

"Jaw Dropping" Sound Clouds: Exploring the Role of Awe in Ambient Computational Systems through Installation Art

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Figure 1: Sound Clouds exhibition. Left: An overview of the installation setup in a re-purposed art space. Right: A participant engaging with an inflatable using their torso.

Abstract

Ambient computational systems—increasingly present in installation art, traffic control systems, and smart homes—can evoke “awe” through their conceptual and physical vastness. While this awe can productively evoke inter-user connectedness and spark dramatic conceptual shifts, this effect has been understudied in Human-Computer Interaction. To investigate this phenomenon, we built *Sound Clouds*, an interactive art installation and ambient computational system designed to evoke awe. Deployed in a public art space and experienced by over 200 visitors, *Sound Clouds* transformed a warehouse-sized urban space into an immersive sound-reactive environment with large-scale neutrally-buoyant inflatables. An interview study ($n=35$) showed that though interactions with *Sound Clouds* provoked a range of uncertain mental models, it also spurred participants to shift their focus towards awe, play, sensory experience, and collaboration. This paper ends with

design considerations for creators seeking to manage the intrinsic role of awe in ambient computational systems.

CCS Concepts

• **Human-centered computing** → **User Studies (HCI)**; **HCI theory, concepts and models**; **Auditory feedback**.

Keywords

Ambient Intelligence, Ambient Systems, Art Installation, Mental Models, Sound Feedback

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1 Introduction

Over the past decade, *ambient computational systems* have increasingly been embedded in smart homes [44], traffic control systems [14], architecture [35] and art installations [49]. While the term *ambient computation* holds a variety of definitions in the literature,



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for the purposes of this paper we use the term to describe systems that bring together two adjacent traditions: 1) ambient displays, which emphasize peripheral awareness and subtle cues [32, 71], and 2) context aware systems, which emphasize responsive adaptation to environmental and user data [2]. Users are often unaware that they are in these ambient computational environments, as these systems operate on the periphery of their awareness [55], collecting data and responsively altering the environment in the background. Other times, when these systems feature a component which is more directly in the foci of attention or incorporates intentional user input—like the Nest Thermostat system [80]—the effect can be more direct. In the former case ambient computational systems can have a strong subliminal effect on user behavior, influencing daily decisions like choosing between the stairs and the elevator [52]; in the latter case these systems can have both a subliminal and more direct impact.

In this paper, we examine the as of yet explored possibility that ambient computational systems evoke *awe*. Awe has been defined as “a sense of enormity that eludes comprehension” [69] and sparks sensemaking [37] and the need to cognitively assimilate. Awe is often associated with natural wonders like seeing the Earth from outer space [78] and is known for its strong effects: provoking connectedness [26], prosocial behavior [21], calmness [43], and intellectual engagement [48]. It has also been suggested that awe also promotes strong mental health [34]. Because ambient computing systems are physically immersive and have an immense complexity which often eludes easy user comprehension [58], we hypothesize that ambient computational systems may evoke awe. If they can evoke awe, then awe may be a significant facet though which designers can encourage users to engage with, and conceptualize, such systems.

Therefore, our first research question is:

RQ1: How, if at all, can ambient computational systems evoke awe?

As a user experiences awe, they often *sensemake* in an attempt to understand their experience [37]. This involves, among other things, the formation of different mental models which aim to predict the behavior of the system. The extent to which users believe that such a mental model is accurate is their *perceived comprehension* of the system. A user’s perceived comprehension may have significant bearing on their sense of awe; if they believe themselves to lack comprehension of a system they are more likely to find it conceptually vast and therefore awe-inspiring. This brings us to our second research question:

RQ2: How might awe and perceived comprehension alter users’ physical and intellectual engagement with ambient computational systems?

To answer the above research questions, we developed *Sound Clouds* (Figure 1), an ambient computational installation that serves as a boundary object [19] for investigating the entanglement between awe, perceived comprehension, and ambient computation. *Sound Clouds* is an ambient computational system in that the installation emphasizes peripheral awareness and obliquely responsive adaptation to user input. *Sound Clouds* examines how awe shapes participants’ interactions and perceptions of an ambient computational installation to reframe system obliqueness as a design value

rather than a usability challenge. A sound-based immersive installation artwork, *Sound Clouds* was installed at a large arts community facility and used by over 200 people during a two-hour public demonstration. Over the course of the demonstration, up to ten participants at a time collaborated to move 10-foot-wide, slow-moving, neutrally buoyant inflatables. As they did, the movements of these inflatables manipulated colored LEDs within the inflatables and a gradually evolving soundscape. The soundscape was then spatialized and played through surround sound speakers placed along the perimeter of the arts facility.

Exit interviews with participants who experienced *Sound Clouds* (N=35) revealed that the system evoked awe. Over the course of their interaction, participants shifted focus from partial mental model formation with a range of perceived comprehensions, to play and sensorial exploration. This experience left them grounded and encouraged feelings correlated with awe including self-diminishment and a sense of vastness. Lastly, the system encouraged participant collaboration and feelings of connectedness. Though participants engaged with *Sound Clouds* briefly, our results have implications for longer term engagement with many ambient computational systems. We end with design recommendations for creators seeking to leverage awe in the design of future ambient computational systems, including leveraging connectedness in design, adding physicality to ambient computational systems, and making use of ambiguity as a design value.

2 Related Work

In this section, we situate our research within prior work on ambient computation to frame the design and study of *Sound Clouds*. We highlight how technologies that operate in the background can shape perception, awareness, and behavior. We then review studies of users’ mental models of ambient computational systems and how users construct them. Finally, we examine the entanglement of awe, HCI, play, and the arts, which demonstrates how interactive systems and art installations can evoke powerful emotional and social responses. Our work builds on these areas by exploring how ambient computation systems can evoke awe by obscuring system logic, demonstrating how ambient computation can affect emotion as well as physical and intellectual engagement.

2.1 Ambient Computational Systems

Ambient computational systems are designed to integrate into the environment while being context-aware, adaptive, and seamless [38]. In this subsection, we review how HCI has conceptualized ambient computational systems across smart environments, and interactive art installations, in order to situate our focus on users’ sensemaking of their often opaque operations. The terms “ambient intelligence” and “ambient computation” have been used in a variety of HCI sub-fields, including ubiquitous or embedded computing [9] and the Internet of Things [30] with varying definitions. For example, Cook et al. defined ambient intelligent systems as “*sensitive, responsive, and adaptive*”, meaning that they take in needed input and respond to that input continuously, demonstrating an awareness of a given situation. They also noted that they were often transparent and ubiquitous, meaning that they were integrated in the environment such that the user may not be aware of

them. Ambient computational systems have often been described as "contextually aware" [61], meaning that they were part of a user's existing environment and capable of adjusting that environment based on the particular moment or occasion that the user is in, whether that be cooking, picking up their child from school, cleaning one's house, or monitoring patient health in intensive care units [46, 57, 65]. The intention of such systems, particularly in smart homes, is often to create an "electronic butler" that preemptively aids users based on their context, for instance turning on the toaster when a person walks down the stairs for breakfast and providing an estimate of the travel time to their child's school [9]. Much of the past literature also focuses on designing ambient systems that output information in the periphery of a user's attention, often with the intention of reshaping their behavior or social interactions [16, 25, 31, 68]. These systems often increase users' peripheral awareness of environmental variables, such as their electricity usage habits or network activity [4, 25, 71].

There is also a long history of using art installations as an inspirational design probe [39] or as a means to understand situated, embodied, and playful interaction with ambient computational systems [36, 59]. Many past artworks have attempted to influence user behavior or broaden user awareness [12, 52], like Natalie Jeremijenko's "The Dangling String", which was an 8-foot piece of plastic spaghetti that whirled depending on nearby Ethernet activity [71]. While such systems are ubiquitous in that they are continuously present in, and involved with, the environment, they are not sensitive or responsive in the manner that Cook et al. defined because they provide peripheral output without responding to input from the environment. Such systems are sometimes called "calm technology" [71] or "ambient displays" [25]. Another set of art installations has used a model more similar to Cook's description, responding to external data and users' movements and changes within the space [47, 74]. For instance, the MIT Media Lab's "AmbientROOM" responded to user movement and newly received emails [18]. Other systems adapted the environment by only focusing on user input, such as heartbeats and respiration [66].

While prior work has focused on contextual awareness, behavior change, and embodied interaction, sensemaking of systems with opaque operations which treat ambiguity as design resource are more recent to HCI [17, 37]. This motivated our research to focus on understanding users' mental models of ambient computation.

2.2 Mental Models of Ambient Computational Systems

The design of an ambient computational system directly shapes sensemaking and the formation of users' mental models [58], which are dynamic, fragile, evolving constructs that can shift depending on environmental complexity, prior experience, social context and feedback. Ambient systems may act irregularly or fail to communicate their internal working, which makes it difficult for users to develop mental models [24, 28, 56, 64]. Some prior work on ambiguity in sound design suggests ambiguity of parameter controls may lead users to use a sound design system in a more personalized way but also focus more on the inner workings of a system at the expense of their creative output [22]. Other work suggests that in striving to reduce ambiguity in sound design, sound designers

may paradoxically end up amplifying ambiguity [50]. In ambient settings like smart homes, users often reduce complexity by relying on metaphors like a "watchdog", a vigilant, unintelligent global observer responsible for watching over users, or as a "remote control", an environment that immediately responds to commands made from a distance, [7]. They also use broader abstractions such as an interconnected network of devices or an intelligent agent [77, 82]. These strategies provide users with mental footholds for navigating the opacity of ambient computational systems, particularly during repeated and private interactions.

Rosenberger and Verbeek's postphenomenological account of human technology relations provides a useful framework for understanding the interaction dynamic and sensemaking practice with *Sound Clouds*. This framework describes how technologies can be experienced as part of the background of everyday life, as extensions of the body, or as distinct others that users must relate to and interpret [53]. *Sound Clouds*, at various points in the interaction, touches on all three of these relations: as is the case with many other ambient computational systems, inflatables embody participant pushes and shoves, and close up observers interpret inflatables as *quasi-other*. This lens allows us to connect participants' shifting sensemaking about *Sound Clouds* with the different roles the installation plays in their lived experience—as environment, as bodily medium, and as enigmatic system.

In multi-user public environments (e.g., media facades [40] and with interactive exhibits [32]), where interactions are brief and stimuli are ambiguous, users rely heavily on analogies and physical world schemata because they offer a mental foothold. These conceptions can lead to misunderstandings of a system's actual logic and capabilities [54, 62] and lead to risk avoidant behavior (e.g., hesitating to interact for fear of breaking the system), trial and error exploration (to probe hidden rules), or a reliance on social proof (waiting for others to engage before attempting to do so themselves) [10, 81]. Some users may never engage deeply with these systems and therefore never achieve deep comprehension. In these contexts, mental models are often partial, erroneous, or socially inferred [54, 62]. This mismatch produces an "expectations gap" [27], where users misinterpret system behaviors through misleading cues like ambiguous responses, or cultural assumptions about autonomy. Such gaps can undermine trust, limit engagement, or discourage playful exploration in public installations. Our work addresses these problems by examining how awe and ambiguity can foster meaningful interactions with ambient systems.

Despite the growing body of literature on users' mental models for ambient computational systems, most studies have focused on how these models are developed in domestic environments, lab settings, or settings where users are performing a particular task. In contrast, ambient public art installations remain underexplored, even though they present unique challenges for multi-user interaction, fleeting engagement, and ambiguity that can profoundly shape how mental models form. Though users often have brief one-time exposure to these ambient public installations that prevent them from refining their mental models, studying the sensemaking process for these systems still yields important insights for long-term engagements with comparable ambient computational systems — this paper therefore focuses on the *development of users' mental*

models, the *perceived comprehension of ambient computational systems*, and the *role of awe* in ambient public art installations, where surprise and uncertainty is at play.

2.3 Awe, the Arts, Play, and HCI

Psychological research has identified several key dimensions of awe, including a vastness of conceptual or physical magnitude, the presence of physical sensations like goosebumps and widened eyes, an enhanced sense of connection with others or the broader world, self-adjustment reflecting a need to reconfigure one's perspective in response to the the witnessed phenomenon, temporal distortions, and self-diminishment characterized by feeling psychologically or physically smaller than previously understood [79]. Such research has also developed tools to systematically measure the complex emotion of awe such as the multi-dimensional Awe Experience Scale (AWE-S) [79] and the Situational Awe Scale, which validates context specific awe experiences [26]. In public installations, awe can prompt users to be more playful and open to learning because it diminishes a user's sense of control [51]. Prior work in HCI has also highlighted how play can be useful to encourage curiosity, experimentation, and embodied exploration among installation users [12, 36].

Within the HCI community, researchers have investigated specific design parameters and strategies that can be used to invoke awe. Mueller et al. introduces awe as a lens for motivating sense-making around future technologies within a design research context [37]. Others have explored design strategies to create "breathtaking experiences" and examined how immersive and interactive technologies can prompt prosocial behavior through awe induction [21, 23]. Others have investigated how familiarity affects awe experiences within VR settings, comparing the effectiveness of first person versus third person perspectives in inducing stronger feelings of awe and presence [6, 41, 42]. Other studies have examined the effectiveness of immersive videos in awe induction [5] or developed novel online VR awe inspiring training programs for metaverse applications [45]. There have also been exploratory investigations into the elicitation of awe in specialized populations, such as using VR to shift the perspectives of cancer patients undergoing treatment [67]. Research has also focused on specific sub-components of awe within VR contexts, exploring self-diminishment experiences based on theories of the sublime [15], physical sensations and goosebumps [49], neurophysiological reactions to the overview effect during virtual space journeys [70], and enhanced interconnectedness through VR experiences [63].

Beyond technological applications, researchers have examined awe experiences within traditional cultural settings like art exhibitions and museums. Some have used artistic and scientific practices in research based design to create awe inspiring immersive installations [49]. In contrast, others have characterized the emotional responses to art beyond simple pleasure, examining the relationship between artworks' emotional characteristics and viewers' responses [33]. Research has also identified how awe plays an essential role in how individuals engage with cultural and artistic content during museum visits [29]. This raises the question of how awe, often triggered by opacity and vastness, might serve as a productive response when system comprehension is limited.

3 Design of Sound Clouds

Sound Clouds was inspired by works like Andy Warhol's *Silver Clouds* [75], which used participation in the art via touch as a central mode of engagement; David Byrne's *Playing the Building* [3], which was a large scale music instrument; and Google's *Project Magenta: The Flaming Lips* [13], which was a unique inflatable interface designed for large group interaction. The research team installed *Sound Clouds* in a large indoor art space that was a repurposed 1880's factory in the southeastern United States. The floor, which was 18 meters by 42 meters, was covered in low-lying dry ice-based fog. The ceiling, which was 9 meters high, was draped in fabric to diffuse the light and protect the inflatables from the ceiling beams (Figure 2).



Figure 2: Pre-installation views of the *Sound Clouds* setup, with the inflatables, canopy structures, and atmospheric dry ice filling the art gallery floor.

The inflatables, of which a maximum of 4 were in the space at a time, ranged from 1.2 to 3 meters in diameter and were filled with a mix of helium and air to float neutrally buoyant within the space. Each inflatable had a cylindrical cavity that ran down the middle with two openings on each end. LED lighting strips were wrapped around wooden rods and inserted into this cavity, with the ends sealed by inflating smaller balloons at each end to secure the rig in place. Inside each inflatable, an ESP32 microcontroller was affixed to each wooden rod, and controlled the LED light strips so the translucent surface oscillated between shades of aqua and magenta (Figure 4). A GoPro camera facing downward recorded the interaction space, and its feed was divided into nine spatial zones (Figure 5 right).

To encourage awe, we designed the inflatables such that a gentle nudge would cause visible and sonic changes in the environment. This combination of minimal interaction effort and perceptual changes reinforced a sense of vastness and immersion in the space, as they moved across different zones (Figure 5).

Designed as an ambient computational system, *Sound Clouds* adapted to direct user input and inflatables movement with subtle cues in the user's periphery. Participants' interaction with the inflatables shaped the system's audiovisual feedback by translating embodied motion into a playful, collaborative surround sound composition (Figure 3). When a participant moved an inflatable between zones, its position change within the Go Pro camera feed was detected using a custom YOLO12n object detection machine learning model and transmitted to Max/MSP, which interfaced with a master ESP32 (Figure 6). The master ESP32 then relayed commands to the servant ESP32 boards inside each inflatable by sending MIDI messages using the ESP-NOW protocol. The messages caused

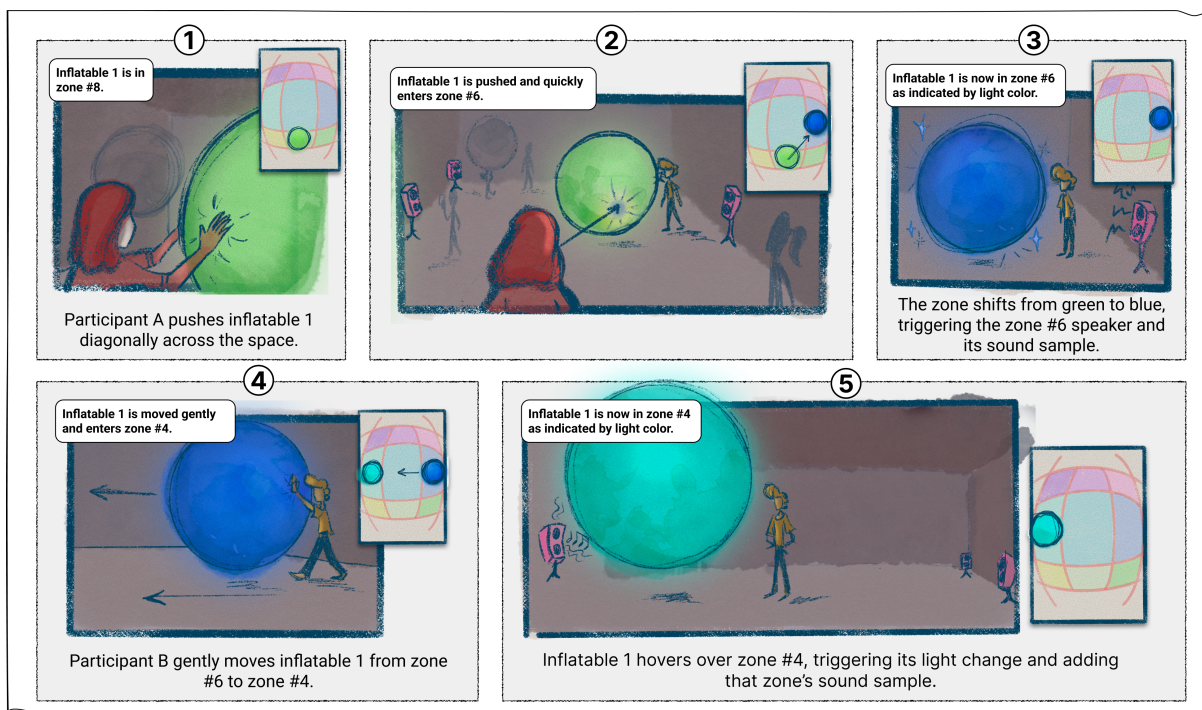


Figure 3: A graphic visualization of how participants interacted with *Sound Clouds*.

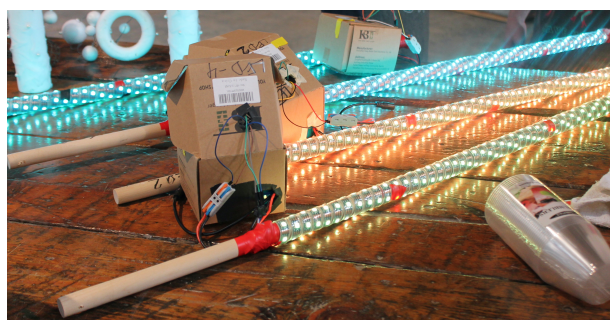


Figure 4: The LED strips mounted onto wooden rods, with the servant ESP32 housed alongside them.

the corresponding LED light strips to change the inflatables color based on its location in the room.

During the experience, oceanic, ethereal tones were also peripherally altered by the movement of the inflatables in real time (Figure 5). For example, if one inflatable entered a new zone, a corresponding, pre-recorded sound would be layered into the existing background soundscape. If two inflatables floated within a certain distance of one another, they generated a distinct sound. Changing the vertical depth of an inflatable would also change some pitches in the background soundscape.

In case the wireless lighting system failed, a backup lighting rig was kept ready with triple-axis accelerometers embedded to detect movement so that participants would receive some direct feedback

upon pushing the balls. While the backup rig lacked the functionality for zone-based color change, it maintained interaction quality. During the last half hour of the installation, the backup rig was deployed to replace one of the failed primary wireless-controlled rigs. The replacement became necessary because the inflatable housing had developed holes, compromising its functionality.

4 Evaluation Method

The refashioned large historical warehouse where *Sound Clouds* was installed is a prominent cultural hub in a city in the Southeast USA. A well-known artist residency and exhibition space, the location attracted a broad audience in part due to its reputation for supporting innovative art events and its established community of artists. We designed a study that combined surveys, emotion mapping, and semi-structured interviews to evaluate how *Sound Clouds* fostered awe, shaped participants' perceived comprehension, and influenced their physical and intellectual engagement.

4.1 Setup and Participation

Our specific experience was advertised through social media, local online platforms, and word of mouth. As a result, *Sound Clouds* attracted more than 200 attendees throughout its duration. The installation was active from 7:00 pm to 9:00 pm, during which attendees lined up to participate, and roughly 10-20 participants were allowed to engage with the installation at a time.

Attendees were informed that both video and photo recordings would be taken and their interactions would be recorded for study

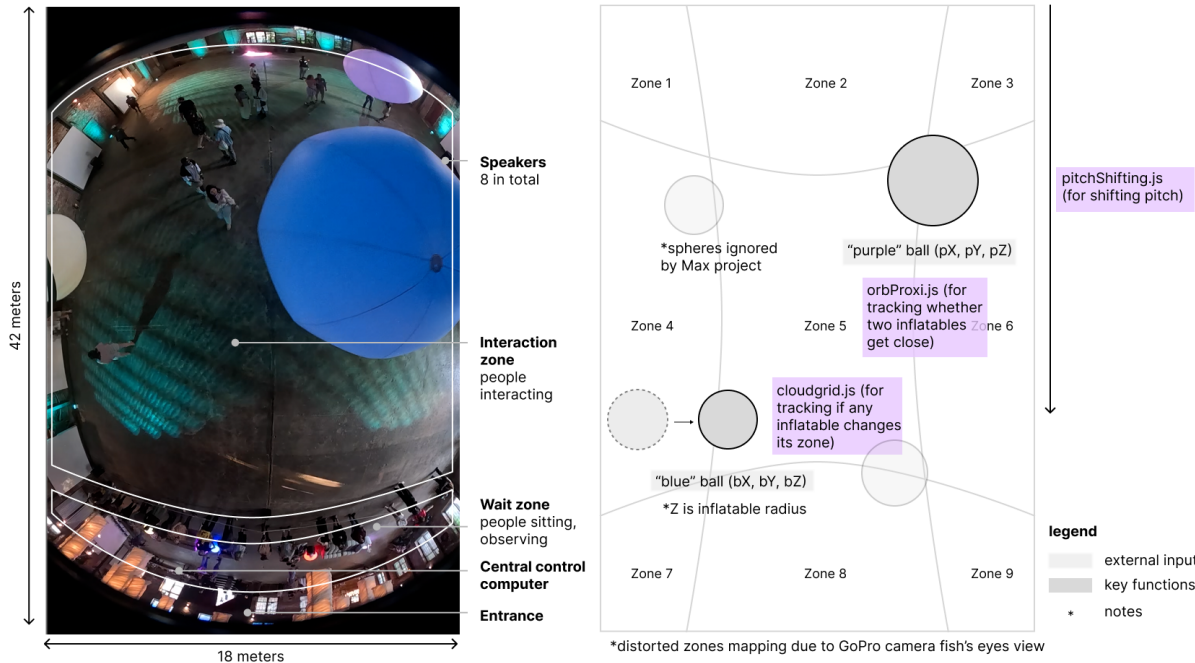


Figure 5: Left: A top-down view of the interaction space as captured by a GoPro camera. Right: A top-down view of the interaction space, its zones, and the three key scripts triggering sound change.

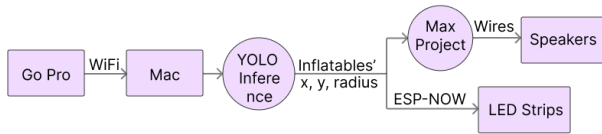


Figure 6: Flow chart of the *Sound Clouds* system architecture.

purposes through physical posters and boards displayed prominently outside the installation. Upon entry, every participant was assigned a unique ID, which allowed the team to later correlate individual interactions with video recordings for detailed analysis. Immediately after they experienced the installation, attendees were invited to participate in a 15-25 minute study consisting of a brief survey and a semi-structured interview. Participation was open to anyone interested. A total of 35 adults completed the survey and chose to be interviewed. Each participant received a \$30 Amazon gift card as compensation for their time.

During the experience, our research team was assigned specific roles to document, manage, and study participant experiences. These roles included: setup (technical systems and audio/ visual capture), support and repair (maintenance of the inflatables), crowd control (onboarding, tagging, and crowd safety), observation (monitoring, documentation, and field notes), and evaluation (surveys and post experience interviews). Together, these teams ensured the smooth operation of *Sound Clouds*, while capturing the technical performance of the inflatables and participant experiences.

4.2 Procedure

Each attendee spent approximately 10–15 minutes interacting with the inflatables. Those waiting to participate in the experience queued inside the venue and observed the installation from a distance, fostering a continuous atmosphere of curiosity. Attendees were invited to participate in completing a survey and one on one interviews immediately following their interaction with the installation. Informed consent was obtained from all participants before they completed the survey and interview. The study received approval from our university's Institutional Review Board (IRB). The evaluation team, located outside the warehouse, conducted these interviews.

Participants were first asked to complete a brief online Qualtrics-based survey that included a series of Likert scale statements to assess their perceived comprehension of *Sound Clouds* and their emotional and intellectual engagement. Example statements included, “*I feel that I comprehend how Sound Clouds works*” and “*While using Sound Clouds, I felt connected to others*”. This survey helped orient participants and prime a deeper reflection of their experience with *Sound Clouds* for the interviews that followed. The survey was informed by existing frameworks such as the Awe Experience Scale [79], but was augmented through an initial pilot study conducted one week before deployment. Seven participants interacted with an early *Sound Clouds* version and completed a survey with the awe scale which revealed three sub-components that emerged as most relevant in our installation: vastness, connection, and physical sensation. These sub-components served as the basis for our final survey.

Following the survey, participants were presented with a feelings wheel with six emotional categories, e.g., *peaceful*, *joyful*, *scared*,

sad, *mad*, and *powerful*, each branched into more nuanced sub-feelings [73]. Participants were instructed to select between two and five emotions that best captured their feelings during their interaction with the installation. This feelings wheel drew inspiration from tools used in psychiatric and therapeutic contexts to facilitate emotional awareness [73]. The wheel served as a scaffold that helped participants recognize and articulate their feelings during the interview (Figure 13).

Members of the research team conducted semi-structured interviews with the participants to elicit more nuanced responses about their understanding, engagement, and interpretation of the experience. The interview began by asking participants to reflect on the emotions they selected on the feelings wheel, prompting them to explain why those particular words resonated with their experience. This opening question served as a bridge to a deeper discussion on how awe was entangled with their physical and intellectual engagement with *Sound Clouds*. Interviewers then guided participants through a set of open-ended questions aimed at uncovering how perceived comprehension shaped their experience. This included probing how participants made sense of the system's behavior, what mental models they constructed, and whether their understanding (or lack thereof) influenced their engagement. These questions enabled the research team to explore the relationship between emotion, understanding, and interaction in the context of ambient computational systems.

4.3 Data Analysis

The Likert scale responses and the emotion mappings were analyzed using Python's pandas library [1]. Likert data was visualized as histogram distributions. Emotion responses, which were taken with text field input were parsed, normalized, and mapped to the predefined categories from the feelings wheel. To address typographical errors, responses were manually reviewed and corrected before aggregation.

All 35 interviews were audio recorded and transcribed using the Otter.ai transcription tool, resulting in roughly six hours of conversational data. Research team members independently reviewed and corrected all interviews to ensure their accuracy. The research team conducted a thematic analysis following a six step framework, which systematically progressed through familiarization with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and finally producing the results [8]. The analysis was aimed at identifying patterns grounded in participant language, their meaning-making and their confidence in comprehension. Three researchers independently coded the interview transcripts and then collaborated through iterative discussions to consolidate and refine the themes.

In vivo codes were created to capture participants' language directly. Themes were refined through team based discussions and cross checking with the dataset to ensure coherence and relevance. We then contextualized and validated these themes using observational data from the Observation Team's field notes and GoPro video recordings in the installation.

5 Results

Below, we describe the results from our observations, exit interviews and surveys with participants of *Sound Clouds*. Participants engaged with the installation in diverse ways, using various body parts (hands, heads, feet, torsos) with intensities ranging from gentle touches to vigorous play. Adult participants pushed, pulled, spun, and balanced the inflatables, while children—often limited by height—rolled them on the ground. Despite the absence of formal instructions, playful collaboration emerged spontaneously: participants laughed as they passed inflatables to one another, including to strangers, without verbal communication. We also observed affectionate gestures (couples kissing beneath inflatables), protective behaviors (redirecting inflatables to avoid collisions), and the Honeypot Effect, with bystanders joining after witnessing others' engagement [76]. Participants often expressed that they were unsure about *Sound Clouds*' underlying mechanisms, exhibiting an overwhelming range of different mental models for *Sound Clouds* with no consistent theory. Despite the range of interpretations and interactions, participants described similar emotional responses: feelings of awe, presence, and self-diminishment. They also describe sensorial exploration, collaboration, and a sense of vastness. The words they have chosen to express their feelings interacting with *Sound Clouds* from the provided feeling wheel were listed in Table 1, and the word cloud is visualized in Figure 7.



Figure 7: Word cloud of reported emotions with word sizes approximately proportional to frequency. Words that appeared less than 3 times were not visualized.

Table 1: Top 10 reported emotions and their frequencies.

Emotion	Frequency
playful	13
relaxed	11
creative	11
serene	9
peaceful	9
amused	7
thoughtful	6
delightful	6
content	5
stimulating	5



Figure 8: People engaged in the experience and interacted with *Sound Clouds* in various ways. Left and middle: people bumping and rotating the inflatables. Right: people collaboratively interacting with the inflatables and passing them to each other.

5.1 Sensory Explorations Led to Feelings of Awe and Presence: “I Felt My Jaw Drop”

Many participants experienced a sense of awe while interacting with the installation. The survey responses noted many embodied awe reactions, with 29 participants agreeing that “I felt my eyes widen” (i.e., 6 slightly, 11 somewhat, 12 strongly), and 19 participants agreeing that “I felt my jaw drop” (i.e., 9 slightly, 7 somewhat, 3 strongly; Figure 9). P12 shared, “I was just kind of in awe, I was just kind of like, this is fascinating, jaw on the floor ... it felt almost dream like.” Some participants described sensations akin to floating, while others felt like they were resting or being enveloped. P15 reflected, “I think the physical sensation of pushing the ball up—I felt it in my body, like inhabiting somatic space, and being like a heart opening motion. That felt important.” Others compared it to peaceful experiences with nature, e.g., “You know how you go and touch grass to be part of nature? It’s like, you forget your current worries and evade stress, just to feel connected to nature in the same way ... just being a part of a greater thing.” (P45).

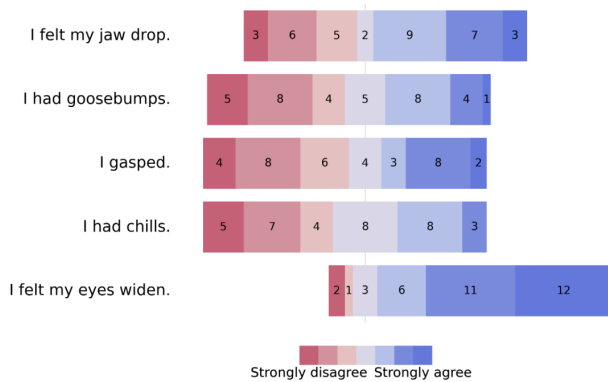


Figure 9: Survey responses to Likert-based statements about physical sensation.

Participants also described feeling a profound sense of presence, often characterized by stillness, inward focus, or gentle attention to their surroundings. 25 of the 36 participants described themselves as being “grounded” or “calm” during the interviews. Calm is often associated with feelings of awe [63]. P11 noted, “it blocked my brain out in a way where I was just kind of focused in the moment and not

really thinking about what’s next, what I need to do was very in the moment and not bigger picture oriented.” P5 stated, “I felt like I was in a space that was a little disconnected from the chaos and erraticness of everyday life. It wasn’t quiet, but it felt aural and experiential. Even when the pitch was going up or I was physically interacting, nothing felt hard or harsh or sharp.” In contrast to many interactive systems that encourage time efficiency and goal-oriented action, *Sound Clouds* deliberately and affectively slowed participants down, creating space for mental stillness and embodied calm.

5.2 Participants Felt Vastness and Self-Diminishment

Several participants expressed more specific feelings found on the Awe Experience Scale [79]: a sense of vastness and self-diminishment. As on the scale, vastness took the form of both conceptual vastness perceived from the complexity of *Sound Clouds* and physical vastness perceived from the scale of the inflatables and space. Twenty five participants agreed “I perceived vastness” (i.e., 8 slightly, 11 somewhat, 6 strongly), 28 participants agreed “I felt that I was in the presence of something grand” (i.e., 15 slightly, 8 somewhat, 5 strongly), and 24 participants agreed “I perceived something much larger than me” (i.e., 8 slightly, 9 somewhat, 7 strongly; Figure 10).

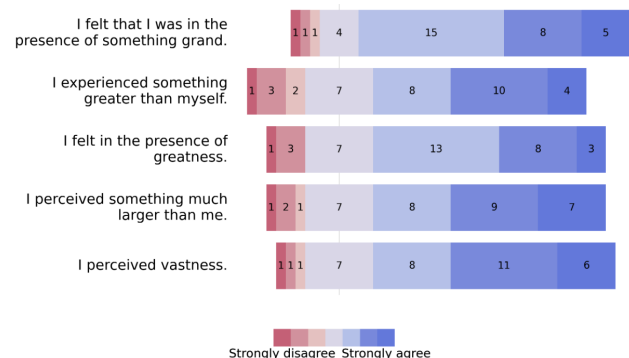


Figure 10: Survey responses to Likert-scale statements about vastness. A substantial portion of participants expressed feelings of vastness, a core component of awe.

Participants described perceiving both conceptual vastness and physical vastness of the inflatables, often entangling these feelings with feelings of self-diminishment, wonder, and play. As stated before, the range of mental models participants had for *Sound Clouds* ranged widely, but the consistent sense of conceptual vastness provides useful insight into the character of these mental models. Speaking of the conceptual vastness of *Sound Clouds*, P36 said, “it makes you feel insignificant, but not in a bad way you know, there’s this big world around us and even though we’re small compared to it, it means that there’s more for us to experience.” This sense of conceptual vastness was reiterated in the survey findings, which noted marked levels of perceptions of something greater than the participants and perceived vastness. Others reflected on how the physical proportions of the inflatables shaped their emotional states, e.g., “it allowed that element of wonder, and I think that that’s one of the things that we lose from childhood as adults. We don’t play because the proportions are off. That sense of wonder and awe are different” (P25). In addition to focusing on the large proportions of *Sound Clouds*, this quote describes a hybrid feeling of vastness and self-diminishment. Feelings of self-diminishment were described by other participants as well. This sense manifested as both physical (e.g., “I almost wanted to be engulfed by one of them” (P1)) and spiritual (e.g., “I feel like I might cry, it gives me the sensation that I’m swimming in a lake that is very peaceful, and I can just float on my back and see the sky and the trees around me... I just feel like a very small part of something much bigger” (P20)).

5.3 Participants Developed Uncertain Mental Models and Then Turned to Play

Twenty four participants noted that they entered the installation with an explicit desire to understand how the system worked (e.g., “when I went in there, I was like, ‘oh, how does this even work?’” (P40)). Consistent with previous research that suggests awe-inspiring experiences evoke a desire to sensemake [37], *Sound Clouds* sparked significant curiosity. This curiosity caused users to actively vary their interactions and experiment with different behaviors to understand the system’s logic. This, in part, had to do with the slow changing and oblique effect moving the inflatables had on the overall soundscape. As P2 explained, “I was interacting very curiously and trying to see how the sound changed.” Twenty two participants noted that they tested different hypotheses about how the installation worked, such as spinning, punching, pushing, bouncing, and tapping the inflatables to probe the system’s logic (Figure 8). P43 shared how they “wanted to see what would happen if the balls were completely still”, while P34 tried to discern patterns, stating, “I was trying to see if I could create a pattern between the music and the sounds and the touching.” This investigative inclination was more pronounced among participants with self-reported technical backgrounds, such as P42, who had a computer science background. They reflected, “I would say [my] tech background definitely helped me be more curious about how it’s working actually and how the sound is being manipulated.” In the survey, 22 participants agreed with the statement “I feel that I comprehend how *Sound Clouds* works” (i.e., 12 slightly, 6 somewhat, 4 strongly; Figure 11).

Despite the survey results stating that the participants understood how *Sound Clouds* works, during the interview, it became

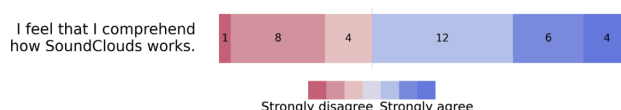


Figure 11: Survey responses to Likert-based statements about perceived comprehension. Participants showed a wide distribution of agreement levels.

clear that participants’ sensemaking formed a range of mental models of how they thought the installation worked. For example, 13 participants associated the system’s behavior with touch sensitivity (e.g., “my assumption is that it’s touch sensitive and so it has a connector that, once you touch it, it will then trigger specific sounds that are part of the soundboard of the computer.” (P25); “I thought it was when we touch the wall, we create a new sound” (P19)). In contrast, others focused on the role of AI, with P5 explaining, “my assumption would be that an AI is sort of tracking the movement of the spheres, and as they’re lifting and lowering and kind of moving throughout a set space, the AI is learning from that and reacting to it.” Others concentrated on spatial mapping, as one participant described: “the position of the ball is sort of being mapped to the space and based on that the sound is changing” (P42). Consistent with previous research on ambient computational systems [77], this attention to different aspects of the system led to a range of understandings about how the system worked and a range of degrees of confidence in this understanding.

In more than half of the interviews, participants described how aspects of the installation’s design obscured how it functioned. For instance, P45 said that “because all inflatables are moving around at the same time, like all the clouds are moving together, it’s difficult to understand how exactly my movement is affecting the sound, or what contribution I have within the bigger picture.” Participants also mentioned how they tried to learn about how the installation worked while waiting in line to participate, but had to change their perceptions once they started participating themselves (e.g., “You notice how other people are interacting with it, and then you notice how the sound is being produced and then ... me actually interacting with it and seeing what sound is being produced” (P35)). These shifting perceptions and sensemaking in the wake of awe-inspiring experiences are consistent with past findings in HCI [37].

When faced with a lack of clarity, some participants shifted from an analytical interpretation to a direct, physical exploration and open-ended play, thereby shifting from cognitive to embodied sensemaking. As P26 reflected, “now that I’ve sort of conceded that I’m not going to figure out how it works, let’s just go play with the thing.” As P2 noted, “At first, I was interacting very curiously and trying to see how the sound changed, but after a while, it became more about the physical touching of the object.” Once participants relinquished their attempts to decipher the system’s mechanics, many found enjoyment focusing on play, sensory pleasure, and the overall ambiance of the experience (Figure 8).

5.4 Collaborative Interactions Fostered Play and Community Without Verbal Communication

Sound Clouds naturally facilitated collaborative experiences among strangers, with 24 of the 36 participants describing feelings of collaboration and connectedness during their interactions. Participants frequently exhibited awareness of others in the space and expressed a desire to help one another achieve common goals, treating fellow visitors as part of a temporary community. Of these, 14 participants specifically described general collaboration or community experiences, with P20 reflecting, “So for that moment, I was like, “we should get into a circle and play together”, So it did make me feel a sense of community.” Similarly, P6 noted, “I definitely felt more connected to other people. Like there was immediately in that space a sense of collaboration.” The survey responses further demonstrated this sense of connection and shared experience with 27 participants agreeing with the statement “I felt closely connected to humanity” (i.e., 9 slightly, 13 somewhat, 15 strongly) and 25 participants agreeing with the statement “I had the sense of being connected to everything” (i.e., 11 slightly, 11 somewhat, 3 strongly; Figure 12).

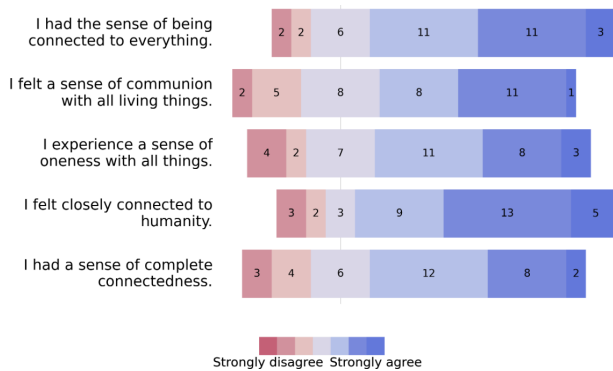


Figure 12: Survey responses to Likert-based statements about connection. Participants reported a pronounced sense of connection.

The physical design of the inflatables naturally encouraged cooperative behavior, particularly with the larger inflatables that, for some participants, required multiple people to manipulate effectively. P35 explained, how “with the big one, I was like, I need another person here with me to help me move it and make sound.” This necessity for collaboration created organic teamwork, as P15 described: “the feeling of pushing that huge, massive ball up in the air and having it go really high up was just really satisfying and playful, because it really elicited the need to have other people play with you.”

Perhaps most remarkably, these collaborative interactions emerged spontaneously without verbal communication. Two participants specifically noted observing others using the inflatables before entering the space themselves, consistently describing non-verbal coordination with complete strangers and the development of intuitive patterns of sharing and turn-taking. P1 observed, “we didn’t even speak to each other, like none of us spoke to each other, but we all just end up, like, going in a circle, just looking at the Sound

Cloud, throwing it in a circle, like we were playing like little kids.” P13 similarly noted, “I just picked up on that fact that everybody was participating together, without spoken word, total strangers. Everybody was keeping the ball off the ground and passing to each other.” This emergent coordination created a shared sense of collaboration among some participants, with P45 reflecting, “you kind of feel like you’re part of a bigger system ... what you are doing is changing the experience for other people as well. If I move alone, what other people hear is also changing—that felt collaborative.”

Some described the nature of play by comparing it to childhood. For example, P20 noted, “When you’re a kid and you go to the pool or playground and go to a kid you’ve never met before, and you’re like, “do you want to play?” and then you just play together. We didn’t speak to other people, but we were passing this thing back and forth between each other.” P40 echoed this saying, “It reminded me of gym class in elementary school when we would play volleyball. I thought it was really interactive, and you’re working with a bunch of people. It made me feel like a little kid again.”

6 Discussion

Our research found that participants developed a strong sense of connectedness and playfulness with one another while interacting with *Sound Clouds*, despite lacking clear mental models or a concrete understanding of how the system worked. Though these findings are in part limited by the short term, first time engagement users had with *Sound Clouds*, our study reveals useful insights into the process of sensemaking with ambient computational installations and comparable ambient computational systems. Over the course of the sensemaking process, strangers formed spontaneous connections, coordinating their movements through body language and visual cues rather than explicit knowledge of the system’s logic. These findings suggest that ambient computational systems can be intentionally designed to foster social engagement and playful exploration, without requiring users to fully grasp how such systems operate. As outlined in the related works section, these playful and exploratory encounters echo HCI research on play in interactive installations, which frames playfulness, curiosity, and embodied experimentation as central resources for engagement rather than incidental byproducts [12, 36, 51].

Sound Clouds, like many installation artworks designed for festivals, was designed to be a short public interaction encounter. Participants’ interactions and partial mental models of the system may have been shaped in part by their first time engagement with the system as they aimed to make sense of how the system worked, curiosity, and novelty. These findings may therefore be most applicable to systems with similar short term engagements or be shaped by the novelty of interacting with *Sound Clouds*. However, though *Sound Clouds* was intended for short term engagements, the results from our study may provide insights for long-term interactions with ambient computational systems as well. This is in part because unlike many computational systems *Sound Clouds* remains difficult to form a mental model of both at the initial stage, second stage of interaction, and in reflection after usage. These results provide insights for many ambient computational experiences in which mental models remain uncertain even with long-term usage. We

examine how partial and uncertain mental models shape participants willingness to experiment, collaborate, and play and in spite of the lack of comprehensive mental models.

In what follows, we explore the implications of these findings for designers of ambient computational systems. We describe how designers should design with the connectedness and awe spurred by ambient computation, and the implications of this on ethics and community building. We also discuss how physicality might be used to spur sensory curiosity and exploration and finish by discussing how ambiguity may be an asset when designing ambient computational systems.

6.1 Connectedness and Awe in Ambient Computational Systems

As our results demonstrated, participants expressed awe or feelings of connectedness with one another or the environment when interacting with *Sound Clouds*. This can be seen most clearly in Section 5.1 and in Section 5.4. These findings echo previous work that has explored how conceptually and physically vast experiences in virtual reality [63] and large scale interactive installations [49] can evoke awe, spark sensemaking [37] and promote prosocial behavior [21]. These dynamics can be understood through the hybrid relations of alterity, embodiment, and background laid out by Rosenberger and Verbeek. *Sound Clouds* at times recedes into the environment, at times becomes an extension of participants' bodies, and at times is encountered as a semi-autonomous partner in interaction [53]. However, *Sound Clouds* is the first installation piece to suggest that feelings of connectedness and awe may be invoked intrinsically by the physical and conceptual vastness of ambient computational systems.

This suggests that future designers of ambient computational systems should consider how awe and feelings of connectedness can be evoked and design their experiences accordingly. For instance, consider the design of a system like SURTRAC in Pittsburgh, an ambient computation system which makes decisions about traffic light timing on the basis of driving and traffic patterns [60]. If city data traffic data were made apparent to users through additional visualizations in drivers' periphery, SURTRAC may be capable of fostering a sense of connectedness among drivers. Such a feeling may be a useful means of combating road rage or otherwise fostering connectedness on the road. Our findings also support existing work that awe in public installations is often entangled with playfulness and wonder [51], since participants treated *Sound Clouds* as a space for shared experimentation and play rather than as a system to be fully understood, suggesting that designing for collaborative play can build awe filled experiences.

There are compelling reasons to consider awe and connectedness in design. First, while awe has been demonstrated to foster prosocial thinking [21], feelings of connectedness with the ambient computation system run the risk of redirecting attention away from critiquing the system when this critique may be warranted. This in turn could have serious ethical ramifications in situations in which the technology is inappropriately surveilling users, making decisions with serious social ramifications, or using exploitative tactics to source data. Importantly, this could be a concern for users themselves, as their attention and judgment may be manipulated

by awe, thus underscoring the need for broader public literacy out how these systems shape perception. Second, designers of ambient computational systems working on art installations could leverage feelings of inter-user connectedness by affording multi-user or inter-user engagement rather than solely individual interaction. In doing so, a designer could leverage ambient computational systems' capacity to build social bonds and transform isolated technological encounters into shared community experiences.

6.2 Leveraging Physicality When Designing Ambient Computational Systems

Ambient computational system design can sometimes overlook the value of materiality, focusing primarily on creating "invisible technology" that seamlessly blended into environments, often with minimal attention to users' sensory interaction [72]. However, designers are now actively incorporating material and tactile features, recognizing their central role in shaping engagement and experience within computational environments [20, 72]. Our research exemplified this trend toward affording physical sensemaking, with 25 participants reporting feeling entranced, grounded, or calm, linking these experiences to the physical sensations of touch and movement during their interaction. This arose in Section 5.1 in the "physical sensation of pushing the ball up," in Section 5.2 in the vastness felt with the inflatables, in Section 5.3 when participants, spun, punched, pushed, or bounced the inflatables, and in the manner in which the physical design of the inflatables encouraged participants to work together.

Consistent with Gaver and Morrison's work which also uses play to encourage curiosity and embodied exploration in installations [12, 36], participants often approached the inflatables through gestures such as tossing, pushing, or jointly steering them, indicating that playful material affordances can catalyze deeper engagement with ambient computation. Such insights could be useful for an ambient computational calendar system. Imagine a system with a mobile of hanging magnets that become more or less entangled throughout the day depending on the user's calendar appointment density. This mobile could be noticed, touched, or absentmindedly spun by the user but the overall state of their schedule would remain legible only through the material feel and configuration of the mobile rather than any explicit readout.

Beyond reinforcing the current emphasis on materiality, our research points to further insights. By placing tangible and sensory engagement at the forefront, designers can foster new forms of agency, curiosity, and play, making ambient systems that transform passive observation into active exploration and participation. Designers can open up new and meaningful user experiences by considering the objects users physically engage with, even if they aren't direct inputs to a system. Using Rosenberger and Verbee's framework as a lens of interpretation, *Sound Clouds* is distinct from many ambient computational systems in that it is, in part, *embodied*. In future work designers should consider how large scale or other embodied interactions could be leverage in ambient computational systems to evoke awe and related feelings.

6.3 Ambiguity as a Design Value

Sound Clouds offers two contributions for designers of ambient computational systems seeking to leverage ambiguity. First, our results highlighted how participants formed an ambiguous understanding of the system and then engaged with it experimentally and playfully. These findings are derived directly from Section 5.3, "Participants Developed Uncertain Mental Models and then Turned to Play."

This demonstrates how Gaver et al.'s argument that ambiguity can be a resource in computational design that invites curiosity and encourages experimentation [11] extends to sensemaking in ambient computational systems as well. This is significant because ambiguity is intrinsic to all ambient computational systems. Therefore, it may be the case that all ambient computational systems can be designed to encourage experimentation, particularly if they leverage the known link between awe and sensemaking [37].

The second is that, in contrast to Gaver et al.'s description of ambiguity being an asset for one-on-one interactions between a user and a computer, this research demonstrated that ambiguity can be a resource for collaborative interaction as well. Participants' ambiguous understanding of *Sound Clouds* created opportunities for collective exploration, discussion, and playful engagement with others. We thus recommend that designers of ambient computational systems consider how ambiguity can be deliberately leveraged, rather than discouraged, to invite curiosity and encourage experimentation. For instance, ambiguity could be evoked by a smart home system by emanating a loud and pleasant tone in response to some members of the household having their shoes off. This could foster togetherness and discussion about the smart home's programming as users aimed to explore what conditions cause the system to generate the tone.

Sound Clouds offers one final contribution for sound designers aiming to understand the role of ambiguity in their work. While one previous study found that when faced with ambiguous parameters designers tended to focus on the inner workings of the tools rather than creative output [22], *Sound Clouds* suggests that it may be possible to push beyond this initial shift in focus back to creativity if the design of the system affords play.

6.4 Limitations and Future Work

Our research has several limitations. First, the unique characteristics of the exhibition space, its reputation for innovative exhibitions, and its regional location may have influenced participant expectations and responses. While we recruited 35 participants from a diverse public audience, our sample was self-selected from attendees of who would frequent an art installation. Installing *Sound Clouds* in other locations, cultural contexts, or inviting different demographics of users (e.g., children or older adults) may result in different participant experiences, especially related to collaboration among strangers. Alternative deployment settings such as public libraries, museums, and schools could reveal how environmental and social factors mediate the experience. For instance, in a school setting, interactions among peers who share familiarity with one another may foster more collaborative and goal-directed engagement compared to the spontaneous, stranger-to-stranger encounters observed in the exhibition context. In public libraries,

the cultural norm of quiet and individual contemplation may shift the experience toward more solitary interaction. These contexts could further illuminate which effects are tied to the artifact itself versus the surrounding event atmosphere.

In addition, participants only engaged with *Sound Clouds* for 10–15 minutes. This length of time may not have been long enough to fully capture how mental models and emotional responses evolved, or could continue to evolve, over prolonged use. Related to this, the data we collected relied heavily on participants' abilities to recall and articulate their experiences after interaction. Although we interviewed participants immediately after they exited *Sound Clouds*, different responses may have resulted if participants used a think-aloud protocol while interacting or we recorded, and later analyzed, the conversations participants had while interacting with *Sound Clouds*. Consequently, future work could examine longitudinal engagement, allowing participants to interact with the installation repeatedly over an extended period. Such studies would enable researchers to assess whether initial responses reflect a novelty effect or represent more durable shifts in participants' mental model creation and their physical and intellectual engagement.

7 Conclusion

In this research, we designed *Sound Clouds*, an ambient computational system consisting of four neutrally buoyant inflatable clouds that generated sound and light based on participants' interactions with them. Post experience interviews found that many participants constructed a wide range of partial mental model of the environment and experienced a sense of conceptual vastness, but shifted focus to meaningful engagement with the system through sensory exploration, awe, and connectedness. Our findings demonstrated that ambient computational systems can engage participants through their physicality and productively leverage ambiguity to spark curiosity and play. By using these qualities as intentional design choices, future ambient computational systems can move beyond tailoring experiences to the individual and cultivate collectively sensorial and calming experiences.

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