2) {
      if (_config.debugMode) {
        debugPrint('[LocationManager] Skipping position update (
            moved only ${distance.toStringAsFixed(1)}m)');
      }
      return;
    }
  }

  _lastProcessedPosition = position;

  // Call the callback
  if (onPositionUpdate != null) {
    onPositionUpdate!(position);
  }
}
```

Listing 5.3: Dart Function: _handlePositionUpdate

5.1.6 How it all works together

The location services work by making a call to the backend that retrieves all the observations for the current season. It uses the location manager to track the user's position and then retrieves sounds from the storage blob using the `azure_storage_service`, based on the user's location. It then uses the `bird_sound_player` to play the retrieved sounds, which internally ensures that the available audio players are used.

The `background_audio_service` plays the sounds when the user turns off their screen. However, since tracking stops working at this point, the sounds will simply repeat. As a result, this service did not play a significant role in the evaluated prototype.

5.2 DATABASESERVICE

This class is responsible for creating and maintaining a connection with the database. This also includes closing the connection. Beyond this it has a function to fetch all the observations from the database to populate the map. Lastly, it provides a function for uploading observations to the database.

5.3 OBSERVATIONUPLOADER

This class once again uses the provider pattern and dependency injection. It relies on a `DatabaseService`, an `UploadNotificationService` instance, and an `ObservationService`. The class **uml!** (**uml!**) diagram can be seen in figure 5.1 and the class is responsible for validating and preparing observation data, preventing duplicate uploads, uploading observations to a remote API, notifying the user of success or failure, and tracking internal state (uploading, error, disposed).

5.4 RECORDINGPLAYERSERVICE

This service plays the audio files that I recorded. It includes functions to play sound files where a bird's name is spoken, as well as functions to play longer sentences based on a prompt key. Additionally, the class provides functions such as `playBirdQuestion` (see Appendix E.3), which combines a prompt with a bird name and notifies listeners waiting for the question to finish.

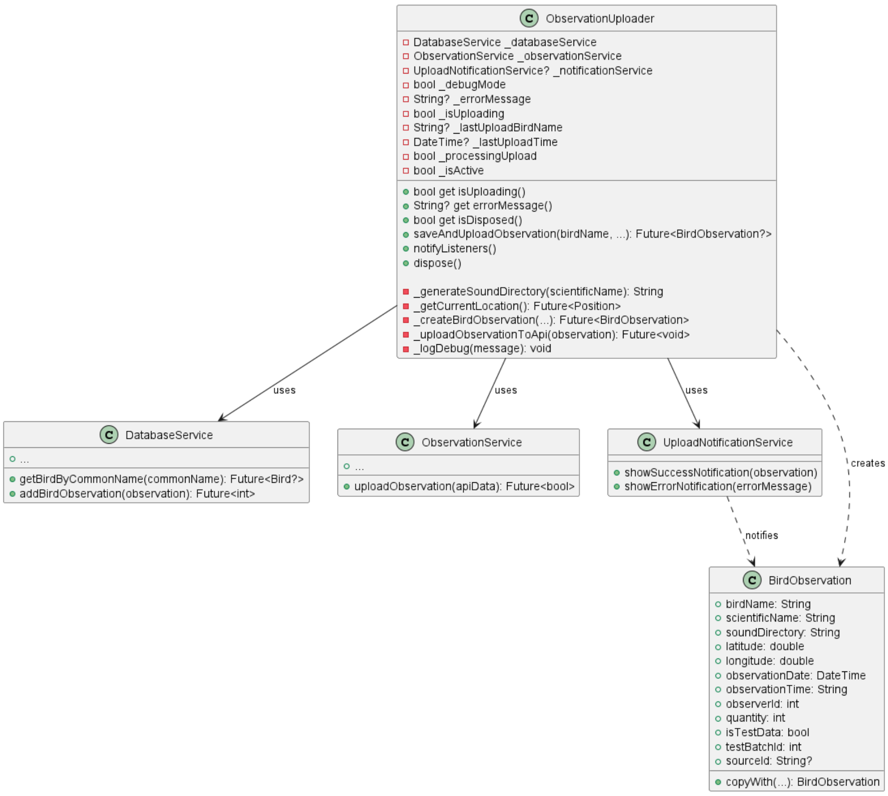


Figure 5.1: ObservationUploader class UML

5.5 SPEECHCOORDINATORSERVICE

The `SpeechCoordinatorService` is a large class extending the `ChangeNotifier` class and follows the provider pattern. It is responsible for the speech interface, which includes word recognition, playing the appropriate sound files, listening for confirmations, and providing updates to listeners such as the UI.

It uses previously discussed services, such as `RecordingPlayerService` and `ObservationUploader`. Additionally, it depends on `BirdRecognitionService`, `WordRecognitionService`, and `SpeechRecognitionService`, each responsible for different aspects of the speech recognition process.

5.6 BACKEND

A `FastAPI` backend written in `Python` and hosted on a student subscription to Azure provides an endpoint for fetching observations. There are other endpoints, but these are not used in the version of the prototype that was evaluated. The backend can be found in Appendix E.2.

As part of the backend, a `PostgreSQL` database holds a table for observations. Additionally, an `Azure Blob Storage` instance is used to host the sound files. All sound files have been collected from *Xeno-Canto* [33] and are organised in folders based on the scientific name of the bird. These folders are associated with the observations in the database, allowing the system to fetch random sound files from specific folders based on the bird observed in a given observation.

Scientific names are used in the backend as they are language-independent, making the system more scalable.

6 EVALUATION

In this section, I describe the evaluation covering the subjects' methodology, participants, and the perspective for the qualitative data analyses. Afterwards, I present the evaluation results in three parts: the interview section, a thematic analysis and lastly responses that did not fit into the thematic analysis but merit more discussion. The chapter concludes with a discussion section where the findings are discussed.

6.1 METHODOLOGY

The prototype was evaluated for a week, with most participants starting the evaluation on the 12th of May and ending on the 19th of May. Three evaluations ran from the 14th to the 21st and were scheduled later, as not all participants had time to start the evaluation on the 12th. During the week, each evaluator was asked to use the application at least once a day for a week. After each use, they were asked to write down their thoughts with an emphasis on writing, preferably 5 lines or more each day. Lastly, they were asked to write final reflections about how they used the app during the week. This study is inspired by diary studies[31] but does not feature prompts. I decided not to include any prompts to allow the evaluators' epistemic knowledge to show. However, not including prompts might have found fewer similarities in the answers than if I had done otherwise. The resulting diaries, both original and, if the original was written in Danish, then translated, can be read in the Appendix C.1.

Each evaluation started with the participant downloading the application. Afterwards, the evaluator and the participant went on a short walk where the participant learned to use the app and could have questions about the app answered. This walk also served to discuss the initial thoughts about the application. After each walk, a small semi-structured interview[1] lasting approximately 15–30 minutes were conducted with all participants, except for Participants 1 and 2.[1] All interview transcripts are in the appendix C.2. Here, the evaluator could grasp the participants' initial experiences with the application and how much of an interest they had in the local bird wildlife. In

1 Participants 1 installed the app remotely and did not participant in the initial walk or interview and participant 2 took longer with the walk which meant there were no time for the interview both were therefore excluded from the interview portion of the study.

addition, the interview serves as a starting point for reflection for the participants.

6.1.1 Participants

The study involved ten participants, aged 21 to 61, comprising four women and six men. The majority were students, with eight participants currently enrolled in study programs. Among these, three pursued a Master's degree in IT Product Development. The remaining students were enrolled in a Bachelor's program in Molecular Medicine, a Master's program in Economics, a Bachelor's program in Chemistry and a Professional Bachelor's program in Diaconia and Social Education. The remaining three participants were employed: one as a Ph.D. candidate in the Department of Chemistry at Aarhus University, one as a system developer in the Department of Physics, and one as a pedagogue at a school. Two participants were already interested in birds, and most were waiting to learn more about their environment.

In addition, an eleventh individual participated in limited capacity due to their Android device running an older operating system, which restricted them to using only the listing activity of the experience. This participant is currently pursuing a Bachelor's degree in Biology.

6.1.2 The perspective for the qualitative data analyses

The study consists of qualitative data gathered from 11 participants. Each participant responded to varying depths, as some did not go walking every day and wrote only brief entries. To identify themes within the responses, I conducted an analysis inspired by thematic analysis, as outlined by Braun and Clarke [14, 19]. The results of this analysis are presented in Appendix C.3.

I describe the analysis as inspired rather than strictly following the thematic analysis method because such analyses typically involve multiple evaluators who independently code the responses to ensure broader generality and reliability. As I conducted this thesis independently, I was the sole coder of the responses. To mitigate this limitation and strengthen the analysis, I occasionally consulted the interview data to cross-reference and support the coding decisions, aiming to achieve a greater sense of generality.

The resulting themes form the basis for the results presented in Section 6.2.2, accompanied by illustrative participant quotes. Certain responses—closely tied to the participants' epistemic backgrounds—offered unique and insightful observations that did not fit within the themes that arose from the thematic analysis. These responses opened up entirely new avenues for development not previously considered by the author, and thus I felt they deserved their section 6.2.3.

6.2 RESULTS

The results have been divided into three sections. The first section presents my reflections on the interview responses. The second covers the themes that emerged from the diary study, based on a thematically inspired analysis. The third section highlights individual perspectives that, while not fitting neatly into the broader themes, were particularly interesting or insightful.

6.2.1 Interview results

As previously discussed, participants 1 and 2 were not interviewed. Furthermore, I accidentally overwrote interview 5, and as such, the interview section consists of only 9 participants.

8 Participants had an overall initial positive response to the application, and all 9 participants noticed more birds than when going for a regular walk. This difference could be due to how they were actively looking for the birds to record them, and looking for the birds they were hearing through the app. All 9 participants used the Merlin ID app to help them identify the birds. However, the 2 participants who had a pre-existing interest in birds and, for the most part, did not use Merlin ID, resorting to only using it when unsure about the observed bird. Multiple participants asked about combining the functionality of the apps in order not to have to change between apps all the time. Something which became a reappearing trend in the dairy study result

Several participants reported going on regular walks, often seeking out areas with nature during these outings. They described the walks as relaxing and helpful for clearing the mind. For some, the soundscape played an important role in this experience: Natural sounds such as birdsong and the wind in the trees contributed to a sense of calm. Others, however, preferred to listen to music while walking. In contrast, many participants found the urban soundscape to be noisy and overstimulating, leading to discomfort when walking near roads or in areas with significant industrial, mechanical, or human-made noise. One participant, however, occasionally appreciated industrial areas—particularly when they had a certain aesthetic cohesion. For example, he described enjoying the atmosphere of the harbour, where even a boat's horn—typically considered an unpleasant sound—could become a positive part of the experience. He clarified, though, that this appreciation did not extend to traffic or road noise.

One participant found it hard to identify which bird sounds were real and which were from the app, forcing him to rely on visually seeing and entering the birds rather than identifying them through sound. Another participant shared this sentiment, saying the experience was somewhat confusing and overwhelming, as they had to relate to both the digital birds and real ones. They did, however, find it intriguing and fun to have a digital element to the bird-watching experience.

One participant was concerned about hearing certain types of birds, namely pigeons and seagulls, as they are quite common in Aarhus. The participant dislikes these birds. When asked why the participant thought this way about the animals, he cited seagulls as food thieves and aggressive, calling their calls unpleasant. As for pigeons, when asked why he disliked them, he somewhat changed his stance and mentioned how he thinks of them as pests, but not as bad as the seagulls. He finds their song/call to be pleasant, but still does not find it as pretty as, for example, the blackbird's song.

Some general concerns with technical issues were shared amongst participants, such as the playback voice being low compared to the bird sounds, and the record button sometimes being a bit unresponsive. One participant in particular had a lot of issues with the observation mechanism, finding the speech interface slow and bothersome, and wished they could use the search system included as a last resort, as the only method for uploading. This participant also faced more difficulties with uploading, with uploads often failing throughout the entire week, something that would rarely happen to other participants but would happen almost every third time for this participant. They also got so frustrated with the speech recognition that they made a false upload during the initial walk after the system heard the bird wrong.

A participant commented on how they could see the application being used as a pedagogical tool to engage people with special needs, such as individuals with Down syndrome, in bird wildlife. They attributed the app's simple interface and task-based/playing interaction of finding and recording birds as observations.

As I walked with them, I also made some observations myself. Most participants walked with the phone out and looked at it when making observations. When not, they were actively looking around the environment, often stopping to identify or look for a bird.

6.2.2 Diary Study Thematic Analysis

Table 6.1 presents the identified themes and the number of responses associated with each. This table provides an overview of the magnitude and distribution of thematic responses gathered during the diary study.

Category	Theme	Count
Positive (30)	Increased knowledge of local birds	8
	Increased awareness and found more birds	18
	Noticing	4
Neutral (22)	Use of app with other media	2
	Integration between merlinID and Urban Echoes	3
	Want more information	5
	Difference in use based on time of day	4
	Importance of how sounds reflect the real world	8
Negative (26)	Uncomfortable with voice recognition as an interface	11
	Technical issues/Bugs	6
	Confusion due to app and real sounds mixing	2
	Fatigue stemming from repeated use	7
Mics		6

Table 6.1: Themes and magnitude of responses categorised as Positive, Neutral, or Negative

6.2.2.1 *Positive*

The most common finding amongst participants was an increased awareness of both sonic and visual elements in their environment. The increased awareness led the participants to notice more birds than usual. It also became apparent that participants sought to connect their auditory and visual environments. A general positive attitude towards this increased awareness was also present in these responses.

> Within about 1 km of Børglum Kollegiet: In the immediate area of Børglum (< 1 km), I was able to hear birdsong through the app. I liked how the resulting attention towards possible bird sightings made me more focused, and gave me a "mental pause" in that way, more so than music would usually do. - Participant 9

It became evident in some participants' responses that the increased awareness and sightings of birds resulting from thereof helped the participants become more engaged in birds. Furthermore, they started to recognise the birds, their calls, and learn their names, increasing their knowledge of the local fauna.

> On the days I have used the app and the times I've been outside, I have become more aware of birdsong and other sounds in the area. I recognise more bird calls now.- Sometimes I've used a mindfulness approach and paid more attention to bird sounds and being present in the moment when listening to the recordings while walking alone. I stop and listen and try to look for the birds—and sometimes, the same bird playing in the app is also there in real life, singing right where I am. - Participant 1

A few participants also began to notice the birds, in a manner akin to Anna Tsing's notion of noticing — an attuned and situated form of attention to the more-than-human. One participant began reflecting on how urban environments might better accommodate birds, observing patterns in their groupings, noticing which birds resided where, and wondering whether they formed communities of their own. This participant thought this information could be used for city planners and communities to help birds of a certain area, as seen in the quote and Figure 6.1. Another participant similarly started to notice what kind of birds were in their local area, but to them it was morose a source of fatigue as the same birds kept appearing. This participant's response was not coded for noticing, as I found it just shy of the attunement described within Tsings' noticing. A different participant had some of their responses coded for noticing due to their focus on biodiversity, considering which types of birds could be found in different areas and was surprised by the variety of birds found in urban and suburban environments. A third often paused to engage in what they described as a mindfulness practice — staying present in the moment while looking for and then observing the birds they heard through the application.

> I've been noticing that within the more Urban areas, the birds seem to have a large preference for one type of environment, therefore making the type of birds you'll see or hear in certain environments very low in diversity. Today I walked through a small neighbourhood with, honestly, a large amount of birds for an Urban area, but they were 95 per cent just one kind of bird. I've noticed the same in another neighbourhood with another type of bird. Maybe it says something about their preferred environment, or maybe they choose to flock together in certain areas like a neighbourhood. Either Way, it made me think that you could possibly set up amenities for the birds that the app plots in certain areas to encourage birds to live within cities - Participant 4

Figure 6.1: A quick sketch by participant 4 drawn after explaining her idea for bird neighbourhoods

6.2.2.2 Neutral

Participants 3,4, and 5 all used the application during the late evening and nighttime. Their reflections point towards how different times of day affect the user experience, both in terms of lower bird activity making observations harder, and in how the audio connects with the visual environment, the audio which evokes ideas of high levels of bird activity does not match the evening/night activities for he birds

> "The bird noises from the app didn't match up with the behaviour of the birds in this instance. Although it is obvious that the birds would need to rest, the behaviour seen in real life vs heard through the app was extremely disconnected."
> - Participant 4

The importance of the visual environment and the real world in relation to the sound was evident in many responses. With positivity in responses where the environments match, and a disconnect when they do not match. This fits with the earlier discussions in section 3.2.1 about aligning the acoustic Ecology with the Visual Environments.

> It feels nice to hear the ambient sound in the headphones almost perfectly match what I could hear IRL. I noticed myself taking longer than usual, just taking in all the sounds of nature, the birds, trees rustling or creaking, a lawnmower in the distance. All together, I feel refreshed. - Participant 7

Two participants used the application's listener role along with other audio content, one an audiobook and the other music. They both had positive experiences with using the app alongside this additional audio content.

> Tiredly walked to return bottles at 9 PM. On the way there, I noticed how many of the same bird species there are in Aarhus. It started to feel a little less exciting to enter blackbirds and wood pigeons over and over again. But then it suddenly got exciting when I turned a corner and heard a great tit and a jackdaw — you get a little rush from discovering a new bird. On the way back from the bottle machine, I was carrying two bags, so I couldn't enter any birds. Instead, I tried listening to an audiobook while the app was still on. It was actually really cool — just as Kublai Khan had conquered a Chinese army, the great tit, jackdaw, blackbird, and wood pigeon I had previously entered all started singing over the battle description. I thought it was pretty cool to hear bird sounds without entering them. - Participant 3

Participants 5 and 11 disagreed on whether or not having to say the bird's real name instead of its common name was annoying or beneficial. Participant 5's reflection also showcases a fault in the suggestion section, with the suggestion algorithm giving results that are too far removed from the spoken word.

> "I heard quite a few birds and also saw some. It would be smart if the app could recognise birds' common names and suggest the correct species. For example, the hooded crow is usually just known as a crow. If you say crow, many suggestions appear, but not hooded crow. If a crow showed up, it would be easier to select the right bird." - Participant 5(translated from Danish)

> "Again, learning birds' real names – it's good that you're forced to give a name to a bird in the database." - Participant 11 (translated from Danish)

Many participants wanted the app to provide more information about the birds they make observations on or hear. Some also requested maps of observations.

> "Generally, I think I've learned about different bird calls/appearances, and there's potential to learn even more. That is also to some extent with the help of Merlin, but your app makes me repeat it, which can help learning (bird Duolingo?) Sound versus visual; data visualisation: detail vs immersion. Would like to be able to dig more into the observations made nearby. Maybe I can look at a map to see where the birds were spotted." - Participant 11

Furthermore, some wanted more integration with MerlinID or the features of MerlinID in Urban Echoes.

> "Went on a longer walk in Nordby Hills with my family. The app isn't always handy to use when walking with others, mainly because it takes time to first open Merlin ID and then Urban Echoes. Integration between the two apps would definitely be a big improvement — maybe with automatic data collection when Merlin ID suggests you've heard a particular bird. It was still fun to discuss with the others which birds we could see and hear. I really enjoy discovering new birds — heard a chiffchaff, a greylag goose, and a bird I've forgotten the name of, but one I hadn't seen in Aarhus. You get the feeling of collecting Pokémon. I think it would be cool with a Pokédex-style feature where you could see the birds you've "collected" — to make it a bit more gamified." - Participant 3

6.2.2.3 Negative

Some experienced difficulty differentiating between real-world sounds and those from the application. While this speaks to the generally high and lifelike audio quality, it also created confusion among these participants, leading to false observations.

> The app worked well; I didn't go on the longest walks and didn't mark all the birds I encountered, partly because I didn't know their names. I also heard bird sounds from the app. That was, of course, a nice touch, but at one point I got a bit confused because I thought it was a real bird and tried to mark it in the app. - Participant 5

Five out of eleven participants experienced some level of fatigue with the use of the application during the week. Perhaps this stemmed from feeling an obligation to use the application and report on the findings. The most common type of fatigue came from responses that said that the app had become something they felt they had to use rather than something they actively wanted during that walk. It should be noted that most of these participant were positive in their final reflections. However, repeated use, along with having to write feedback, might have made this fatigue appear faster and more frequently than in the intended use case. However, a participant experienced fatigue due to the number of repeating birds of the same kind. He suggested having a filter to avoid hearing these when you did not want it, something which is against the intended application of Urban Echoes.

> "On the way there, I noticed how many of the same kinds of birds there are in Aarhus. It started to get a bit less exciting to enter blackbirds and wood pigeons over and

> over again. But then it suddenly became exciting when I walked around a corner and heard a great tit and a jackdaw — you get a little rush from finding a new bird." - Participant 3(translated from Danish)

The most common negative coding in the responses related to the speech interface. The act of saying bird names out loud in public for the interaction made many participants feel like they drew unwanted attention. This was exacerbated when they had to repeat themselves if the application did not hear correctly. Some participants said only making observations when nobody was around, while others simply felt uncomfortable. This all hints towards how, at least in Denmark, speech interfaces are not socially acceptable for public spaces. Another complaint about the speech interface was how slow it was compared to using a more traditional search bar approach. This, however, is probably more a result of the direct application rather than an inherent limitation of speech interfaces.

> Another reason I would love this feature [talking about the search bar] is because I hate making verbal observations in public. As such, if I were a normal user, the lack of this feature would be enough for me to stop using the app entirely. So I think giving the user the option to choose to make the observation through verbal or written means would be an improvement to the app." - Participant 6

Several participants recorded frustrations with the technical aspects of the application. Issues related to the microphone button, speech recognition and upload difficulties plagued many participants' experience. A critical bug related to the confirmation card not appearing with some birds proved so detrimental that an update fixing this problem was pushed on the second day of the evaluation, and all participants then had to update.

> "Record button does not change back to green, but stops using the microphone. With a repeat press (while it is red and inactive) will turn the microphone back on. So it functions as it should, but the visuals are off. It was windy, so it was very hard to log observations. And therefore I think a search option from the start menu would be a huge quality of life feature. " - Participant 6

6.2.3 Analytical Exceptions and Developmental Implications

This section is made up of the responses that did not fit into the themes but nevertheless have some developmental implications.

Participant 7 thought of a share feature where they would be able to share what they are hearing with someone not located at the same geographical position. The share feature was something also originally envisioned as part of the application, but was not implemented for the prototype. Having it be brought up in the evaluations, however, shows the value of such a feature, which would be a prime candidate for further development.

> "Something that came to mind when making new observations and hearing the ones from yesterday. Is that it could be great if I could share the observation, the sound ambience, with someone who isn't in the same locale as me. To share with them how it sounds to be here in nature." - Participant 7

One participant who is on the autism spectrum and struggles with overstimulation also noted how it helped them pay attention to the sounds of nature, something they normally struggle with in cities due to the noisy soundscape. How the app could help people struggling with overstimulation from the city soundscape was not something I had considered when developing the app.

> "I found the app made a notable difference in the more urban environments, where it was very easy to spot the birds but hard to hear them. When the birds were flying in the sky and between buildings, they stood out easily, but due to noise pollution from cars and people, it was hard to hear them. Especially as an autistic individual, it is very hard not to get overstimulated by the noises in the city and not even enjoy the sounds of nature at all. Using the headphones with the app, I was able to synchronise the sound of the birds as I saw them." - Participant 4

As mentioned in the Section 6.2.1, one participant currently under education within social pedagogy found Urban Echoes to have some educational applications, especially if further development expanded on educational aspects. Beyond educational aspects, the participant also suggested adding more gamified elements after having a discussion with their educator about the app.

> "If these small issues are resolved, I believe — as stated — that Urban Echoes has great educational potential. Beyond fostering connection with nature, there are other pedagogical perspectives worth exploring. I hope that further development of the app will include a strong focus on its educational applications."- Participant 9

6.3 discussion

The application effectively encouraged users to be attentive to their auditory and visual environments. Several participants reported excitement when discovering and identifying new bird species in their local surroundings, often noting that the number and diversity of birds exceeded their expectations. Biggs describes a similar phenomenon in *Watching Myself Watching Birds* [10], where she recounts how, after noticing birds, they seemed to appear everywhere. One participant in this study shared a similar realisation, remarking that despite having lived in the same city for their entire life, they had never noticed the abundance and variety of birdlife all around them. This individual now consistently sees and hears birds throughout their daily activities. Likewise, during the application development, I became more aware of avian life. I had not paid attention to my local birds before this project.

There is a broader discussion about how many people simply exist with the birds, paying them little attention, to the point of blending into the background; however, with very little effort, we start to notice the birds. That *Urban Echoes* was able to significantly heighten participants' awareness of birds and, for some, cultivate a deeper sense of excitement about local bird populations, represents a major success criterion for the application.

6.3.1 Temporality

One key finding from the evaluation was the impact of temporality on the user experience. The responses highlighted that a cohesive and enjoyable experience depended on the alignment between the auditory and visual environments. In particular, a temporal mismatch—such as hearing bird sounds at times when birds are typically inactive—was found to be disorienting. One participant remarked that the sounds felt disconnected when played at night, as the surrounding environment was quiet and birds were not visibly present. This suggests a need for greater user control over the temporal settings of the application. Allowing users to select the time of day for auditory playback could help mitigate this issue by offering a more contextually appropriate experience. For instance, subdued or quieter nighttime soundscapes could be used as the default for nighttime use, with an option for users to override the current temporal setting and explore different soundscapes, such as a morning chorus, regardless of the actual time.

Further discussion with one participant also raised the idea of long-term temporal dissonance. One example involved a formerly forested area that had been converted into an industrial zone. In such cases, the ability to "go back in time" and hear what the space may have sounded like 20 years ago could offer emotional or reflective value, even if the auditory and visual environments no longer align.

This introduces a broader design question: Can intentional temporal dissonance, such as hearing daytime at night or historical soundscapes, provide a meaningful experience? While speculative, it may be valuable to offer users both realism and imaginative temporal exploration, depending on their goals.

6.3.2 Fatigue after consecutive use

During the evaluation, 5 out of 11 participants reported experiencing fatigue or a sense of obligation to go on walks and use the app as the study progressed. This suggests that the application may not be suited for daily use over extended periods, but rather for more occasional engagement. Such as exploring a new area, or when seeking the experience the app provides, rather than becoming a routine or habitual tool. Since the participants were encouraged to go for daily walks, these feelings of fatigue might be more prevalent than if used more naturally over a longer period.

6.3.3 Information

Another success criterion for the application was an increase in users' knowledge of their local avian wildlife—learning calls, species names, and appearances. The app largely succeeded in this endeavour, particularly with the help of *MerlinID*, which was used in conjunction with *Urban Echoes* by all participants. *Urban Echoes* effectively provided the motivation and experiential context for users, many of whom had little prior interest in birds, but did not offer built-in mechanisms to identify or learn more about the birds themselves. In contrast, *MerlinID* is well-designed for bird identification and learning, but it assumes that the user already has a certain level of curiosity or interest in birdwatching.

In this sense, the two applications complemented each other: *Urban Echoes* sparked interest to learn, while *MerlinID* enabled users to deepen their understanding. Multiple participants expressed a desire for additional information about the birds they encountered through *Urban Echoes*—those they recorded, or those they heard. Specifically, they requested access to details such as species names, images, and other contextual information to help identify and learn more about the birds they were listening to.

These responses suggest an app design in which more of the learning experience is integrated into *Urban Echoes* itself. This could eliminate the need for an external app like *MerlinID*, as users would be able to learn and identify birds through a combination of images, names, and calls. In earlier versions of the prototype, the name of the bird was displayed on-screen while the call was played. However, I later removed this feature to encourage users to focus more on their surroundings rather than looking at their phones. Following the evaluations, though, I now believe that future development would benefit from incorporating more educational elements. A user seeking a less information-rich experience can simply put the phone away and immerse themselves in the soundscape.

6.3.4 Evaluating the Aesthetics in Sonic Interaction

Using the previously discussed framework shown in Figure 3.2, the current approach of selecting sound files with high-quality ratings from Xeno-Canto provides very little control over *Intensity, Pitch, Timbre,* and *Fidelity* [23]. That being said, only two responses were coded for *Intensity*—one participant commented on the voice and playback audio being too quiet compared to the sounds, while another felt the sounds were too loud when used at night. To ensure higher aesthetic quality across these parameters, sound files could be hand-picked; however, this would be a rather time-intensive task.

More relevant for the application—both in terms of what is more controllable and what responses were coded for—are *Context, Spatial, Originality,* and *Expectation*.

Context: Generally, the context was perceived positively; however, as previously discussed, when the context did not match the sound, the experience suffered. Night-time use, in particular, is an area that requires further refinement to create better contextual alignment.

Spatial: Responses were mixed—some users found the spatial aspect of the experience confusing and disorienting, struggling to differentiate between real-world sounds and the audio from the headphones, which was only spatially mapped in terms of loudness and left or right ear. Others, however, reported paying close attention to whether the observation was perceived in the left or right ear. From the responses, it was unclear whether users were using noise-cancelling headphones or keeping one ear free. However, it can be hypothesised that the spatiality of the audio experience works better when using noise-cancelling headphones in both ears. If users are only wearing one earbud, which may be necessary to allow ambient sound for making observations, the mixing can become confusing and may not be perceived positively. This confusion could stem from the fact that users must focus not only on listening but also on identifying sounds to make observations.

Originality and Expectation: These aspects were considered satisfactory, with most sounds aligning with what users expected—namely, bird sounds. Exceptions included one recording in which a dog barking could be heard in the distance, which confused one participant. The previously discussed issue of hearing activity that does not match what is visible, particularly at night, also applies here.

Many responses were coded as describing the sound as pleasant and providing a sense of calm, to a greater degree than, for example, music. This highlights that the experience was, overall, an aesthetic sonic one. It was also mentioned as a more pleasant alternative to the urban noise of traffic and people.

The dichotomy between urban noise, such as traffic, typically perceived as undesirable, and natural sounds like birdsong or running water, commonly associated with positive experiences, also appears in soundscape research as a key variable influencing well-being and environmental perception [2].

6.3.5 Audio interface

In addition to the previous discussion points, this study also highlighted specific challenges associated with using an auditory interface. Some participants found the interface slow or cumbersome, particularly because they had to listen to full sentences before being able to respond or take action. However, this perceived slowness may be more a result of the particular design choices in this implementation rather than a fundamental limitation of audio interfaces in general. For instance, shorter audio cues or non-verbal sounds could potentially replace longer spoken instructions to improve responsiveness. A more inherent difficulty with auditory interfaces, however, appears to be related to speech recognition. Many participants reported feeling uncomfortable using voice commands in public settings, indicating a social barrier to adopting speech-based interaction for use in public settings.

7 CONCLUSION

In this thesis, I investigated *Urban Echoes*, an aesthetic auditory map experience designed to engage people with their local avian wildlife. The application was tested over the course of a week by 11 participants, who wrote diary entries about their experiences using the application. The responses were analysed using thematic analysis [19]. The results showed that *Urban Echoes* succeeded in engaging users with their local wildlife, as the prototype consistently increased users' awareness and perception of local birds. Participants also expanded their knowledge of bird calls, names, and habitats. Most participants perceived the aesthetic experience as pleasant. However, technical issues reduced the overall experience, at times discouraging participation and making interaction more cumbersome. Broader implications concerning the public acceptability of speech interfaces also emerged.

Both application activities, *Listener* and *Observer*, contributed to the goal of engagement with birds. However, aspects relating to the *Observer* role were consistently perceived as a source of frustration and fatigue. Furthermore, repeated use of the application in the same geographic areas reduced novelty and decreased engagement, as users became familiar with the birds in their surroundings. This suggests that the application is best suited for occasional use or for exploring new areas, rather than for use during daily walks.

7.1 DID URBAN ECHOES SUCCEED AS AN ONTOLOGICAL DESIGN?

While few responses were explicitly coded for *noticing*, I argue that *Urban Echoes* succeeds when viewed through the lens of ontological design. A consistent finding was that *Urban Echoes* heightened users' awareness of birds beyond their prior baseline. This constitutes a subtle but meaningful shift in one's way of being. Although a more definitive assessment of deeper epistemic or ontological changes would require a longer evaluation period and in-depth follow-up interviews, the findings suggest that the application initiated ontological transformation for several participants.

On a more personal level, designing and creating *Urban Echoes* has greatly expanded my knowledge and interest in birds. The work has changed my ontological perspective on how we co-exist with avian life, especially with pigeons, who were the original focus of the project.

7.2 DESIGN IMPLICATIONS FOR SIMILAR PROJECTS

Findings related to *Urban Echoes* offer several design implications for similar systems, particularly those that seek to employ speech interfaces or location-based sound experiences.

7.2.1 Location-Based Sound and the Aesthetic Quality of Natural Sounds Compared to Urban Soundscapes

Bird sound playback, even when digitised, was generally perceived by participants as pleasant and restorative. These sounds were in stark contrast to typical urban sounds dominated by traffic, construction, and mechanical noise. This supports existing literature on the positive psychological effects of natural soundscapes (e.g., [3, 4, 44, 57]). However, for some participants, the bird sounds confused when mixed with real-world sounds. The aesthetic experience also depended on the alignment between the auditory and visual environment; when the sounds did not correspond with the visible surroundings, participants experienced a sense of dissonance, decreasing the aesthetics of use.

7.2.2 The individual's perception using Speech interface in a public setting

The findings of this project found limitations in the practical deployment of speech interfaces in public, non-controlled settings. Some issues related to the specific implementation in *Urban Echoes*, such as the slowness of the interface, but larger technological and social implications remain. At least in a public setting in Denmark, the speech interface was perceived as unacceptable to use, drawing unwanted attention. Different public settings might provide different results, but this needs to be investigated further. However, in Denmark, the speech interface provides a significant barrier to entry and hinders usability.

7.2.3 Desire for Informational Content

Users expressed a clear interest in learning more about the birds through the application. Although the original intention was to create an ambient and aesthetic experience with minimal emphasis on information, the system required explicit knowledge of bird calls and names when submitting observations. As a result, many participants expected that the system would provide more educational content since they needed this knowledge to use the application effectively. In cases where users lacked prior knowledge of birds, the system encouraged curiosity but did not offer any integrated mechanisms to support learning.

This created a fundamental contradiction: While the system encouraged exploration and discovery, it did not provide the tools necessary to support that learning journey. However, the participants' desire to increase their knowledge represents a form of positive engagement that aligns with the principles of ontological design. Instead of offering in-app support, users were directed to use *MerlinID* for learning and identification, although the expectation was that the application itself would facilitate this process.

Specific requests for integrating learning into the listener experience were prominent. Some participants expressed a desire to identify the birds they were hearing, while others suggested adding complementary access to additional details, such as names, calls, and images, when making an observation. An option for future iterations of the application would be to incorporate some of these suggestions to better support learning.

7.3 FUTURE WORK

There are several different avenues for further development, each of which expands certain strengths of the current application. Most of these avenues for future work present vastly different use case scenarios.

7.3.1 Isolating bird sounds for playback in application

The current app uses recordings sourced from *Xeno-Canto*; however, as discussed, these come with their sound ecologies, introducing many unknowns and potential sources of dissonance in the experience. AI could be used to isolate bird sounds in recordings sourced from *Xeno-Canto*, providing cleaner samples without preexisting sound ecologies.

A model might be trained on the existing *Xeno-Canto* recordings. Additionally, the sound files could be checked for recording levels and normalised to ensure that all sounds fall within the same loudness range.

The drawback of this approach is a reduction in sustainability by design, as generative AI models typically involve high energy consumption during training. This impact could potentially be mitigated by training the model exclusively on days when large amounts of green energy are available on the power grid.

7.3.2 Optimise the app for learning potential

Several participant suggestions could be implemented to enhance the educational value of the experience while maintaining the simplicity of use. For example, displaying images and offering on-demand information during the listening activity can help users identify and learn more about the birds they encounter.

Furthermore, integrating the features of *Urban Echoes* into larger birding applications such as *MerlinID* or *GoBirds*—or at least providing a stronger coupling between these applications - could significantly increase accessibility and functionality. Integrating *Urban Echoes* into *MerlinID*, for example, would combine the strengths of both platforms: the immersive and aesthetic engagement of *Urban Echoes* with the comprehensive species identification and educational resources of *MerlinID*.

7.3.3 Citizen science

It is unclear whether *Urban Echoes* could be used effectively for citizen science. However, it may result in more frequent observations than platforms like *eBird*, as users often encounter and observe common birds regularly. Looking at DOFbasen[25], there are already more observations in the Danish region than on *eBird*, although these still mostly concern sightings of rarer birds.

To use sightings as a reliable database, it would be necessary to implement a verification system. One possible approach could involve cross-referencing observations with data from *eBird* and other users. A user with a history of high-credibility observations could be assigned a higher confidence level when uploading new data. Another verification method could involve the use of AI for sound identification or image recognition, although this would require users to submit a photograph or an audio recording. Like other AI-based solutions, this approach would also require energy for training, even when using transfer learning.

Part I

APPENDIX

A PROJECT WORK ON MORE THAN HUMAN-CENTRED DESIGN

A.1 THE REPORT FROM THE PROJECT WORK

. **Link to a GitLab project containing the report Link:** https://gitlab.au.dk/pigeon-project/exploring-multi-species-perspectives-in-hci-through-th

A.2 THE EARLY PROTOTYPE FOR URBAN ECHOES

Link to GitLab containing the source code for the project prototype
Link: https://gitlab.au.dk/pigeon-project/audioapp

B DIAGRAMS

B.1 ENTIRE FOLDER

Link to folder containing images of UML diagrams Link: https://drive.google.com/drive/folders/1letQ1mWmleg6uo56rQRYFna5eWOfV-VU?usp=sharing

B.2 SYSTEM

Link to image of UML diagram for system Link: https://drive.google.com/file/d/1WT6pASitg1UFn4xd5wHVHeyNV2pvO95j/view?usp=sharing

B.3 OBSERVATIONUPLOADER

Link to image of UML diagram for ObservationUploader Link: https://drive.google.com/file/d/1rHogMhxW6ZIaOhle8OVvPJrv0Z8DcW6O/view?usp=sharing

B.4 SPEECHCOORDINATOR

Link to image of UML diagram for SpeechCoordinator Link: https://drive.google.com/file/d/1YjbqzQLCuby6OZMSTODcS5TB3lxnKwVr/view?usp=sharing

B.5 LOCATIONSERVICE

Link to image of UML diagram for LocationService Link: https://drive.google.com/file/d/1lYM_c3QfkrPgCmqy6ks3TIhOP45PkOPu/view?usp=sharing

C EVALUATIONS

C.1 DIARY STUDY RESPONSES

Link to Google Docs folder containing the evaluation diary responses Link: https://drive.google.com/drive/folders/1lUAUgP384W6d9hCbFUsGoeR75pICr5
usp=sharing

C.2 INTERVIEWS

Link to Google Docs folder containing the interview notes Link:
https://drive.google.com/drive/folders/18Wezf2twcPnk5ZnoG_evCXTw7fCqPF4z?usp=sharing

C.3 THEMATIC ANALYSE

Link to Miro board containing the evaluation diary thematic analysis
https://miro.com/app/board/uXjVIxEIwWs=/?share_link_id=365318141653

D GITHUB

D.1 PROJECT GITHUB

Link the project GitHub containing the project code https://github.com/Jakob-worm/UrbanEchoes

E CODE SNIPPETS

E.1 MULTI PROVIDER SETUP

```
Widget build(BuildContext context) {
  return MultiProvider(
    providers: [
      // State managers
      ChangeNotifierProvider<PageStateManager>(
        create: (context) => PageStateManager(),
      ),
      ChangeNotifierProvider<MapStateManager>(
        create: (context) => MapStateManager(),
      ),
      ChangeNotifierProvider<NavigationProvider>(
        create: (context) => NavigationProvider(),
      ),
      ChangeNotifierProvider<UploadNotificationService>(
        create: (context) => UploadNotificationService(),
      ),
      Provider<DatabaseService>(
        create: (context) => DatabaseService(),
        lazy: false,
      ),
      Provider<ObservationService>(
        create: (context) => ObservationService(
          apiUrl: dotenv.env['API_URL'] ?? 'https://api.urbanechoes.org',
        ),
      ),
      ListenableProvider<ObservationUploader>(
        create: (context) => ObservationUploader(
          databaseService: Provider.of<DatabaseService>(context, listen: false),
          observationService: Provider.of<ObservationService>(context, listen: false),
          notificationService: Provider.of<UploadNotificationService>(context, listen: false),
        ),
        dispose: (context, uploader) {
          debugPrint('ObservationUploader provider dispose called - keeping uploader active');
        },
      ),
      ChangeNotifierProvider<RecordingPlayerService>(
```

```
      create: (_) => RecordingPlayerService(debugMode:
          debugMode),
      lazy: true,
    ),
    ChangeNotifierProvider<SpeechRecognitionService>(
      create: (_) => SpeechRecognitionService(debugMode:
          debugMode),
      lazy: true,
    ),
    ChangeNotifierProvider<BirdRecognitionService>(
      create: (_) => BirdRecognitionService(debugMode:
          debugMode),
      lazy: true,
    ),
    ChangeNotifierProvider<WordRecognitionService>(
      create: (_) => WordRecognitionService(debugMode:
          debugMode),
      lazy: true,
    ),
    ChangeNotifierProxyProvider4<
      SpeechRecognitionService,
      BirdRecognitionService,
      WordRecognitionService,
      RecordingPlayerService,
      SpeechCoordinator>(
      create: (context) => SpeechCoordinator(
        speechService: Provider.of<SpeechRecognitionService>(
            context, listen: false),
        birdService: Provider.of<BirdRecognitionService>(
            context, listen: false),
        wordService: Provider.of<WordRecognitionService>(
            context, listen: false),
        audioService: Provider.of<RecordingPlayerService>(
            context, listen: false),
        observationUploader: Provider.of<ObservationUploader>(
            context, listen: false),
        debugMode: debugMode,
      ),
      update: (context, speechService, birdService, wordService
          , audioService, previous) {
        if (previous == null) {
          return SpeechCoordinator(
            speechService: speechService,
            birdService: birdService,
            wordService: wordService,
            audioService: audioService,
            observationUploader: Provider.of<
                ObservationUploader>(context, listen: false),
            debugMode: debugMode,
          );
        }
        previous.updateServices(
```

```
      speechService: speechService,
      birdService: birdService,
      wordService: wordService,
      audioService: audioService
     );
     return previous;
    },
   ),
   ChangeNotifierProvider<SeasonService>(
    create: (_) => SeasonService(),
   ),
   Provider<AppStartupService>(
    create: (_) => AppStartupService(),
   ),
   Provider<bool>.value(value: debugMode),
   ChangeNotifierProvider<LocationService>.value(value:
     locationService),
  ],
  child: MaterialApp(
   title: 'Urban Echoes',
   theme: ThemeData(
    primarySwatch: Colors.blue,
    bottomNavigationBarTheme: const
      BottomNavigationBarThemeData(
     backgroundColor: Colors.black,
     selectedItemColor: Colors.white,
     unselectedItemColor: Colors.grey,
    ),
   ),
   home: const InitialScreen(),
  ),
 );
}
```

Listing E.1: MultiProvider setup in Flutter

E.2 FASTAPI BACKEND CODE

```
from fastapi import FastAPI, HTTPException, Query, Depends
import requests
import psycopg2
import random
import os
import logging

from fastapi.middleware.cors import CORSMiddleware
from dotenv import load_dotenv
from psycopg2.extras import RealDictCursor

load_dotenv()
```

```

app = FastAPI()

app.add_middleware(
    CORSMiddleware,
    allow_origins=["*"],  # Change to specific domains for security
    allow_credentials=True,
    allow_methods=["*"],
    allow_headers=["*"],
)

# Configure logging
logging.basicConfig(level=logging.INFO)
logger = logging.getLogger(__name__)

# Database connection function
def get_db_connection():
    return psycopg2.connect(
        user=os.getenv("DB_USER"),
        password=os.getenv("DB_PASSWORD"),
        host=os.getenv("DB_HOST"),
        port=os.getenv("DB_PORT", 5432),
        database=os.getenv("DB_NAME ", "urban_echoes_db "),
        sslmode="require"
    )

EBIRD_API_URL = "https://api.ebird.org/v2/data/obs/geo/recent"
EBIRD_TAXONOMY_URL = "https://api.ebird.org/v2/ref/taxonomy/ebird"
XENO_CANTO_API = "https://www.xeno-canto.org/api/2/recordings"
EBIRD_API_KEY = os.getenv("EBIRD_API_KEY")
DATABASE_URL = os.getenv("DATABASE_URL")

if not EBIRD_API_KEY:
    raise ValueError("EBIRD_API_KEY is missing! Set it in Azure.")

if not DATABASE_URL:
    raise ValueError("DATABASE_URL is missing! Set it in Azure.")

LAT = 56.2639 # Copenhagen coordinates TODO change to your location
LON = 9.5018  # Copenhagen coordinates TODO change to your location

async def get_danish_taxonomy():
    """Fetch the eBird taxonomy with Danish names."""
    headers = {"X-eBirdApiToken": EBIRD_API_KEY}
    params = {"fmt": "json", "locale": "da"}

    try:
```

```python
        response = requests.get(EBIRD_TAXONOMY_URL, headers=headers, params=params)
        response.raise_for_status()
        taxonomy_data = response.json()
        return {species["speciesCode"]: species["comName"] for species in taxonomy_data}
    except requests.exceptions.RequestException as e:
        raise HTTPException(status_code=500, detail=f"Error fetching taxonomy: {str(e)}")

@app.get("/observations")
def get_observations(after_timestamp: str = Query(None, description="Fetch only observations created after this timestamp")):
    """Fetch bird observations from the database, with optional filtering by timestamp."""
    try:
        conn = get_db_connection()
        cursor = conn.cursor(cursor_factory=RealDictCursor)

        if after_timestamp:
            cursor.execute("""
                SELECT id, bird_name, scientific_name, sound_directory, latitude, longitude,
                       observation_date, observation_time, observer_id, created_at,
                       quantity, is_test_data, test_batch_id
                FROM bird_observations
                WHERE created_at > %s
                ORDER BY created_at ASC
            """, (after_timestamp,))
            logger.info(f"Fetching observations created after {after_timestamp}")
        else:
            cursor.execute("""
                SELECT id, bird_name, scientific_name, sound_directory, latitude, longitude,
                       observation_date, observation_time, observer_id, created_at,
                       quantity, is_test_data, test_batch_id
                FROM bird_observations
                ORDER BY created_at ASC
            """)
            logger.info("Fetching all observations")

        observations = cursor.fetchall()
        logger.info(f"Returning {len(observations)} observations")

        cursor.close()
        conn.close()

```

```
        return {"observations": observations}
    except Exception as e:
        logger.error(f"Error fetching observations: {str(e)}")
        raise HTTPException(status_code=500, detail=f"Internal
            Server Error: {str(e)}")

@app.get("/birds")
def get_birds():
    try:
        conn = get_db_connection()
        cursor = conn.cursor(cursor_factory=RealDictCursor)
        cursor.execute("SELECT common_name, scientific_name,
            danish_name FROM birds")
        birds = cursor.fetchall()
        cursor.close()
        conn.close()
        return {"birds": birds}
    except Exception as e:
        logger.error(f"Error fetching birds: {str(e)}")
        raise HTTPException(status_code=500, detail="Internal
            Server Error")

@app.get("/birdsound")
def get_bird_sound(scientific_name: str):
    params = {"query": scientific_name}
    response = requests.get(XENO_CANTO_API, params=params)

    if response.status_code != 200:
        return {"error": "Failed to fetch recordings"}

    data = response.json()
    recordings = data.get("recordings", [])

    if not recordings:
        return {"error": "No recordings found"}

    high_quality = [rec for rec in recordings if rec.get("q") in
        ["A", "B"]]

    if not high_quality:
        return {"error": "No high-quality recordings available"}

    selected = random.choice(high_quality)
    sound_url = f"https://www.xeno-canto.org/{selected['id']}/
        download"

    return sound_url

@app.get("/search_birds")
def search_birds(query: str = Query(..., min_length=1,
    description="Bird search query")):
    """Search birds by Danish name dynamically"""
```

```
    try:
        conn = get_db_connection()
        cursor = conn.cursor()
        cursor.execute("""
            SELECT common_name, scientific_name
            FROM birds
            WHERE common_name ILIKE %s
            LIMIT 10
        """, (f"%{query}%",))
        birds = [{"common_name": row[0], "scientificName": row[1]} for row in cursor.fetchall()]
        cursor.close()
        conn.close()
        return {"birds": birds}
    except Exception as e:
        logger.error(f"Error searching birds: {str(e)}")
        raise HTTPException(status_code=500, detail="Internal Server Error")

@app.get("/birdsOLD")
async def get_bird_list():
    """Fetch recent bird observations with Danish names and corresponding sounds."""
    headers = {"X-eBirdApiToken": EBIRD_API_KEY}
    params = {
        "lat": LAT,
        "lng": LON,
        "fmt": "json",
        "maxResults": 100,
        "includeProvisional": True
    }

    try:
        danish_names = await get_danish_taxonomy()
        response = requests.get(EBIRD_API_URL, headers=headers, params=params)
        response.raise_for_status()
        bird_data = response.json()

        birds = []
        for bird in bird_data:
            species_code = bird.get("speciesCode")
            scientific_name = bird.get("sciName")

            bird_info = {
                "danishName": danish_names.get(species_code, bird.get("comName")),
                "scientificName": scientific_name,
                "observationDate": bird.get("obsDt"),
                "location": bird.get("locName"),
                "speciesCode": species_code
            }
```

```
            birds.append(bird_info)

        return {
            "birds": birds,
            "count": len(birds),
            "location": f"Coordinates: {LAT}, {LON}"
        }
    except requests.exceptions.RequestException as e:
        raise HTTPException(status_code=500, detail=f"Error
            fetching bird data: {str(e)}")

@app.get("/health")
async def health_check():
    """Health check endpoint to verify that the API is running.
        """
    return {"status": "ok"}
```

Listing E.2: Full FastAPI Backend Code

E.3 PLAYBIRDQUESTION

```
\begin{lstlisting}
Future<void> playBirdQuestion(String birdName) async {
if (_isMuted) return;

_logDebug('Playing bird question for: $birdName with
    callbacks');

// Stop any current playback
await stopAudio();

try {
  // Reset sequence counter and set type
  _sequenceCompletedCount = 0;
  _expectedCompletions = 2; // Intro + Bird Name
  _lastPlaybackType = 'bird_question';

  // Cancel any existing subscriptions first
  _introCompleteSubscription?.cancel();

  // Prepare the bird name path
  String simplifiedName = _simplifyName(birdName);
  String birdPath = 'audio/recorded/birds/$simplifiedName.mp3
      ';
  String silentPath = 'audio/seilent.mp3'; // Path to silent
      audio file

  // 1. Set up the completion handler for the intro (one-time
      listener)
  _introCompleteSubscription =
```

```
          _introPlayer.onPlayerComplete.listen((event) {
        _logDebug('Intro completed, playing bird name immediately');
        if (!_isMuted) {
          // Try to play bird name, catch any errors
          _birdPlayer.play(AssetSource(birdPath)).catchError((error) {
            _logDebug(
                'Error playing bird file: $error, using silent file instead');
            _birdPlayer.play(AssetSource(silentPath));
          });
        }

        // Cancel this subscription after it's used
        _introCompleteSubscription?.cancel();
        _introCompleteSubscription = null;
      }, cancelOnError: true);

      // 2. Start playing intro
      await _introPlayer
          .play(AssetSource('audio/recorded/har_du_observeret_en.mp3'));
      _isPlaying = true;
      notifyListeners();
    } catch (e) {
      _logDebug('Error in playBirdQuestion: $e');
      _isPlaying = false;
      _lastPlaybackType = '';
      notifyListeners();
    }
  }
```

BIBLIOGRAPHY

[1] William C Adams. "Conducting semi-structured interviews." In: *Handbook of practical program evaluation* (2015), pp. 492–505.

[2] Francesco Aletta and Jian Kang. "Soundscape approach integrating noise mapping techniques: A case study in Brighton, UK." In: *Noise Mapping* 2.1 (2015).

[3] Jesper J Alvarsson, Stefan Wiens, and Mats E Nilsson. "Stress recovery during exposure to nature sound and environmental noise." In: *International journal of environmental research and public health* 7.3 (2010), pp. 1036–1046.

[4] Matilda Annerstedt, Peter Jönsson, Mattias Wallergård, Gerd Johansson, Björn Karlson, Patrik Grahn, Åse Marie Hansen, and Peter Währborg. "Inducing physiological stress recovery with sounds of nature in a virtual reality forest—Results from a pilot study." In: *Physiology & behavior* 118 (2013), pp. 240–250.

[5] American Birding Association. *ABA Code of Birding Ethics*. https://www.aba.org/aba-code-of-birding-ethics/. Accessed: 2025-04-10.

[6] Rochester Birding Association. *Birdsong*. https://rochesterbirding.org/conservation/ethical-birding/birdsong/. Accessed: 2025-04-10.

[7] Baseflow. *Geolocator: A Flutter plugin for accessing geolocation information*. https://pub.dev/packages/geolocator. Accessed: 2025-05-16. 2024.

[8] Frauke Behrendt. "The sound of locative media." In: *Convergence* 18.3 (2012), pp. 283–295.

[9] Nicola Besana, Peter Gall Krogh, Marianne Graves Petersen, and Davide Spallazzo. "Expanding the Concept of Sustainable Interaction Design: A Systematic Review." In: *Sustainability* 16.17 (2024), p. 7486.

[10] Heidi R Biggs, Jeffrey Bardzell, and Shaowen Bardzell. "Watching myself watching birds: Abjection, ecological thinking, and posthuman design." In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 2021, pp. 1–16.

[11] Eli Blevis. "Sustainable interaction design: invention & disposal, renewal & reuse." In: *Proceedings of the SIGCHI conference on Human factors in computing systems*. 2007, pp. 503–512.

[12] Bluebrain. *The National Mall*. Accessed: 2025-06-02. 2011. URL: https://bluebrainmusic.blogspot.com/2011/03/national-mall.html.

[13] Sophie Boehm, Louise Jeffery, Judit Hecke, Clea Schumer, Joel Jaeger, Claire Fyson, Kelly Levin, Anna Nilsson, Stephen Naimoli, Emily Daly, et al. "State of climate action 2023." In: (2022).

[14] Virginia Braun and Victoria Clarke. "Using thematic analysis in psychology." In: *Qualitative research in psychology* 3.2 (2006), pp. 77–101.

[15] Christina Bremer, Bran Knowles, and Adrian Friday. "Have We Taken On Too Much?: A Critical Review of the Sustainable HCI Landscape." In: *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. CHI '22. New Orleans, LA, USA: Association for Computing Machinery, 2022. ISBN: 9781450391573. DOI: 10.1145/3491102.3517609. URL: https://doi.org/10.1145/3491102.3517609.

[16] Janet Cardiff. *Forest Walk*. Audio walk created during a residency at the Banff Centre for the Arts. 1991. URL: https://cardiffmiller.com/walks/forest-walk/.

[17] Janet Cardiff. *Her Long Black Hair*. https://cardiffmiller.com/walks/her-long-black-hair/. Audio walk with photographs, 46 minutes. Curated by Tom Eccles for the Public Art Fund, June 17–September 13, 2004, Central Park, New York. 2004.

[18] Louise Chawla. "Significant life experiences revisited: A review of research on sources of environmental sensitivity." In: *The Journal of environmental education* 29.3 (1998), pp. 11–21.

[19] Victoria Clarke and Virginia Braun. "Thematic analysis." In: *The journal of positive psychology* 12.3 (2017), pp. 297–298.

[20] Jeffrey P Cohn. "Citizen science: Can volunteers do real research?" In: *BioScience* 58.3 (2008), pp. 192–197.

[21] CSDC Corp. *speech_to_text: A Flutter plugin that exposes device specific speech to text recognition capability*. https://pub.dev/packages/speech_to_text. Version 7.0.0, Accessed: 2025-05-14. 2024.

[22] Paul Coulton and Joseph Galen Lindley. "More-than human centred design: Considering other things." In: *The Design Journal* 22.4 (2019), pp. 463–481.

[23] Stuart Cunningham, Iain McGregor, Jonathan Weinel, John Darby, and Tony Stockman. "Towards a Framework of Aesthetics in Sonic Interaction." In: *Proceedings of the 18th International Audio Mostly Conference*. AM '23. Edinburgh, United Kingdom: Association for Computing Machinery, 2023, 109–115. ISBN: 9798400708183. DOI: 10.1145/3616195.3616219. URL: https://doi.org/10.1145/3616195.3616219.

[24] Dansk Ornitologisk Forening. *DOFbasen - Dansk Ornitologisk Forening*. Accessed: 2025-03-31. 2025. URL: https://dofbasen.dk/.

[25] Dansk Ornitologisk Forening. *DOFbasen: Observationer*. https://dofbasen.dk/observationer/. Accessed: 2025-05-28. 2025.

[26] Cedric Donnat and Flutter Community. *flutter_tts: Flutter Text to Speech Plugin*. https://pub.dev/packages/flutter_tts. Accessed: 2025-05-01. 2024.

[27] Robert R. Dunn, Michael C. Gavin, Monica C. Sanchez, and Jennifer N. Solomon. "The Pigeon Paradox: Dependence of Global Conservation on Urban Nature." In: *Conservation Biology* 20.6 (2006), pp. 1814–1816. ISSN: 08888892, 15231739. URL: http://www.jstor.org/stable/4124710 (visited on 11/08/2024).

[28] ElevenLabs Inc. *ElevenLabs: Free Text to Speech & AI Voice Generator*. Accessed: 2025-04-22. 2025. URL: https://elevenlabs.io/.

[29] Arturo Escobar. "The Ontological Reorientation of Design." In: *Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds*. Duke University Press, 2018. Chap. 3 4, pp. 79–134.

[30] Anders Fagerjord. "Between place and interface: Designing situated sound for the iPhone." In: *Computers and Composition* 28.3 (2011), pp. 255–263.

[31] Jixiang Fan, Derek Haqq, Morva Saaty, Wei-Lu Wang, and Scott McCrickard. "Diary Study as an Educational Tool: An Experience Report from an HCI Course." In: *Proceedings of the 56th ACM Technical Symposium on Computer Science Education V. 1*. 2025, pp. 311–317.

[32] Flutter Team. *Flutter - Build apps for any screen*. Accessed: 2025-04-21. 2025. URL: https://flutter.dev/.

[33] Xeno canto Foundation and Contributors. *Xeno-canto: Sharing bird sounds from around the world*. Accessed: 2024-03-06. 2024. URL: https://xeno-canto.org.

[34] Tony Fry. "Design futuring." In: *University of New South Wales Press, Sydney* (2009), pp. 91–124.

[35] William Gaver, Andy Boucher, Michail Vanis, Andy Sheen, Dean Brown, Liliana Ovalle, Naho Matsuda, Amina Abbas-Nazari, and Robert Phillips. "My naturewatch camera: disseminating practice research with a cheap and easy DIY design." In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 2019, pp. 1–13.

[36] William Gaver, Peter Gall Krogh, Andy Boucher, and David Chatting. "Emergence as a Feature of Practice-based Design Research." In: *Proceedings of the 2022 ACM Designing Interactive Systems Conference*. DIS '22. Virtual Event, Australia: Association for Computing Machinery, 2022, 517–526. ISBN: 9781450393584. DOI: 10.1145/3532106.3533524. URL: https://doi.org/10.1145/3532106.3533524.

[37] Lon Åke Erni Johannes Hansson, Teresa Cerratto Pargman, and Daniel Sapiens Pargman. "A Decade of Sustainable HCI: Connecting SHCI to the Sustainable Development Goals." In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. CHI '21. Yokohama, Japan: Association for Computing Machinery, 2021. ISBN: 9781450380966. DOI: 10.1145/3411764.3445069. URL: https://doi.org/10.1145/3411764.3445069.

[38] J Berton C Harris and David G Haskell. "Simulated birdwatchers' playback affects the behavior of two tropical birds." In: *PLoS One* 8.10 (2013), e77902.

[39] Alan Irwin. *Citizen science: A study of people, expertise and sustainable development*. Routledge, 2002.

[40] Peter Gall Krogh, Thomas Markussen, and Anne Louise Bang. "Ways of Drifting—Five Methods of Experimentation in Research Through Design." In: *ICoRD'15 – Research into Design Across Boundaries Volume 1*. Ed. by Amaresh Chakrabarti. New Delhi: Springer India, 2015, pp. 39–50. ISBN: 978-81-322-2232-3.

[41] Mari Laakso and L Tiina Sarjakoski. "Sonic maps for hiking—use of sound in enhancing the map use experience." In: *The Cartographic Journal* 47.4 (2010), pp. 300–307.

[42] David Lack. "The breeding seasons of European birds." In: *Ibis* 92.2 (1950), pp. 288–316.

[43] Mark Lawton, Stuart Cunningham, and Ian Convery. "Nature soundscapes: an audio augmented reality experience." In: *Proceedings of the 15th International Audio Mostly Conference*. 2020, pp. 85–92.

[44] Szu-Yu Liu, Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio, and Shaowen Bardzell. "Exploring noticing as method in design research." In: *Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion*. 2019, pp. 377–380.

[45] Clara Mancini. "Animal-computer interaction: a manifesto." In: *interactions* 18.4 (2011), pp. 69–73.

[46] Jennifer C Mankoff, Eli Blevis, Alan Borning, Batya Friedman, Susan R Fussell, Jay Hasbrouck, Allison Woodruff, and Phoebe Sengers. "Environmental sustainability and interaction." In: *CHI'07 extended abstracts on Human factors in computing systems*. 2007, pp. 2121–2124.

[47] Mark Monmonier. "Rhumb lines and map wars: A social history of the Mercator projection." In: *Rhumb Lines and Map Wars*. University of Chicago Press, 2010.

[48] Stuart Moran, Nadia Pantidi, Tom Rodden, Alan Chamberlain, Chloe Griffiths, Davide Zilli, Geoff Merrett, and Alex Rogers. "Listening to the forest and its curators: lessons learnt from a bioacoustic smartphone application deployment." In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '14. Toronto, Ontario, Canada: Association for Computing Machinery, 2014, 2387–2396. ISBN: 9781450324731. DOI: 10.1145/2556288.2557022. URL: https://doi.org/10.1145/2556288.2557022.

[49] Netfugl. *DK listen*. Accessed: 2025-05-14. 2025. URL: https://www.netfugl.dk/artslister/dk.

[50] Luan Nico and Flutter Community. *audioplayers*. https://pub.dev/packages/audioplayers. Accessed: 2025-05-16. 2024.

[51] Valentina Nisi, Enrico Costanza, and Mara Dionisio. "Placing Location-Based Narratives in Context Through a Narrator and Visual Markers." In: *Interacting with Computers* 29.3 (July 2016), pp. 287–305. ISSN: 0953-5438. DOI: 10.1093/iwc/iww020. eprint: https://academic.oup.com/iwc/article-pdf/29/3/287/11149005/iww020.pdf. URL: https://doi.org/10.1093/iwc/iww020.

[52] Claudia Núñez-Pacheco and Anton Poikolainen Rosén. "Articulating felt senses for more-than-human design: A viewpoint for noticing." In: *Proceedings of the 2024 ACM Designing Interactive Systems Conference*. 2024, pp. 1029–1043.

[53] Cornell Lab of Ornithology. *Merlin Bird ID App*. 2025. URL: https://merlin.allaboutbirds.org/.

[54] Tilde Pedersen, Edith Terte Andersen, and Anders Sundnes Løvlie. "Designing a "no interface" audio walk." In: *Museums and the Web*. 2019.

[55] Marianne Graves Petersen, Ole Sejer Iversen, Peter Gall Krogh, and Martin Ludvigsen. "Aesthetic interaction: a pragmatist's aesthetics of interactive systems." In: *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques*. 2004, pp. 269–276.

[56] Manon Raimbault and Danièle Dubois. "Urban soundscapes: Experiences and knowledge." In: *Cities* 22.5 (2005), pp. 339–350. ISSN: 0264-2751. DOI: https://doi.org/10.1016/j.cities.2005.05.003. URL: https://www.sciencedirect.com/science/article/pii/S0264275105000557.

[57] Eleanor Ratcliffe, Birgitta Gatersleben, and Paul T. Sowden. "Bird sounds and their contributions to perceived attention restoration and stress recovery." In: *Journal of Environmental Psychology* 36 (2013), pp. 221–228. ISSN: 0272-4944. DOI: https://doi.org/10.1016/j.jenvp.2013.08.004. URL: https://www.sciencedirect.com/science/article/pii/S0272494413000650.

[58] Chandler S Robbins. "Effect of time of day on bird activity." In: *Studies in avian biology* 6.3 (1981), pp. 275–286.

[59] Anton Poikolainen Rosén, Maria Normark, and Mikael Wiberg. "Noticing the environment–A design ethnography of urban farming." In: *Nordic Human-Computer Interaction Conference*. 2022, pp. 1–13.

[60] R Murray Schafer. *The soundscape: Our sonic environment and the tuning of the world*. Simon and Schuster, 1993.

[61] Simone Scully. *Play a Song, Hurt a Bird?* https://www.audubon.org/news/play-song-hurt-bird. Accessed: 2025-04-10. 2013.

[62] David Sibley. *The Proper Use of Playback in Birding*. https://www.sibleyguides.com/2011/04/the-proper-use-of-playback-in-birding/. Accessed: 2025-04-10. 2011.

[63] Tore Slagsvold. "Bird song activity in relation to breeding cycle, spring weather, and environmental phenology." In: *Ornis Scandinavica* (1977), pp. 197–222.

[64] Brian L. Sullivan, Christopher L. Wood, Marshall J. Iliff, Richard E. Bonney, Daniel Fink, and Steve Kelling. "eBird: A citizen-based bird observation network in the biological sciences." In: *Biological Conservation* 142 (2009), pp. 2282–2292.

[65] Alex Taylor. "After interaction." In: *Interactions* 22.5 (Aug. 2015), 48–53. ISSN: 1072-5520. DOI: 10.1145/2809888. URL: https://doi.org/10.1145/2809888.

[66] Samuel Thulin. "Sound maps matter: expanding cartophony." In: *Social & Cultural Geography* 19.2 (2018), pp. 192–210. DOI: 10.1080/14649365.2016.1266028. eprint: https://doi.org/10.1080/14649365.2016.1266028. URL: https://doi.org/10.1080/14649365.2016.1266028.

[67] Anna Lowenhaupt Tsing. *The mushroom at the end of the world: On the possibility of life in capitalist ruins*. Princeton University Press, 2015.

[68] United Nations, Department of Economic and Social Affairs, Population Division. *2018 Revision of World Urbanization Prospects*. Accessed: 2025-03-17. 2018. URL: https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.

[69] Yang Wang, Jiaogen Zhou, Caiyun Zhang, Zhaopeng Luo, Xuexue Han, Yanzhu Ji, and Jihong Guan. "Bird object detection: Dataset construction, model performance evaluation, and model lightweighting." In: *Animals* 13.18 (2023), p. 2924.

[70] Kendall Wrightson. "An introduction to acoustic ecology." In: *Soundscape: The journal of acoustic ecology* 1.1 (2000), pp. 10–13.

[71] eBird. *eBird Live Subscriptions*. Accessed: 2025-03-31. 2025. URL: https://ebird.org/livesubs.

[72] iNaturalist. *iNaturalist: A Community for Naturalists*. Accessed: April 8, 2025. 2025. URL: https://www.inaturalist.org/.

[73] jebbs. *PlantUML: Rich PlantUML support for Visual Studio Code*. https://marketplace.visualstudio.com/items?itemName=jebbs.plantuml. Visual Studio Code extension; over 2.7 million installs. 2025.

[74] pgAdmin Development Team. *pgAdmin 4 v9.0 Released*. Accessed: 2025-06-02. 2025. URL: https://www.postgresql.org/about/news/pgadmin-4-v90-released-3010/.