University of California
Santa Barbara

Morphologies of Sonically Actuated Spatial Agents

A dissertation submitted in partial satisfaction
of the requirements for the degree

Doctor of Philosophy
in
Media Arts and Technology

by

Şölen Kıratlı

Committee in charge:

Professor Curtis Roads, Chair
Professor Marko Peljhan
Professor Yon Visell

March 2021

The Dissertation of Şölen Kıratlı is approved.

Professor Marko Peljhan

Professor Yon Visell

Professor Curtis Roads, Committee Chair

March 2021

Morphologies of Sonically Actuated Spatial Agents

To my beloved grandmother, my first teacher, Hayriye Soykut, the first woman in her family to read and write, an elementary school teacher who went great lengths to make sure many other underprivileged children could read and write, as well.

Acknowledgments

I would like to first and foremost thank my committee: Dr.Curtis Roads, Prof. Marko Peljhan, and Dr. Yon Visell for supporting this dissertation.

In addition, a big thank you to the following people and communities:

- UCSB Media Arts and Technology Community, professors, colleagues, and staff.
- My collaborators and dear friends, Hannah Wolfe and Akshay Cadambi, for inspiring and empowering me.
- My colleagues and dear friends Owen Campbell, Sahar Sajadieh, and Joseph Tilbian for their love, friendship, and support.

Beyond all, I cannot express my gratitude enough for my partner, Alex Bundy, without whose immense patience, help, support, and empowerment it would have been an exponentially harder period of my life to get through.

Finally, a deep deep thanks to my parents and my brother for their constant support and life-long belief in me.

Curriculum Vitæ

Şölen Kıratlı

Education

2021	Ph.D. in Media Arts and Technology, University of California, Santa Barbara.
2003	M.Arch. in Architecture, University of Southern California
2001	B.Sc in Architecture, Istanbul Technical University

Academic Experience

current	Adjunct Faculty, Department of Visual Arts, University of California, San Diego
2018-2020	Graduate Student Instructor, Department of History of Art and Architecture, University of California, Santa Barbara
2016-2018	Teaching Associate / Instructor of Record, Department of Art, University of California, Santa Barbara
2015-2016	Teaching Assistant, Department of Art, University of California, Santa Barbara

Professional Experience

2013-2015	Architectural Design Consultant, Harley Ellis Devereaux, Los Angeles, California
2007-2009	Architect, DeStefano & Partners, Los Angeles, California
2004-2007	Architect, Harley Ellis Devereaux, Los Angeles, California

Awards and Honors

2020	”Best in Show” Award, by ACM SIGGRAPH, Art Gallery 2020
2019	Doctoral Travel Grant, Media Arts and Technology Program, University of California, Santa Barbara
2018	Systemics Artistic Production Grant, University of California, Santa Barbara
2017	Doctoral Travel Grant, Graduate Student Association, University of California, Santa Barbara
2017	Systemics Artistic Production Grant, University of California, Santa Barbara
2016	ReTouch Lab Artistic Production Grant, University of California, Santa Barbara

2012	Visual, Performing, and Media Arts Awards, Interdisciplinary Humanities Center, University of California Humanities Network
2010	Artistic Production Incentives Grant, Vida 13.0, Fundación Telefónica, Spain
2010	California-Centric Embedded Arts Research Grant in Social Ecologies, UCIRA (University of California Institute for Research in the Arts)
2010	Graduate Block Grant Award, University of California, Santa Barbara
2003	Graduate Architecture Grant, University of Southern California, Los Angeles
2003	John Parkinson Scholarship, University of Southern California, Los Angeles
2002	Graduate Architecture Grant, University of Southern California, Los Angeles

Exhibitions

2020	*Cacophonic Choir* (interactive virtual experience), IEEE VISAP 2020 (Collaboration with H.Wolfe and A.Bundy)
2020	*HIVE* (interactive installation), International Symposium on Electronic Art (ISEA) 2020, Montreal, Canada (Collaboration with H.Wolfe and A.Bundy)
2020	*Cacophonic Choir* (interactive installation), ACM SIGGRAPH, Art Gallery (Collaboration with H.Wolfe and A.Bundy)
2019	*Cacophonic Choir* (interactive installation), Contemporary Istanbul / Plug-in, Istanbul, Turkey (Collaboration with H.Wolfe and A.Bundy)
2018	*HIVE* (interactive installation), CURRENTS New Media, El Museo Cultural, Santa Fe, New Mexico, USA (Collaboration with A. Cadambi and ReTouch Lab)
2017	*HIVE* (interactive installation), ACM SIGGRAPH Asia - Art Gallery, Bangkok, Thailand (Collaboration with A. Cadambi and ReTouch Lab)
2017	*HIVE* (interactive installation), Santa Barbara Center for Art, Science, Technology (SBCAST), group show, "First Thursday", Santa

	Barbara, California, USA (Collaboration with A. Cadambi and ReTouch Lab)
2016	*HIVE* (interactive installation), Media Arts and Technology End of the Year Show, "White Noise", University of California, Santa Barbara, USA (Collaboration with A. Cadambi and ReTouch Lab)
2012	*The New Dunites* (interactive installation), ACM Multimedia - Art Gallery, "Eternal/Moment", Todaiji Art and Cultural Center, Nara, Japan (Collaboration with A. Burbano and D. Bazo)
2012	*The New Dunites: An Immersive Experience* (interactive immersive media), Allosphere New Media Research Facility, University of California, Santa Barbara, USA (Collaboration with A. Burbano and D. Bazo)

Publications and Conference Presentations

S. Kiratli, H.E. Wolfe, and Alex Bundy, *Cacophonic Choir: An Interactive Art Installation Embodying the Voices of Sexual Assault Survivors*, *Leonardo* 53 (July, 2020) 446–450. Publisher: MIT Press.

D. C. Llach, J. L. Liu, Y. C. Lee, H. E. Wolfe, S. Kiratli, A. Bundy, S. Brueckner, N. Mendoza, Pazera, D. Franusich, T. Klein, E. Polyak, Y. Katsumoto, J. Kuchera-Morin, A. Cabrera, K. H. Kim, G. Rincon, T. Wood, L. Demarest, S. Hong, H. Kim, S. Kim, B. Lee, and M. Breeze, *Mediating Public Space: Art and Technology That Goes Beyond the Frame Art Gallery*, *Leonardo* 53 (July, 2020) 455–473. Publisher: MIT Press.

S. Kiratli, H.E. Wolfe, and Alex Bundy, *Cacophonic Choir*, conference presentation, *SOUND:: GENDER:: FEMINISM :: ACTIVISM (SGFA)*, (Tokyo, Japan), Tokyo University of the Arts, Oct., 2019.

S. Kiratli and A. Cadambi, *HIVE: Explorations in Sonic Intelligence*, conference presentation, *SIGGRAPH Asia 2017 Art Gallery*, SA '17, (Bangkok, Thailand), Nov., 2017.

S. Kiratli and A. Cadambi, *HIVE*, in proceedings *SIGGRAPH Asia 2017 Art Gallery*, SA '17 (Bangkok, Thailand), p.1, Association for Computing Machinery, Nov., 2017.

S. Kiratli, A. Cadambi, and Y. Visell Y, *HIVE: An Interactive Sculpture for Musical Expression* in *Proceedings of New Interfaces for Musical Expression (NIME)*, (Copenhagen, Denmark), pp 267-270, Aaolborg University Copenhagen, 2017.

A. Burbano A., D. Bazo, S. (Kiratli) DiCicco A. Forbes, *The New Dunites*, in proceedings *20th ACM international conference on Multimedia*, (Nara, Japan), pp.1501-1502, 2012.

Abstract

Morphologies of Sonically Actuated Spatial Agents

by

Şölen Kıratlı

This dissertation explores the ways in which media artworks depict agency and convey life-like qualities. This exploration is centered around the design and implementation of two interactive media artworks, *HIVE* (2016–2018) and *Cacophonic Choir* (2019–2020), and makes use of a novel conceptual framework grounded in an approach to media arts practice that uses the notion of agency as a lens for examining and creating artworks. Starting with an inquiry into novel agent-based art practices that neither feature robotic nor virtual agents, the dissertation reevaluates the notion of agency in artistic contexts in light of the relatively recent establishment of sonic interaction design as a field in its own right and the renewed emphasis on materiality as the result of rapidly evolving design and fabrication technologies. To this end, I introduce *Sonically Actuated Spatial (Sono-spatial) Agent* practice as an area of artistic practice that fuses digitally designed and fabricated artifacts, sonic expressions, and interactive behaviors in order to create 'perceived' life-like systems. In summary, this dissertation aims to expand upon the theoretical and conceptual underpinnings of interactive media arts via the products of my artistic practice, as well as theoretical discussions, design methods, principles, and strategies, all of which are distilled from this practice.

Contents

Chapter 1

Introduction

This dissertation explores the ways in which media artworks depict agency and convey life-like qualities. This exploration is centered around the design and implementation of two interactive media artworks, *HIVE* (2016–2018) and *Cacophonic Choir* (2019–2020), and makes use of a novel conceptual framework grounded in an approach to media arts practice that uses the notion of agency as a lens for examining and creating artworks. Starting from an inquiry into novel agent based art practices that can stand as an alternative to those that feature robotic or virtual agents, the dissertation reevaluates the notion of agency in artistic contexts with a consideration of the following two conditions: The first is the relatively recent establishment of sonic interaction design as a field in its own right, and the second is a renewed emphasis on materiality through the rapidly evolving design and fabrication possibilities of the digital medium.

To this end, fusing aspects of several design fields—such as sound design, sonic interaction design, architectural and interior design, speculative design, parametric design—I explore a previously neglected field of practice, which I call *Sonically Actuated Spatial (Sono-spatial) Agent* practice. The agents featured in *Sono-spatial Agent* practice differ from both robotic agents and virtual A-Life (Artificial Life) agents—the two most common agent-based practices—in that they neither rely on kineticism or locomotion to convey agency, nor are they confined to the boundaries of a screen. Instead, *Sono-spatial Agent* practice relies on a fusion of sonic, sculptural, and architectural qualities of the artistic system to depict agency. Based on a primacy of embodied experience in physical space, *Sono-spatial Agent* practice fuses digitally designed and fabricated artifacts, sonic expressions, and interactive behaviors in order to create 'perceived' life-like systems. To sum up, *Sono-spatial Agents* are agents or agentic ecologies that are fundamentally based on a unique combination of sound, form, material, and spatial configuration, in which a physical bodily experience of being in it or walking through it is essential.

The artistic practice is the basis of inquiry here, constituting the starting point, the method, and the end goal of this research. That said, I believe that prominent art practices exist in a constant feedback loop with theory and discourse. As such, I offer a novel conceptual framework that is aimed at a deeper understanding of agent-based art practices, their lineages, and theoretical underpinnings. I am looking into expanding media arts practice and theory in several ways: Defining an under-explored area of agent-based art practice and a novel conceptual framework around it, presenting and discussing two of my major artworks as case studies, and finally offering an evaluation and qualitative analysis of the case studies in light of the research question and the proposed framework.

In summary, this dissertation aims to expand upon the theoretical and conceptual underpinnings of interactive media arts via the products of my artistic practice, as well as theoretical discussions, design methods, principles, and strategies, all of which are distilled from this practice.

1.1 Context

1.1.1 Agency and Interactive Art

More than half a century ago, the British artist Roy Ascott helped define the conditions and aesthetics of interactivity in what we now call as media arts via his seminal article *Behaviorist Art and Cybernetic Vision* (1967) [1]. Inspired by the field of Cybernetics, he approached artworks as systems that were created by an open-ended information exchange between the artwork, artist, and audience. He pointed out an emerging shift of focus from the “visual” to the “behavioral” in the arts. This shift of focus from the production of a fixed object to a kind of ephemerality marked by performances and processes was favored by many other artists and theorists of the time. In the decades to come after Ascott’s article, many artists and theoreticians helped develop the theory of Media Arts establishing it as a field of practice in its own right.

This dissertation focuses on the interactive systems within media arts, which I will call “interactive media arts” or “artistic interactive systems” here. Interactive media arts commonly regard behavior as the main focus of aesthetic experience, as opposed to formal and conceptual concerns. Artwork as an open ended system that “behaves” implies autonomy, whether an actual autonomy of the system or one that is perceived so by the viewer. Such preeminence of behavior and autonomy inevitably brings forth the notion of the agency of the artwork, or “artworks as agents”, as phrased by Simon Penny [2]. Penny describes interaction as “involving two (or more) agents engaged in ongoing, dynamical exchanges” and argues that “the capacity for interactivity depends on the capacity for agent-like behavior on both sides” [3].

If behavior is the main medium that determines the conditions and the quality of the aesthetic experience of an interactive artwork, and agency is strictly entwined with behavior, are all interactive artworks agents? Looking into all interactive media artworks through this lens, we can regard agency as a continuous spectrum—ranging from artworks that display agency via simple-reflex based responsive behavior to works that display complex behaviors that present high levels of autonomy. Following this thread, we can regard the "lens" of agency as the bases of a conceptual framework, through which we can establish taxonomies for a subset of media arts practices. Such taxonomies are aimed at contributing to the theoretical discourse, design, and implementation of artistic interactive systems.

In order to expand upon this discussion on agency and agents, in the next section I will examine some definitions of these terms and clarify how I will be construing these notions throughout this dissertation.

1.1.2 Agency and its Attribution

The terms "agent" and "agency" are used in a range of disciplines from sociology to AI (Artificial Intelligence), and in the context of both biological systems and artificial systems. An agent can be defined in very general terms as "a being with the capacity to act, and *agency* denotes the exercise or manifestation of this capacity" [4]. Given the context here—interactive media arts—my focus is on the agency of artificial systems in which life-like qualities are designed through computational means—encompassing both hardware and software—and are manifested through human-computer interaction.

As such, in the fields of Robotics and AI, an agent is defined as "anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators" [5]. This coupling between the environment and the agent through sensors and actuators also happens to be one of the fundamental ways that agency in Interactive Art is described [2], demonstrating parallel understandings of agents and agency across computational disciplines.

There are nuances, however, as unlike in engineering and scientific contexts, AI in artistic contexts is "not concerned with building something that is intelligent independent of any observer and their cultural context" [6], [7]. This difference that is inherent in artistic practice versus scientific research is described by Mateas via a framework that he developed for heuristic purposes under the overarching title of *Expressive AI* [6]. He argues that AI research in the scientific context is concerned with task competence, objective measurement, generality, and realism, while an AI-based artistic practice is concerned with poetics, audience perception, specificity, and artistic abstraction.

The understanding of the notion of agency in the fields of HCI (Human Computer Interaction) and HRI (Human Robot Interaction), however, arguably operates within a liminal area between the two approaches. Both HCI and HRI are concerned with studying how humans interact with computers, and designing novel technologies based on these studies. Due to the human centric nature of these disciplines, a consideration of agency from a subjective viewpoint becomes inevitable. For example, agency attribution—defined as how we perceive something as an agent—is one of the important concerns in HCI and HRI research because it significantly influences how humans relate to artificial co-actors [8], [9].

Such focus on the subjective experience of agency is especially imperative in artistic contexts, since art primarily operates via phenomenological processes that are rooted in the subjective psychological, social, and cultural background of the viewer. That said, the objective approach of engineering and scientific research should not be dismissed when designing agent-based systems in artistic contexts. This is because, in order to manipulate their medium to desired effects (here, even a general concept such as emergence can be considered a desired effect) artists have to deeply understand objective aspects of their medium (i.e. technical aspects of hardware and software), especially when working with complex technology. This calls for a synthesis of the two approaches—an understanding of agency as an objectively described capacity of action based on the internal structure of the agent and an understanding of agency as a quality that can be attributed to objects and environments as a result of subjective experience.

1.1.3 Agency and Embodiment

Embodiment, also called *embodied cognition*, and *embodied intelligence*, is one of the most important concepts surrounding agency both in philosophical contexts, and in the computational disciplines of AI, robotics, HCI, and Interactive Art [10], [11], [12], [13]. The term *Embodiment* is used in different fields with nuanced differences. Its usage can arguably be problematic, especially in artistic contexts, where it is loosely construed and used interchangeably as merely having a physical presence, or as being physically instantiated. Since the term *Embodiment* and its implications in the context of how we approach agents will be considered throughout this dissertation, it is important to discuss how it will be understood here. In this section, I will briefly discuss this notion and how it is construed in AI, HCI, and artistic contexts.

The notion of embodied cognition is rooted in cognitive science and it encompasses several fields, such as philosophy, AI, and robotics. In general terms, it is described as "aspects of the agent's body playing a significant causal or physically constitutive role in cognitive processing" [10]. Embodied cognition has important implications for our understanding of both natural and artificial agents.

The notion of embodied intelligence was introduced to AI and robotics by Rodney Brooks and is considered as a paradigm shift from a cognitivist approach to an embodied approach to AI. The former takes intelligence as understood and modeled through abstract symbolic representations, while the latter takes it as understood and modeled through an ontological status of being situated in the physical world with a physical body [14]. The quote "the world is its own best model" [15] summarizes Brooks's stance. According to embodiment approach, an intelligent system does not need to possess intentions, mental representations, or abstract symbolic processing. Rather, he argues, "the ability to carry out survival related tasks in a dynamic environment provides a necessary basis for the development of true intelligence" [11]. The major implication here is that intelligence is primarily shaped by the body and that "our thoughts have their foundation in our embodiment—in our morphology and the material properties of our bodies" [16]. Embodiment in the AI context focuses on understanding how natural intelligence is enabled by the body, and its coupling with the environment in order to model and design artificial systems with an "objective agency" that is independent of the observer.

HCI, on the other hand, as discussed in the previous section, is a human-centric discipline, and as such it focuses on studying how humans interact with machines and how to design effective interfaces between humans and machines. While overlapping with computer science and cognitive science to a degree, the notion of embodiment in HCI, introduced by Paul Dourish as "embodied interaction" [17], has slightly different concerns, definition, and scope. Embodied interaction is an approach in HCI that is grounded in phenomenology and focuses on designing systems based on the *situatedness* principle. Situatedness is a theoretical position that regards the mind as ontologically and functionally intertwined within environmental, social, and cultural factors [18]. As such, embodiment in HCI contexts shares the same fundamental principle with embodiment in AI and cognitive science in that it is a major departure from the cognitivist stance that "characterizes the mind as an essentially interior entity one that is conceptually separated from the environment but can interact with it through computational manipulations of mental representations" [18].

Dourish defines embodied interaction as "the creation, manipulation, and sharing of meaning through engaged interaction with artifact" [12]. Embodied interaction capital-

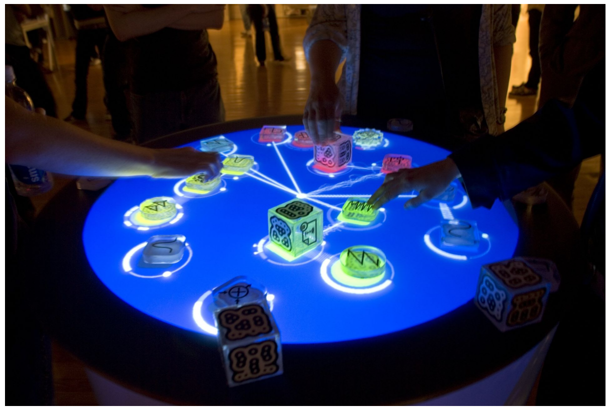


Figure 1.1: *reacTable* (2003-2010) is a multi-touch tangible interface for electronic music composition. Photo credit: Daniel Williams, © CC BY-SA 2.0, Created: 10 June 2007

izes on the situatedness of human agents, that is, the ways in which human agents are intertwined within environmental, social, and cultural contexts. For example, tangible computing, which, along with social computing, constitutes one of the two main pillars of embodied interaction, takes advantage of the tactile and physical skills that we employ in dealing with the world around us [17]. It is concerned with designing physical objects, surfaces, and spaces as tangible embodiments of digital information [19]. This is described as a shift from using the real world as a "metaphor" for interaction (i.e. desktop metaphor in computers) versus a "medium" for interaction (i.e. *reacTable*, 2003-2010, a physical desktop-like surface that is a tangible user interface (TUI) for electronic music composition [20]) (Figure 1.1). It is a transition from the realm of ideas to the realm of everyday experience. As such, practical action replacing abstract reasoning constitutes the foundations of embodiment in the context of HCI.

In artistic contexts, as in HCI, embodiment is regarded as a necessary condition for interactivity [21], [22], but, what does it exactly denote? Akin to my previous discussion on agency, here I suggest a synthesis of the two approaches—that of AI and HCI–in our understanding of embodiment. This can also be seen broadly as a synthesis between the domain of technical and human-centric practices. In designing agents for artistic practice, an HCI-based approach would guide us towards an understanding of embodiment as it relates to how meaning emerges as we engage in responsive artifacts and environments in a performative way. An AI-based approach, on the other hand, would guide us towards an understanding of embodiment as it relates to the ways in which agency is afforded by the agent's morphology based on its structure and organization. In other words, in HCI-based approach the focus is on the ways in which the physical structure of an agent or a system enables a third party—the human participant—to interact with the agent. In AI-based approach the focus is on the behaviors and expressions that an agent's body enables the agent to exhibit. The former is more concerned with the agency of the participant, whereas the latter is concerned with the agency of the artificial agent-system.

In the HCI-based approach to embodiment, the focus is on the opportunities of action and interpretation that an agentic system provides the participant. As an example, let us consider the agent-based art piece *A-Volve* (1994), by Christa Sommerer and Laurent Mignonneau. The work is based on A-Life agents that display complex evolutionary behavior such as mutation, adaptation, and evolution within a virtual world [23]. The system is projected on a water filled glass pool and allows the viewer to dip their hand into the water and manipulate the system via hand gestures. The participant can create new creatures using their finger to draw creature profiles that automatically come to life and will abide by the laws of the system. Once created, these creatures will continue to interact with the visitors by reacting to their hands movement in the water. Despite being based on completely virtual agents, this work can be considered as embodied, from the "embodied interaction" point of view. This is because the role of the participant is not reduced to a passive observer watching these virtual worlds unfold. On the contrary, the participant here can directly manipulate the system through a physical medium—water—using hand gestures.

An AI-based approach, on the other hand, would guide us towards an understanding of embodiment as it relates to the ways in which agency is afforded by the agent's morphology based on its material properties, structure, and organization. Here, the focus is on technical practices and the opportunities of expression that they provide. An excellent example of this notion is Hannah Wolfe's *Furbot* (2019). *Furbot* is an installation featuring a small agent that can respond to touch, stroking, and squeezing via various sounds [24]. In addition to the pressure sensors embedded in the agent's body, it is enveloped in a conductive fur that was fabricated by the artist. Woven into the fur's fabric are many conductive wires, seamlessly turning this faux fur into a stroke sensor that can detect different types of touch, like scratching, petting and tickling. Here, the agent's morphology (material properties, structure, and organization) is designed such that it can capture the manner in which the creature is touched. Moreover, amplified, filtered, and processed, this signal constitutes part of the response of the agent. In addition, sewn to the fur are small motors allowing the agent a low frequency vibrational response akin to a cat purring. All in all, the fur of the agent determines the aesthetics of its interaction through directly enabling and mediating the sensing and response of the agent.

Embodiment in this dissertation is taken as a synthesis between these two approaches to embodiment—that of HCI and AI. In other words, here, embodiment is not construed merely as an agent possessing a body, but denotes how that body facilitates agency and interaction.

1.1.4 Agent-Based Art Practices

There are very few clear and explicitly stated definitions of agent-based art in the literature. Agent-based art is defined as "a specific branch of artistic works that make use of artificial agents, that is, human-made autonomous systems who act within their environment in response to what they perceive" [25], or as artworks that feature artificial agents, "autonomous entities that act in an environment, usually in response to observations" [26]. In this dissertation, I define *Agent-Based Art* as an umbrella term for an art practice that is concerned with creating interactive artistic environments or artifacts, in which the major focus is perceived life-like qualities. The most common forms of agent-based art practices are Robotic Art and A-Life Art.

A-Life is defined as a field of study that "uses informational concepts and computer modeling to study life in general" [27]. A-Life Art borrows techniques from this field of study, such as evolutionary programming, cellular automata, L-systems, etc. to create artistic systems or environments that exhibit complex biological behaviors and processes. A-Life Art includes a variety of media and practices, such as evolved painting, evolved sculpture, evolved animation, virtual ecologies, text based agents and chatbots, etc. [28]. Physically instantiated A-life systems, such as mobile robots, robotic sculpture and interactive environments, constitute only a fraction of this type of art, rendering the majority of these practices as virtual and "body-less" [29] systems. A significant example here is Haru Ji and Graham Wakefield's *Artificial Nature* series (2008–current). *Artificial Nature* is a series of artworks that are made up of immersive environments that feature biologically-inspired complex systems [30]. These works are composed of numerous virtual agents that can adapt to their environment and evolve.

Robotic Art features artificial agents with physical bodies that can exhibit autonomous behavior, specifically locomotion. There are significant overlaps between A-Life Art and Robotic Art since both are concerned with creating autonomous artificial systems that can display emergent quasi-biological behavior. More specifically, numerous Robotic Art pieces can also be regarded as A-Life Art pieces. A-Life Art, as discussed before, contains a large amount of practices that are neither robotic, nor physical in any sense. It is most commonly practiced within the confines of software and the computer screen. This is because the emergent qualities in such systems usually manifest themselves over a great number of iterations—such as evolutionary processes—or would require a large number of agents—such as insect-like self-organization—which may not be feasible to implement through robotic systems.

To reiterate, physicality of the agents—that is, whether or not the agents are equipped with physical bodies—can be taken as a criteria for a taxonomy. Hardware based agentic artworks are commonly considered robotic art in which the agency is depicted via the artwork's responsive movements and gestures, whereas virtual agents are usually considered A-Life Art, in which agency is primarily depicted in the sophisticated biomorphic meta-behavior (i.e. adaptation and evolution) of the agents and their relationship with their environment. In an effort to situate the research problem, what follows is a discussion on the historical lineages of these practices.

1.1.5 Genealogies of Agent-Based Art

The twentieth century gave way to many new art forms and while no artistic practice evolves within a single lineage and there are many valuable points of view considering nuanced histories, I will discuss a few positions by prominent figures, such as Jack Burnham, Frank Popper, and Ernest Edmonds, whose respective approaches helped shape the practices, theories, and histories of the field. While both A-Life Art and Robotic Art are inarguably heavily influenced by cybernetics, their lineages as fields of practice, can be tied respectively to Generative Art and Kinetic Art practices, both of which gained momentum around the mid-twentieth century. What follows is a short discussion on these lineages.

From Generative to A-Life Art

A-Life Art is regarded within the lineage of Generative Art [29]. Generative artworks are "rule-driven systems that appear to have a greater degree of autonomy, relative to the conscious decisions of the human artist" [29]. In other words, authorial control is given up by the artist in favor of emergent aesthetics and the artworks are generated in a bottom-up fashion from a set of overarching rules.

Although often associated with computers, this type of practice precedes computers. John Cage's aleatoric compositions (1951–1953) and Kenneth Martin's *Chance, Order, Change* painting series (1951–1954) are some early examples of Generative Art that do not utilize computers. As computational power became more advanced throughout the last quarter of the twentieth century, artists began to work with computational means in practicing Generative Art. A quintessential example of such work is Harold Cohen's *AARON* (1973–2016), a procedural coloring and drawing program that he developed over decades in order to have a deeper understanding of his own creative process. Over the decades,"it has shown progression along various aesthetic dimensions" [29]. For example, *AARON*'s early "works" featured an abstract aesthetic style that, over time, evolved towards a more representational style, depicting human figures and interior spaces, as well as incorporating color.

Generative Art gave way to A-Life Art when it started "acquiring biological overtones" [29] in the late 1980s due to the artists practicing in this field borrowing concepts (i.e. emergence, evolution, and self-organization) and techniques (i.e. cellular automata, L-systems, and evolutionary programming) from the field of A-Life. We can consider Karl Sims's *Panspermia* (1990) and John McCormack's *Turbulence* (1994–1995) as prominent examples of early A-Life Art. Both works feature arrays of digitally animated evolved synthetic life forms [31].

From Kinetic to Robotic Art

The term *Kinetic Art* refers to "the work of avant-garde artists who were interested in creating movement with mechanical media" [32]. Early experimentations in kinetic art started with mechanical movement around 1913–1920 by a few isolated figures such as Marcel Duchamp, Vladimir Tatlin and Naum Gabo and continued into 1920s and 1930s by several artists, such as László Moholy-Nagy and Alexander Calder. However, it was not until 1950 that the breakthrough into kinetic art took place and it began maturing into its final form through the works of artists like Jean Tinguely, Nicolas Schöffer, and Frank Malina [33]. Kinetic Art was focused on experimentation between movement, technology and art and as such, it is regarded as an early precursor to Robotic Art [34], [35], [36].

Moreover, several artworks of Tinguely (i.e. *Homage to New York*, 1960) and Schöffer (i.e. *CYSP 1*, 1956) are considered both Kinetic and Robotic Art, and as such, they are evolutionary crossovers between Kinetic and Robotic Art [37], [38]. *CYSP 1*, for example, is reminiscent of Alexander Calder's mechanized sculptures, "mobiles" (1931-1959) in not only that motion is a defining property of the artwork, but also due to the material attributes of the sculpture—a spatial composition of abstract geometric elements made out of metal sheets and rods assembled together. However, much beyond these "spatio-dynamic" qualities, *CYSP 1* is a cybernetic entity, capable of autonomous behavior. It can respond to changes in sound, light, and color and has autonomy of movement. All in all, *CYSP 1* is regarded as "the milestone which indicates the passage from mechanics and electronics, to kinetics and robotics" [37], [39].

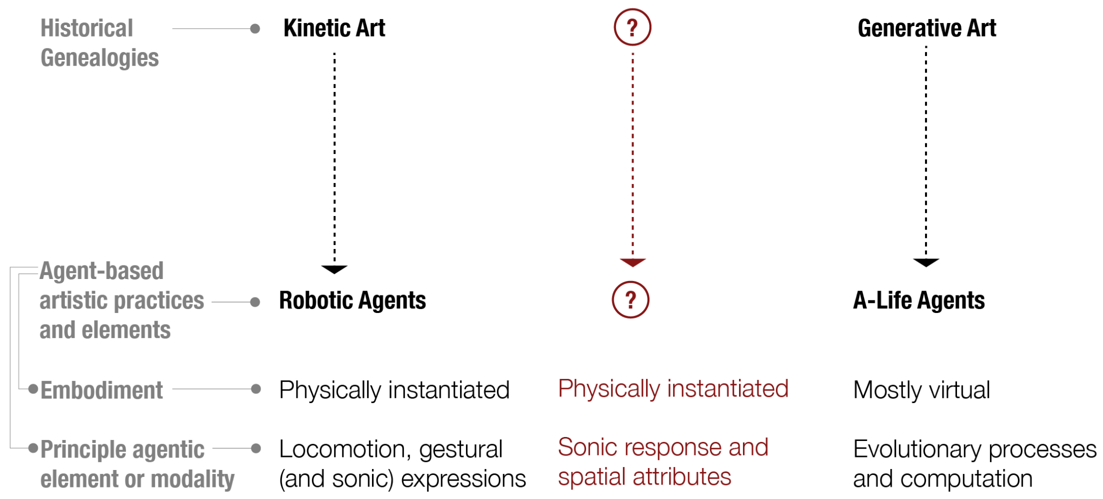


Figure 1.2: Most common agent-based art practices and their genealogies. "?" indicates the research problem.

1.2 Research Problem

As I have discussed in the previous section, the two primary forms of practice in Agent-Based Art are A-Life Art and Robotic Art. Between the two, they encompass a large area of practice that comprises agents with physical bodies that can locomote—rooted in kinetic art practices—and agents with virtual bodies that are driven by overarching rules and marked by biological processes—rooted in generative art practices. In depicting agency and designing agents, is there any space in between these two forms of art? (Figure 2.1). **Can we conceive of an agent-based art practice with alternative genealogies and alternative ways of depicting agency—alternative ways that are neither robotics and motion based, nor dependent on virtual bodies that are confined to the screen or projection?**

To reiterate, the research problem calls for an inquiry into a possible agent-based art practice which feature agents that:

- are life-like

- are embodied and physically instantiated
- do not necessarily operate based on evolutionary processes
- do not necessarily locomote

I argue that by focusing our design efforts on a unique combination of sonic response and spatial morphology (both form and structure) of an agent, we can create powerful ways to depict agency—without relying on motion, or being constrained to the computer screen. That is, through a fusion of digitally designed and fabricated artifacts, sonic expressions, and interactive behaviors, we can create exceedingly compelling artistic life-like systems. This constitutes the focus of inquiry in this dissertation.

1.3 Approach

In tackling this research question, I take guidance from an aesthetic concept coined as *Gesamtkunstwerk*—"total work of art", or "total artwork"—by the composer Richard Wagner in *Das Kunstwerk der Zukunft (The Artwork of the Future)* (1849) to describe his aesthetic ideals [40]. Wagner thought of his pieces not merely as musical works but rather as unified works of art that include set design, costume design, acting, content, and musical composition. Also described as "several art forms combined to achieve a unified effect" [41], *Gesamtkunstwerk* is regarded as an early precursor to both practical and theoretical systems for an extensive integration of the arts [42]. For example, it is widely regarded as a historical precursor to installation art [43][44], upon which my proposed genealogy for *Sono-spatial Agents* is built. This is further discussed in the next chapter.

Gesamtkunstwerk has deeply infiltrated the domain of fine arts and design. It is no wonder that this notion was widely embraced by architecture, an intrinsically multidisciplinary practice, which deals with shaping the human experience in space through incorporating various sensory modalities [45]. In fact, the German architect Walter Gropius, founded Bauhaus (1919–1933), which undeniably affected all the design practices that succeeded it, on this very principle.

> "Architecture was to assimilate all forms of the visual and performing arts into a single totalizing project that would define the twentieth century. The Bauhaus would attempt to resolve the split between art and craft as well as performer and audience, the alienation of the subject from art, and the artist's alienation from technology and commerce. In the totalized project of art, object-making, music-making, and building would form a singular modernist unity" [43].

Following this thread, I take an interdisciplinary approach that fuses several design practices, and the tools, strategies, and concepts borrowed from them. These design practices include both relatively recently emerged ones—such as parametric design, sonic interaction design, digital design and fabrication—and long established ones—such as architecture and interior design. The common denominators here are spatiality and sonority, and the fusion of the two. In other words, in approaching agent-based media arts, I propose a conceptual framework that is broadly founded upon an aesthetic fusion of sound and space, and borrows concepts and tools from the design practices around them. I discuss this conceptual framework more extensively in the next chapter. What follows here is a short introduction to each of the fields I propose to borrow from and the possible ways that they can inform agent-based art practice.

1.3.1 Architectural and Interior Design

Architecture uses the language of space—the collective effect of the visual, formal, and tactile qualities of the built environment—for the purpose of guiding human experience in space. [46] Whether a given space is organized radially or linearly, is flooded with natural light or artificial light, is tight or spacious will have direct impact on human actions in and interactions with that space. As such, agency in architecture is determined by the materiality—form, material, and configuration—contrary to agency in interactive media arts, which is primarily determined by control systems—behavior, computation, and program. The former is marked by a material agency and aesthetics, while the latter is marked by behavioral aesthetics. Synthesizing the two approaches would yield richer aesthetic experiences, for such synthesis calls for an integration of material affordances with computational interactive ones to depict agency. So, in addition to the digital and interactive processes, the design of spatial elements—that is, their form, material, and configuration—shall be taken into consideration as an important parameter in depicting agency.

1.3.2 Digital Design and Fabrication

While material and formal concerns have always been a background player in interactive media arts [3] [1] [47], materiality is arguably gaining more currency in these fields of practice and research today, due to the emerging widespread availability of cutting edge digital design and fabrication tools, and the subsequent flourishing of material cultures and maker communities. Such communities are rapidly growing through both research and production, inside and outside academia. The availability of these technologies allows us to work with material and form in new ways, opening up new possibilities of artistic expression. One such possibility is a marriage of this culture with agent based art, allowing us to conceive of formal expressions—such as mathematically defined biomorphic geometries based on natural processes—that could not be generated, or conveniently fabricated with prior tools.

1.3.3 Parametric Design and Architecture

Parametric design and parametric architecture predates computers as it is attributed to earlier works of the Catalan architect Antoni Gaudí. The term "Architettura Parametrica" (parametric architecture) was coined by the Italian architect Luigi Moretti in the 1940s. However, it was not realized until the 1960s, when he presented the stadium he designed for the *XII Triennale di Milano*, with the aid of a 610 IBM computer [48]. Parametric Design, as it is practiced today, is a subset of digital design and defined as "a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response" [49]. With the use of iterative generative procedures, parametric design allows us to create a vast number of instantiations of a geometric form whose parameters can be controlled via variables. This allows us to implement complex biological concepts in designing and creating agent bodies, such as morphogenesis, genotypic or phenotypic variations, mutations, growth, etc.

1.3.4 Speculative and Critical Design

The terms "critical design" and "speculative design", oftentimes used interchangeably, emerged from product and industrial design practice and were introduced by Anthony Dunne and Fiona Raby in the late 1990s. Design is typically associated with problem solving and serving a utilitarian function. Dunne and Raby argue that many of the challenges that humanity faces today are unfixable unless we change our values, beliefs, attitude, and behavior. [50]. Speculative design artifacts can serve this purpose —to share a critical perspective, inspire debate [51], and increase awareness of environmental or social issues. Based on satirical, witty, ironic, and oftentimes dystopian scenarios about "how things could be", speculative design artifacts or environments "can act as a catalyst for collectively redefining our relationship to reality" [50]. This approach is undeniably conducive to designing agents in the context of artistic practice, which generally strives to critically reflect or question social, cultural, or ethical issues.

1.3.5 Sonic Interaction Design

Sound is a very powerful medium for communication, both in biological and in cultural contexts, for it has a potential to carry multiple kinds of information —emotional, spatial, kinetic, semantic, and ecological. That said, sonic interfaces in mediating interactions have long been overshadowed by an overemphasis on visual ones and this situation even arguably constrained the development of interactive systems [52]. In the last fifteen years or so, the field of *Sonic Interaction Design (SID)* has been gaining more currency owing to a milestone workshop at the *CHI (Conference on Human Factors in Computing Systems) 2008* conference that helped define the discipline and its scope [53], [54].

Facilitated by the increasing possibilities offered by physical computing and digital audio technology, SID is defined as: "practice and inquiry into any of various roles that sound may play in the interaction loop between users and artifacts, services, or environments, in applications that range from the critical functionality of an alarm, to the artistic significance of a musical creation" [53]. In other words, "SID is the activity of shaping the relation between humans and objects by means of sound" [52]. As such, SID is directly related to sonic agency in that it explores the ways in which sound can be used to convey information, meaning, aesthetic and emotional qualities in interactive products, artworks, or environments. Informed by this design field, sound constitutes an exceedingly powerful medium for depicting agency and conveying many aspects of agentic systems.

1.4 Objectives

Agent-based Art practices fall under the broad umbrella of Media Arts and have been researched, theorized, and practiced by several artists, such as Simon Penny, Ken Rinaldo, and Eduardo Kac [2] [55] [36]. Building upon the works of these figures, the objective of this dissertation is to expand upon the agent-based art practices via defining the following:

- A novel subarea of agent-based art, as informed by recent developments in several spatial and sonic design fields, such as sonic interaction design, parametric design, and digital design and fabrication, yielding new possibilities of expressions.
- A novel conceptual framework that is aimed at a deeper understanding of agent-based art practices, their lineages, and theoretical underpinnings.

To reiterate, my research investigates the potential of alternative means to agency than robotics and A-Life via posing the primary question: What are some alternative ways to the prevailing robotic and a-life practices, in which physically instantiated non-kinetic forms of interactive art can depict agency? More specifically, this research is an investigation into an interdisciplinary art and design practice with focus on the role of sonic response and material morphology in creating agent-based artworks. Therefore, the practice of devising and developing such systems is central to this work. As such, my chosen approach is *practice-based artistic research*, the details of which is discussed in the next section.

1.5 Methodology

The definition and the scope of practice-based artistic research is widely debated [56]. One discussion in the literature is about whether an artwork can constitute *the* contribution to knowledge in itself without the need of a typical textual dissertation where the research problem, the methods, findings, and wider contributions are discussed. The proponents of this argument claim that by forcing artistic research into scientific approaches and criteria, we diminish the intrinsic value of art that cannot be reduced to declarative knowledge [57]. The opponents of this position argue that while the artistic artifact is important and may have a pivotal role in a PhD level research, it is not sufficient without a textual counterpart that situates, elaborates, and analyses the candidate's position and demonstrates critical reflection [58].

While this issue has many nuances and still a widely agreed upon disciplinary standard does not exist, I will comply with the latter position for the purposes of this dissertation. Specifically, I will largely follow the views of Linda Candy and Ernest Edmonds, which are stated in their 2018 article titled "Practice-Based Research in the Creative Arts" [58]. Here, practice based research is defined as "an original investigation undertaken in order to gain new knowledge, partly by means of practice and the outcomes of that practice". Following Candy and Edmonds's approach, the process of practice constitutes the primary method in practice-based artistic research. In this dissertation, as opposed to being depicted within a stand-alone chapter, the methods, tools, strategies, and processes are embedded in the chapters that document and discuss my practice as case studies. In other words, the questions related to methodology are discussed in relation to the specific artworks that are presented as a part of the main body of the dissertation.

1.6 Outline and Summary

In addressing these points, I will take the following steps:

- Background and conceptual framework (Chapter 2)

  Like most significant practices, the practice that I present here exists in a constant feed-back loop with theory and discourse. As such, it is my intention to provide theoretical and conceptual contributions, as well as the products of my artistic practice, to the field of Media Arts. To this end, I introduce and situate *Sono-spatial Agents* through discussing its historical lineage, and theoretical underpinnings in Chapter 2. Here, through artwork examples, I also describe a framework aimed at helping understand, conceptualize, practice, and further develop a strand of agent-based art that is neglected. Borrowing from many design disciplines, such as architecture, parametric design, speculative design, sonic interaction design and digital design and fabrication, the framework focuses on two primary modalities in depicting agency: sonic response and spatial morphology.

- Artistic process and products as case studies (Chapters 3 and 4)

  Following the conceptual framework, I will present two major agent-based systems as well as their design and production processes following a practice-based research method with a focus on sonic interaction design and parametric design. Each project is discussed in a dedicated chapter—Chapters 3 and 4. Taken as case studies, each of these chapters start with a set of specific problems as it relates to artistic agents and describes the artistic process in relation to these questions, from its conceptual underpinnings to concrete implementations. Chapter 3 discusses *HIVE* (2016–2018), an agent-based artwork that is based on the notions of *niche hypothesis*[59] and *umwelt*[60]. HIVE is a *Sono-spatial Agent* that explores the notion of agency in the sonic medium. Chapter 4 discusses *Cacophonic Choir* (2019–2020), another agent-based interactive installation that aims to bring attention to the first-hand stories of sexual assault survivors. *Cacophonic Choir* is an *Sono-spatial Agent* that addresses the ways in which their experiences are distorted by digital and mass media, and how these distortions may affect survivors. Both chapters describe the conceptual background, design, and implementation of the respective pieces, as well as their reception and evaluation.

- Conclusion and future work (Chapter 5)

  Here, the research problem is revisited and addressed. I propose to turn the key concepts that were presented in the conceptual framework into a set of questions, the answers to which can help guide the design efforts of agent-based art projects. I demonstrate how these sets of questions can be answered in the context of the case studies—*HIVE* and *Cacophonic Choir* and propose the framework as a system to guide further practice in this area. I list the contributions and briefly discuss the future directions of this research.

1.7 Permissions and Attributions

1. The content of Chapter 3 is the result of a collaboration with Akshay Cadambi and Yon Visell, and has previously appeared in the proceedings of the international conference on *New Interfaces for Musical Expression (NIME'17)* [61] and in the proceedings of *Association for Computing Machinery - Special Interest Group on Computer Graphics (ACM SIGGRAPH) Asia, Art Gallery 2017* [62]. It is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0). Copyright remains with the authors. It is reproduced here with the permission of

Akshay Cadambi and Yon Visell. ©2017

2. The content of Chapter 4 is the result of a collaboration with Hannah E. Wolfe and Alex Bundy, and has previously appeared in *Leonardo Journal*, vol.53, no.4 [63] and the *Proceedings of ACM SIGGRAPH Art Gallery 2020* [64]. Copyright is held by the authors. It is reproduced here with the permission of Hannah E. Wolfe and Alex Bundy. ©2020

Chapter 2

Elements and Examples of Sonically Actuated Spatial (Sono-spatial) Agents

In this chapter, I layout a conceptual framework through which we can approach media arts in general and agent-based art in particular. To this end, I define and situate *Sonically Actauated Spatial (Sono-spatial) Agent* practice. This chapter discusses the specific ways in which *Sono-spatial Agents* operate—especially in depicting agency—as well as the fundamental elements of this practice in further detail.

I define *Sono-spatial Agents* as agents that rely on a unified aesthetic that is composed of sonic response and spatial attributes of form, material, and configuration, and I historically situate this practice within the lineage of sound installation art. After I lay out the primary modalities of *Sono-spatial Agents* as spatial morphology and sonic response, I describe the roles that these modalities can take in an agentic system as architecture, body, and aesthetic object—in the case of spatial morphology— and ecology, territory, and actuator—in the case of sonic response. I discuss each of these roles via

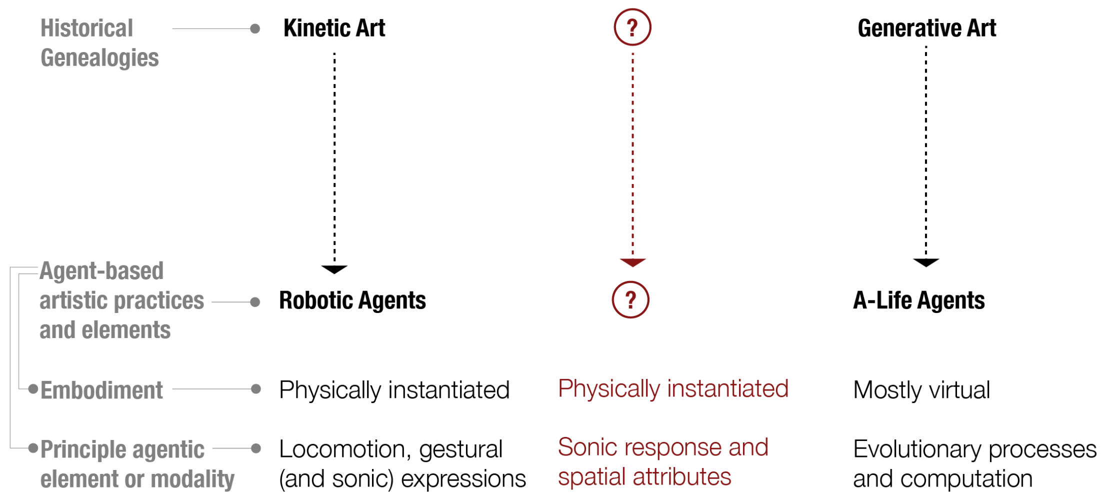


Figure 2.1: Most common agent-based art practices and their genealogies. "?" indicates the research problem.

reviewing relevant artworks.

2.1 Defining and Situating *Sono-spatial Agents*

My research problem calls for an inquiry into possible alternative practices of agent-based art that inherit aspects of robotic and A-Life agents, but not fulfill their core conditions, namely kineticism—in the case of robotic agents—and adaptation–in the case of A-Life agents. (Figure 2.1) A perceived agency, that is at the core of agent-based artworks, arguably can exist in a liminal space that is located at the peripheries of these practices. Occupying such a domain, I propose *Sonically Actuated Spatial (Sono-spatial) Agent* as:

- Agents that rely on a unified aesthetic that is composed of sonic response and spatial attributes of form, material, and configuration. *Sono-spatial Agents* fuse sonic expression and physical form, behavioral and material aesthetics, discrete objects and immersive environments.

- A practice that fuses several spatial and sonic design practices with interactive digital media.

2.1.1 Genealogies of ***Sono-spatial Agents***

Sono-spatial Agent practice is historically related to sound art—more specifically to sound installation art—a hybrid of experimental sonic practices rooted in electronic music, and installation art practices that are rooted in fine arts. Early precursors of sound art can be dated back to the 1910s, with the works of Luigi Russolo [65]. Originally a Futurist painter, Russolo not only designed and constructed a number of noise-generating devices called *Intonarumori*, but also wrote a seminal manifesto titled "The Art of Noises" (1913), where he argues for the aesthetic of industrial sounds and noise [65]. Despite his influence, the acceptance of sound as a medium for art practice did not take until the late 1950s [66]. To be able to examine the historical roots of sound art, we should consider the histories of two essential fields of origin—music and fine arts—leading up to the late 1950s. This is because sound installation art emerged through a crossbreeding between these fields.

In terms of music history, sound art and sound installation art is rooted in an era of immense experimentation. The advances in sound reproduction technologies that began in the first half of the twentieth century and developed rapidly afterwards have allowed composers—such as Pierre Schaeffer, Edgard Varèse, Karlheinz Stockhausen, and John Cage amongst many others—to challenge the various norms of western music traditions and experiment beyond these established norms. The dawn of electronic music brought about immense creative freedom through experimentation. As a way to convey his expansive aesthetic vision in music, Varèse coined the term *organized sound* [67],

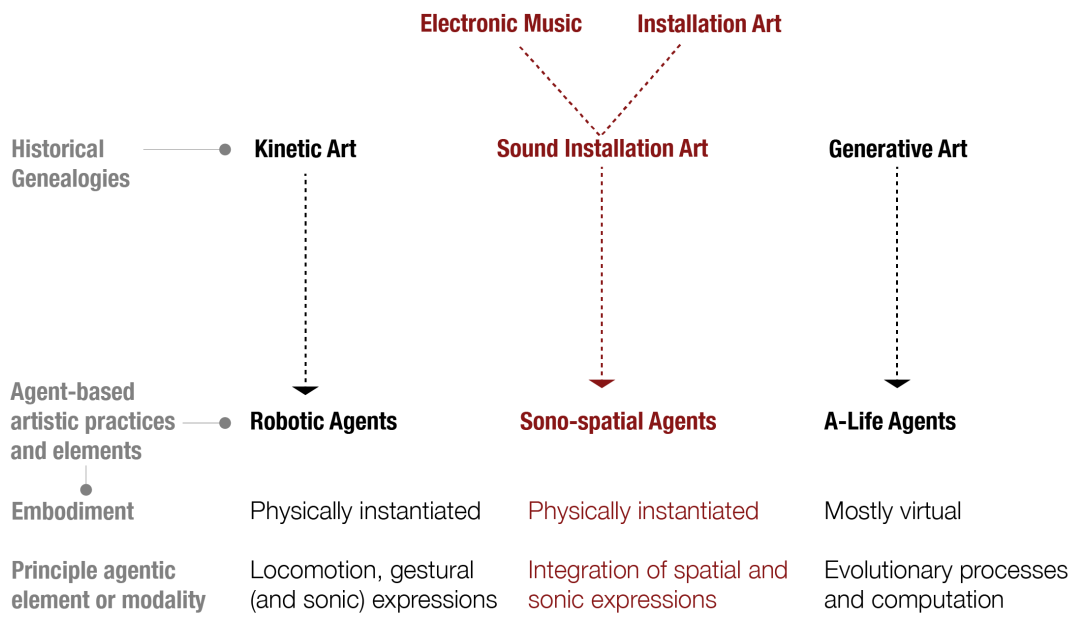


Figure 2.2: Situating *Sonically Actuated Spatial Agents* and their genealogy.

which became a prevalent definition of music over the last century as the world of music has gradually "opened up to all sounds"[68].

In terms of the history of visual and fine arts, sound art and sound installation art is rooted in installation art, which emerged in an era marked by several interrelated changes. A significant one of these changes is a collapse of medium specificity bringing about a shift from the strictly visual toward the multi-sensory. Artists in this era (late 1950s and 1960s) started practicing across the boundaries that had defined the visual art disciplines [43]. Other momentous changes happening in this era are the shifting foci of artistic practices from discrete objects to environments, from formal concerns to conceptual ones, from fixed conditions to ephemeral ones, from end products to processes, and so on. Installation art primarily emerged at this time, beginning with Allan Kaprow's "environments" in 1957 onward [44], [43]. Installations rapidly became the favored practice of many Minimalist and Process artists, such as Donald Judd, Carl Andre, Dan

Flavin, Robert Morris, Richard Serra and Eva Hesse.

It is widely accepted that installation art is historically rooted in the notion of *Gesamtkunstwerk*, introduced by the composer Richard Wagner [40]. As discussed in the previous chapter, as an attempt to fuse different art forms into one work of art, *Gesamtkunstwerk* is regarded as an early effort to establish both a practical and a theoretical system for an extensive integration of the arts [42]. As such, it has deeply infiltrated the domain of fine arts and design. For example, Bauhaus (1919–1933), which undeniably affected all the design practices that succeeded it, was found on this very principle. "The Bauhaus would attempt to resolve the split between art and craft as well as performer and audience, the alienation of the subject from art, and the artist's alienation from technology and commerce. In the totalized project of art, object-making, music-making, and building would form a singular modernist unity. Installation art aspires to this continuum" [43].

Following this thread, Installation Art is defined as multimodal physical environments in which "the space, and the ensemble of elements within it, are regarded in their entirety as a singular entity" [69]. It moves away from the role of the viewer as a contemplator of the passive art object, to an agent who enters and inhabits the space defined by the artwork. Here, the artwork is taken as a singular totality offering an embodied experience in physical space. Informed by a multitude of disciplines, especially spatial ones, such as architecture, interior design, landscape design and so forth, "collectively the work of installation and site specificity engages the aural, spatial, visual, and environmental planes of perception and interpretation. . . Installation is the art form that takes note of the perimeters of that space and reconfigures it" [43].

In being spatial, atmospheric, ephemeral, and temporal all at the same time, sound undoubtedly constituted a medium of extraordinary potential in the changing artistic contexts of the late 1950s and 1960s. Moreover, the composer John Cage had an immense influence on several artistic practices and trends of this era, such as fluxus, minimalist sculpture, and conceptual art, as well as happenings and environments, which were the early examples of installation art [70]. All in all, it is through this crossbreeding of electronic music with installation art that the liminal field of sound installation art emerged. Spatial concerns constitute the common denominator of electronic music and installation art. The focus is the configuration of sounds in space, as opposed to time. We can consider La Monte Young's *Dream House* (1964–current), and David Tudor's *Rainforest* series (1968–2015) as significant examples amongst many of sound installation art from the 1960s—its coming of age era. *Dream House*, a collaboration between Young and Marian Zazeela is an immersive sound and light field, in which sound "takes on a physical mass" through long sustained instrumental drones and fields of audible harmonics [70]. Tudor's *Rainforest V*—in collaboration with Composers Inside Electronics—is described as "an ecosystem of objects that envelops you in sound" [71]. It is made up of tens of audio transducers each attached to a designed or found objects that funnel the sounds, giving them a resonating body and directionality.

In the last decades, due to the fusions of sound installation art with electronic and digital media, several new fields and practices have emerged, such as interactive sound installations; a number of such works will be discussed in the next chapter. *Sono-spatial Agent* practice is situated within this continuum and belongs to this lineage. In other words, *Sono-spatial Agent* practice is an agent-based artistic practice that is rooted in sound installation art and that features physically instantiated artistic agents that rely on non-kinetic means to depict agency (Figure 2.2). These agents may or may not possess kinetic capabilities and their agency is primarily rooted in their spatiality and sonority. With spatiality, I focus on configuration, formal and material qualities of their morphology; with sonority I focus on sonic expressiveness. *Sono-spatial Agents* fuse digitally designed and fabricated artifacts, sonic expressions, and interactive behaviors in order to create 'perceived' life-like systems where the viewer enters and experiences the work in its totality. *Sono-spatial Agent* practice incorporates notions and tools from many design fields like architecture, parametric design, digital fabrication, speculative design, and sonic interaction design and fuses these into a comprehensive integrated environment in order to depict agency. It is based on a primacy of embodied experience in physical space. In other words, *Sono-spatial Agent* practice features agents or agentic ecologies that are fundamentally based on a unique combination of sound, form, material, and spatial configuration, in which a physical bodily experience of being in it or walking through it is essential.

To sum up, I am offering the notion of *Sono-spatial Agents* both as a conceptual framework aimed at understanding, defining, theorizing, and historicizing media arts, as well as an area of practice. The framework and the form of practice will each be discussed further in the upcoming chapters.

2.2 General Qualities of *Sono-spatial Agents*

In addressing the research question, I proposed a domain of practices on the peripheries of Robotic Art and A-life Art—*Sono-spatial Agents*. In the previous section, I tied this practice historically to sound installation art. I defined *Sono-spatial Agents* as agents or agentic environments, ecologies that are fundamentally based on a unique combination of sound, form, material, and spatial configuration, in which a physical bodily experience of being in it or walking through it is essential. *Sono-spatial Agents* rely on non-kinetic means to depict agency and their agency is primarily rooted in their spatiality and sonority. With spatiality, I focus on configuration, formal and material qualities of their morphology; with sonority, I focus on sonic expressiveness. Spatial elements generate a material type of agency, whereas sonic elements generate a performative agency, complementing one another. To sum up:

- *Sono-spatial Agents* are spatial; they focus on attributes of space or spatial elements, namely, form, material, and configuration.
- *Sono-spatial Agents* are sonic; they rely primarily on a sound-based interaction and incorporate elements of sound art and design

In the next sections, I further discuss both of these primary attributes of *Sono-spatial Agents* via examining artwork examples.

2.3 Agency and Spatial Morphology

2.3.1 Defining Materiality, Material Agency, and Spatial Morphology

Akin to the notion of embodiment in HCI, in architecture and all spatial arts, human interaction with built environments and physical artifacts is afforded, facilitated and guided by the materiality of these environments and artifacts. Materiality here is understood as a combination of formal, material, and configurational properties of objects and environments. The **formal properties** are attributes of space and objects that have to do with form, such as shape, geometry, color, etc. The **material properties** pertain to the physical properties of the material used, such as texture, transparency, luminosity, viscosity, elasticity, etc. The **configurational properties** refer to the way in which the elements are organized in space, such as uniform, clustered, scattered, stacked, orthogonal, radial, linear, etc. Taken altogether, these aspects of a given artifact—environment or an object—guide and shape our (inter)actions, and as such, play an essential role in determining the agency of the artifact. This condition is called "material agency" and it encompasses a spectrum of positions ranging from an argument that (passive) artifacts have a significant role in determining the nature of agency to an argument that the artifacts are agents themselves, actively constructing or challenging social reality [72].

Artifacts ranging in scale from an urban landscapes to a household object can be given as examples of this notion. At the urban scale, large public spaces afford public gatherings and therefore political resistance. It is well known that in oppressive states, such spaces are continually redesigned to discourage democratic action. For example, during the 2011 uprising in Egypt, in an effort to discourage the people from gathering for political protests, Mubarek government erected fences and subdivided open areas into manageable plots of grass and sidewalks in Tahrir Square, one of the main squares in Cairo [73]. On an architectural scale, we can consider panopticons, designed by the eighteenth century English philosopher Jeremy Bentham. Designed to enable surveillance with maximum efficiency, a *panopticon* is a building typology for a prison. Panopticons have a radial plan with an elevated central hall in which the long corridors attaching to this hall can be observed with ease [74]. This kind of material agency is also present in the scale of objects. As an apotheosis of this notion, we can consider Bruno Latour's *Actor-Network Theory (ANT)*. ANT attributes equal agency to tools and technologies as humans themselves and considers them as existing within a network and in a constant feedback loop with one another. For example, he argues that a gun is not just an enabler of violence, but it "instructs, directs, even pulls the trigger"[75].

Whether one agrees with Latour's example or not, it is inarguable that artifacts, environments, and their materialities impact our actions and interactions. This is especially true for many artworks, which deliberately make use of this material language embedded in artifacts in order to create certain effects, like inducing certain actions and inhibiting others. This furnishes them with some kind of agency in mediating human actions, not very unlike the mediation of technological products. Thus, the role of the materiality

Figure 2.3: *Hylozoic Soil*, 2009, by Philip Beesley. The photograph depicts the biomorphic, ecological and architectural qualities of the artwork. Photography credit: John Marshall (CC BY-NC-SA 2.0)

in artworks—that is formal, material, and configurational properties— need not be a passive one inducing aesthetic contemplation, but can take an active role in agent-based artistic works. I will call these three aspects that constitute the materiality of an agent-based work as its "spatial morphology". Working in tandem with electronic elements of the system, these spatio-morphological elements can take on certain roles within media artworks in depicting agency. In the context of Sonically Actuated Spatial Agents, spatial morphology can take on any of the following roles: **Architecture, body, and aesthetic object**. These are discussed further with *Sono-spatial Agent* artwork examples in the following subsections.

2.3.2 The Roles of Spatial Morphology in *Sono-spatial Agents*: *ARCHITECTURE*

Through a fusion of physical and electronic elements, spatial morphology can take on an architectural function, creating spaces, ecologies, and worlds in which the viewer and the agents cohabit. In order to discuss this notion, we can take Philip Beesley's *Hylozoic Series* (2007-2017) as an example. (Figure 2.3)

Hylozoic Series is a series of agent-based interactive installations that is described by the artist as an "artificial forest made of an intricate lattice of small transparent acrylic meshwork links, covered with a network of interactive mechanical fronds, filters, and whiskers" [76]. Also described as a "synthetic ecology", *Hylozoic Series* are made up of digitally fabricated biomorphic structures that are fitted with microprocessors and proximity sensors. They respond to the proximity of the viewer via a subtle choreography of motion and light. The motion is afforded by thin SMA (shape memory alloy) wires that are intertwined with the delicate and fibrous sculptural elements. The work also features a soundscape made up of gentle creaking and rustling sounds due to the subtle motion of the agents. In *Hylozoic Soil: Meduse Field* (2010), for example, the installation also features small resonators that produce a cricket-like chirping sound.

> *"Dozens of microprocessors, each controlling a series of sensors and actuators, create emergent reactions akin to the composite motion of a crowd. Visitors move freely amidst hundreds of kinetic devices within this environment, tracked by many dozens of sensors organized in 'neighbourhoods' that exchange signals in chains of reflexive responses. The installation is designed as a flexible, accretive kit of interlinking parts organized by basic geometries and connection systems"* [77].

The piece's spatial morphology is made up of parametrically designed intricate forms digitally fabricated out of metal, acrylic, mylar, and glass forming a delicate sculptural assembly. There are several different primary forms that are repetitive with variations, like different species. As an assembly, they are suspended from the ceiling creating a sense of a space reminiscent of being enveloped by grapevines or a forest canopy. Akin to the experience of being in a forest and being surrounded by various sizes of trees, shrubs, bush, and flora, these structures form "intimate sculptural spaces that envelope viewers in floating forms". Here, "audiences are gathered and guided by small clusters of activity into a highly intimate and shared sculptural space" [78].

> *"Hylozoic Soil is a project within a body of work that has been gradually moving from individual figures composed of complex hybrid organisms towards immersive architectural environments that behave like highly mobile crowds of interlinked individuals acting in chorus"* [77].

In the *Hylozoic Series*, agency is distributed over the entire space via an integrated work of digital and material elements, creating an architecture-agent hybrid ecology enveloping the viewer. This is a more atmospheric approach, in which the morphologies of a system of spaces and objects working in tandem with physical computing elements (i.e. sensors, actuators, microprocessors) facilitate the creation of a world, a landscape, or an ecology, in which the viewer and the agents cohabit.

2.3.3 The Roles of Spatial Morphology in *Sono-spatial Agents*: *BODY*

As discussed in the "Agency and Embodiment" section of the previous chapter, an agent's body and its morphology can be designed to not only house its sensory-motor systems, but also can work in tandem with the software systems to determine the control of the agent. That is, an agent's body and its spatial morphology partially determines its agency [16].

An exemplar artwork embodying this notion is Kenneth Rinaldo's *Autopoiesis* (2000) (Figure 2.4). Inspired by the phenomenon of self-organization in nature, in which a group of organisms of the same species show complex emergent global behavior through simple rules and interactions between one another, *Autopoiesis* features fifteen agents with physical bodies. Agents are distributed in space within a grid organization and each agent is suspended from a structural frame overhead. The agents communicate with each other via audible telephone tones. When an agent locates a visitor, it "calls" other agents in this "language". They respond by repeating this song, and pointing their arms in the direction of the calling agent, which is the closest to the participant.

The body of each agent consists of three primary elements –sculptural, mechanical, and electronic. The sculptural elements are composed of a three-part flexible lightweight biomorphic structure made up of grapevine branches with two custom designed joints. The electronic and the mechanical elements are housed at the top "anchor point" of the agents. The mechanical elements comprise custom designed pull string mechanisms controlled by simple motors threaded through the grapevine arms enabling them to move in multiple directions. Each agent is equipped with its own microprocessor, loudspeaker, and infrared proximity sensors, constituting the electronic elements.

Here, the infrared sensors are extremely simple, and each of them detect motion in their vicinity and output one bit information. They "gain" directionality through their organization within the physical body of the agent. In other words, the agent's body is designed such that it can accommodate four of these one bit sensors in four primary directions. These simple one-bit sensors are located within the agent's body so they can cover eight directions. That is, if two adjacent sensors are triggered—say, south and east corners—the agent knows that someone is located in the southeast direction, so

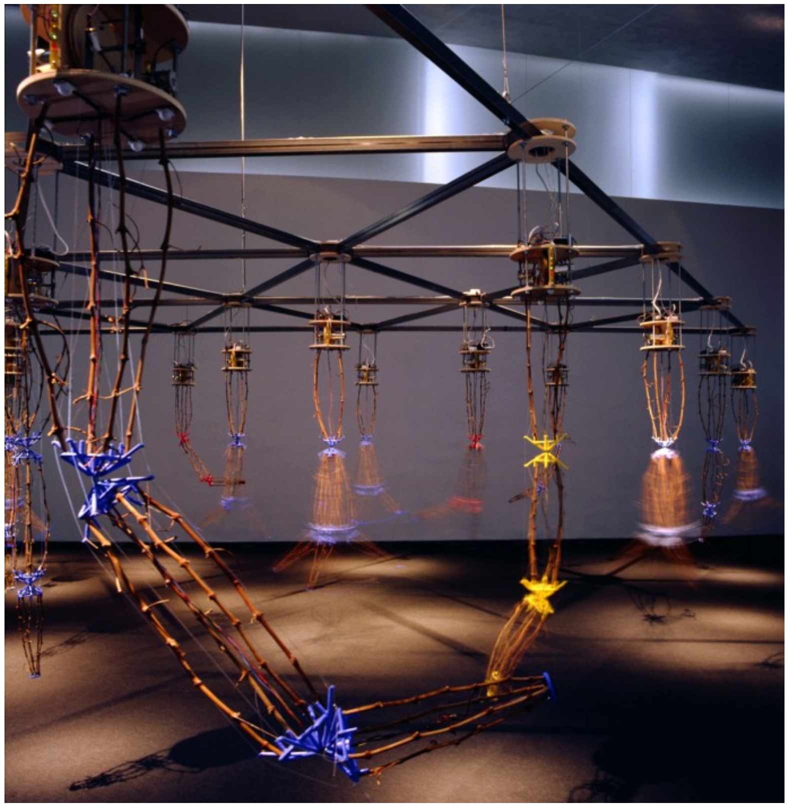


Figure 2.4: Both figures depict *Autopoiesis* (2000) by Ken Rinaldo. Photograph of the installation from *Alien Intelligence Exhibition* curated by Erkki Huhtamo for Kiasma Museum of Contemporary Art Helsinki, Finland, in February 2000. Photography credit: Ken Rinaldo (CC-BY-SA-4.0)

the agent's arm can move towards that direction. At the tip of each agent's body, an active infrared sensor (proximity sensor) is located. This is normally pointing downwards towards the floor. However, when agents bend in a given direction—that is, pointing their arm towards that direction—this proximity sensor at the tip of the arm becomes an efficient detector of visitor proximity and helps the agent avoid colliding with the visitors. As a result, the agents display both attraction and repulsion behaviors.

Rinaldo describes the sensor configuration in Autopoiesis as "smart-sensor organization" [79]. This is akin to the fundamental notions of the embodiment paradigm, where the morphology of agents contribute to their cognition and in some cases, the computational expense can be reduced via offloading certain tasks to the body and the way it is physically configured. An early argument of this notion can be found in the seminal 1959 article titled “What the Frog’s Eye Tells the Frog’s Brain” by Lettvin et al [80]. In this article, the authors argue that a significant part of the information processing is executed by the eye of the frog due to its specific morphology.

Applied to artistic context, embodiment does not merely denote that the agent is equipped with a physical body, but is concerned with the ways in which that body mediates and enables its actions. Following this thread, an agent’s spatial morphology can be designed to not only house its sensory-motor systems, but can work in tandem with the software system to determine the control of the agent. As a result, the spatial morphology of an agent’s body can strictly be intertwined with its hardware organization, and the software procedures in depicting agency.

2.3.4 The Roles of Spatial Morphology in *Sono-spatial Agents*: *OBJECT*

Formal aspects of agents directly impact how we attribute agency to them. In HCI research, it is argued that the perception of agency is influenced by the appearance of the agent, especially in the case of zoomorphic or anthropomorphic features [81], [9]. The physical body of an agent can go beyond the electronic hardware assemblage and incorporate a sculptural materiality that acts as an aesthetic device in its own right. For example, it can reinforce the agent’s quasi-biological status via biomorphic features, or its cultural status via anthropomorphic elements.

In media arts, the emphasis on behavior and performance arguably comes at the expense of materiality and objectness. An agent based artwork, however, can perform simultaneously as an aesthetic object and a behaving entity. What follows is a subsection that discusses this issue further.

A discussion on the ontological status of the aesthetic object in media arts

A rejection of formal concerns as the focus of the artwork in favor of conceptual and performative concerns has been a theme in art since Duchamp and Dadaism. It has become the prevalent focus in the art world starting in the 1960s. Works that reflect this change have been described variously as conceptual art, post-object art, post-formalist art, systems art, behaviorist art, and cybernated art. Essentially a reaction to overemphasis on formal aspects of the artwork, as well as the extreme commodification thereof, this tendency is described as "a polarity between the finite, unique work of high art, that is, painting or sculpture, and conceptions that can loosely be termed *unobjects*, these being either environments or artifacts that resist prevailing critical analysis" [34].

Such themes were echoed by prominent artists of the time, such as Robert Morris, who advocated for the notion of anti-form, or anti-formalism, striving to end the overwhelming dominance of formal qualities in fine arts, in favor of processes, concepts, and relationships [82]. Similarly, Roy Ascott argued that "the vision of art has shifted from the field of objects to the field of behavior" [1]. These discourses and their counterparts in practice pushed the notion of the art object as a discrete aesthetic object as the primary focus of the artwork to the background, eventually leading to the notion of 'dematerialization' [83] or 'disappearance' [35] of the art object.

While the art object, nonetheless, has not 'disappeared' or completely 'dematerialized', it is certainly pushed back further into the background. And the polarity—rooted in 1960s art discourse—between the finite art object with strict material limits and an 'unobject' [34] that is marked by participatory processes and performative environments arguably still has an overarching influence today, especially in media arts.

Physically instantiated interactive artwork, however, like most artwork, has the ability to operate on multiple levels at the same time. That is, an interactive artwork can perform simultaneously as an aesthetic object and a behaving entity that can create atmospheric experiences. It follows that such polarity is uncalled for, and we do not have to reject the aesthetic object and its materiality to be able to embrace the behavioral and the performative.

Auspiciously, numerous practices today do not fully reflect this pushback on materiality in art discourse. Materiality is arguably gaining more currency in media arts today, due to the emerging widespread availability of cutting edge digital design and fabrication tools, and the subsequent flourishing of material cultures and maker communities. Such communities are rapidly growing through both research and production, within and outside of academia. These technologies allow us to work with material and form in a new way, enabling us to conceive of forms that could not be generated or transfigured with prior tools. Moreover, new expressions are available to us through computational fabrication, including mathematically defined geometries based on natural processes. This is opening up new formal possibilities for artistic practice. One of such possibilities is an integration of these technologies into agent based art, constituting yet another reason to conceive of an artwork that performs simultaneously as a (fabricated) aesthetic object and a behaving entity. While both of these fields—agent-based art and digital design and fabrication—are very commonly practiced today, hybridization of the two is arguably rare.

As an example, we can once again consider Philip Beesley's body of work, which fuses parametrically designed and digitally fabricated sculptural elements —using materials such as metal, acrylic, mylar, and glass [84]—with physical computing systems to create agent-based responsive environments and ecosystems. As an example, we can consider *Hylozoic Ground*, which was featured as a part of the Canadian Pavilion in 2010 Venice Biennale. *Hylozoic Ground* is conceived as a "living system" with "embedded machine intelligence (that) allows human interaction to trigger breathing, caressing, and swallowing motions and hybrid metabolic exchanges" [85]. One of the many agentic components that make up this artificial ecosystem/landscape are "breathing pores", which help circulate the air in the system that gets filtered subsequently. These are carefully designed agents that are composed of thin feather-like mylar membranes, and equipped with SMA-driven levers and filament tendons. Acting like dynamic fins creating air flow, they exhibit an upward-curling motion.

Here, the parametric design of these species allows for nuanced variations amongst the members of a given species. Digital design and fabrication allows for highly customized actuator components, such as the breathing pore, which are not only performative, but also are rendered with an immense degree of aesthetic appeal. Highly biomorphic both in appearance and behavior, the visual and spatial aesthetic qualities of these works match the behavioral and performative qualities. In other words, in depicting agency, the form and the function of the agents are tightly intertwined and equally significant. As such, this is an exemplar direction for media arts in re-embracing the aesthetic object.

2.4 Agency and Sonic Response

2.4.1 Defining Sonic Agency

This section is about what I call "sonic agency", that is, the notion of behavior and agency within the sonic context. In the previous chapter, I defined agents as interactive artistic environments or artifacts, in which the major focus is perceived life-like qualities. Here, I will first discuss the potentialities that lie within the sonic medium to depict such qualities. This will be followed by the fundamental roles that sonic modality may take in *Sono-spatial Agents*, especially when the system is inanimate (non-kinetic). Disputing the view that physical movement is a prerequisite for agency [86], the sonic medium will be considered as an alternative way to convey agency due their immense potential to convey space and motion, as well as meaning and emotion.

As discussed in the previous chapter, sound constitutes an excellent medium for human-computer interfaces. As such, it is already ubiquitous in our everyday lives. Its pervasiveness ranges from home appliances, to VAIs (intelligent virtual assistants), from electronic instruments to auditory displays. The potential of sonic interaction and agency goes beyond utilitarian applications and commercial products. It helps generate novel artistic expressions in music, media arts, and agent-based media arts.

The ability to behave through sound is obviously not limited to technological artifacts and humans. The prevalence of sonic expression and acoustic communication extends to nature, constituting an essential means for survival in non-human animals. "Sound is an important component of the majority of the terrestrial, freshwater, and marine ecosystems and becomes an essential context with which organisms daily interact performing their vital functions." [87]

Sounds generated by animals, coined as "biophony" [88], can contain many types of information, such as emotional, spatial, and ecological, as it relates to their survival and fitness. For example, bird calls are used for mating, or informing others of danger [87]. Pitch changes in birds and humans alike can indicate pain or pleasure; it is argued vocalization ascending in pitch indicates pleasure, whereas descending in pitch indicates pain [89]. Sound is also colored by space and many animals have evolved to perceive this and get spatial cues from sound in order to locate predators, prey, or to mate [87]. Due to this spatiality, sound is the primary modality for information in some species, such as bats. Furthermore, animals also use spatial aspects of sound as a strategy for survival. For example, it is argued that the vocalizations of a frog population in vernal pools in the spring tend to be in a chorus where the frogs "crescendo" and "decrescendo" simultaneously. This cooperative behavior creates a wide sound image, making it difficult

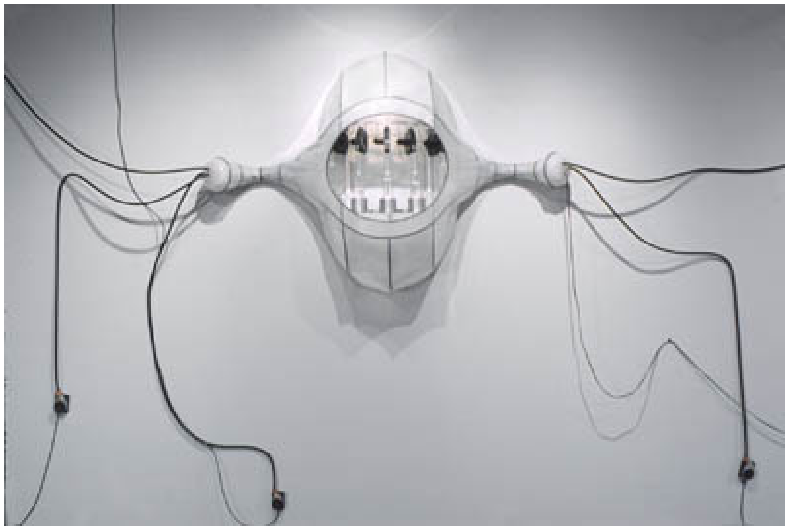


Figure 2.5: *The Unstoppable Hum*, 1999. © Sabrina Raaf. Photo credit: Tom Van Endye

for a predator to locate individual frogs [90]. Spectral aspects of sound, in addition to spatial, become essential in animal communication and survival. It is argued that species in a given biome have evolved to establish and maintain their own vocal bandwidth, so that their voices are not masked by other sounds; they each have their own spectral territories [88], [91].

Both machine-based and biological expressions or the principles thereof can be used in depicting agency in agent-based arts. That is, both technologically and biologically based sonic communication can be a basis for aesthetics in agent-based art. Two examples of this notion are Sabrina Raaf's *The Unstoppable Hum* (1999), featuring sonic expressions that are technologically-based, and Simon Penny's *Sympathetic Sentience II* (1996), featuring sonic expressions that are biologically-inspired.

The Unstoppable Hum features agents with biomorphic appearances (Figure 2.5). One of these agents is equipped with various contact microphones that listen to the humming in the walls, pipes, and machinery. This agent receives the signals from the contact mics and activates a motor that blows air over the water filled bottles of different sizes, creating dissonant but expressive tones. The other agent is equipped with a geophone that records the footsteps of the visitors, and a video camera that tracks their movements in space. It translates the human activity into sounds of wheezing water bags and droning bass noises. These sounds dissipate into the background, while the expressive sounds of the first agent come to focus.

The machine sounds, such as humming, that were not intentionally designed for interface purposes that come out of appliances, electrical systems, etc. is a part of our everyday soundscape. Typically they are considered as noisy background sounds that are void of information and aesthetic quality and we tend to tune them out. As a commentary on the nature of our hearing, as well as our aural biases, The Unstoppable Hum reverses this sonic relationship between humans and machines [92] by translating the machine sounds into expressive foreground sounds. Furthermore, Raaf directly attributes agency to machines and architecture. The resulting compositions from the first agent expresses how the computer hears the electrical, non-human parts of the gallery environment, while the second agent expresses how the building environment perceives the humans constantly walking through it. [92]

In *Sympathetic Sentience II* (1996), Simon Penny creates an emergent system through "vocalizing" agents interacting with each other [93]. Sympathetic Sentience II is made up of eight agents, each equipped with a microprocessor, an IR (infrared) sensor and emitter, as well as a buzzer. Each agent outputs an original starting signal, constituting its unique "vocalization". These signals are also sent and received as IR signals between the agents. Once an agent receives a signal emitted by another agent, it adds this new signal to its repertoire. This new signal is sent to both the audio amplification circuit to be played back and the IR emitter, and hence sent to the next agent. Simply put, each agent passes its rhythm to the next. The receiving agent then combines this rhythm with its own, and passes the resulting new rhythm to the next agent. As a result of this constant cycling, new rhythms emerge and the system increases in complexity. This continues until a visitor interrupts this chain of communication by merely moving through the space, in which case the complexity starts diminishing due to occlusion. So, human movement becomes a modulator impacting the communications and the "vocalizations" of these biologically inspired audio agents, whose collective behavior is reminiscent of a frog chorus.

All in all, both works can be regarded as *Sono-spatial Agents* in that they use the expressive qualities of sound as the primary modality to convey behavior and depict agency.

The notion of sound as a primary interface modality is informed by the relatively recently established field of Sonic Interaction Design (SID), while incorporating concepts and theories from biophony, electronic music, and sound art. *Sono-spatial Agents* fuse the notion of sonic agency in nature with culture to create rich interactive experiences that are primarily mediated via the sonic medium. In other words, it relies on an agency in which perception–action loops are mediated by acoustic signals. As such, in the context of *Sono-spatial Agents*, sonic agency is afforded by audio input and output devices—such as loudspeakers and microphones—as well as acoustics and mechanical-wave based input and output devices—such as ultrasonic sensors, buzzers, and piezo elements. Here, these devices or assemblies thereof can take on several roles —defining an **ecology**, inscribing a **territory**, and acting as an **actuator**. The next sections further discuss these roles with artwork examples that can be described as agent-based, in general terms.

2.4.2 Roles of Sonic Agency in *Sono-spatial Agents*: *ECOLOGY*

Soundscape ecology, also defined as the set of the acoustic relationships between living organisms, and their environment[91], can be a basis for aesthetics in *Sono-spatial Agents*. It is argued that "sound reflects natural and human activities and thus serves as an excellent "universal" variable to consider in any study of a coupled natural-human system" [91]. An understudied field, the study of soundscape ecology can be very crucial to understand and preserve the fitness of a habitat. Bioacoustician Bernie Krause defines soundscape as all of the sounds (biophony, geophony and anthrophony) present in an environment at a given time and argues that soundscape is a finite resource and that many organisms compete for spectral space. Also called the *niche hypothesis*, species within a given biome have evolved such that their vocalizations are not masked by one another. In other words, spectral space is partitioned between species [88]. Following this thread, sonic response in *Sono-spatial Agents* can take on the form of a soundscape ecosystem in order to depict agency and create life-like qualities. Demonstrating this notion, I will discuss three artworks: *Excuse Me* (2006) by Tom Davis, *Evolving Sonic Environment* (2006) by Usman Haque and Robert Davis, and *Autopoiesis* (2000) by Kenneth Rinaldo.

Excuse Me is an emergent sound installation comprising six agents that generate an evolving sonic ecosystem. The body of each agent is made up of two transducers—one acting as a microphone, the other as a speaker—attached to the body of a violin. The agents are suspended from the ceiling and the installation allows the visitors to walk around and in between the agents and interact via using their voices or generating other sounds. Each agent listens to their environment and analyzes the input signal from their microphone. Going through an internal database of sounds, the given agent finds the "best fit" for this sound, which constitutes its interpretation of the sound. The agent then plays this "best fit" back and adds the original input signal to its internal database, expanding its repertoire. Any sounds that the participants generate directly influences this evolving soundscape. Simply put: "The agents pick up their environmental noise and try to recreate it; bits of speech and other sounds are broken up and reinterpreted, passed from one agent to another creating an evolving shared language of communication, a sonic ecology, an emergent texture of sound" [94]. All in all, the piece demonstrates a kind of sonic ecology within a physical soundscape environment that is shared in between the agents, as well as between the agents and the visitors.

Evolving Sonic Environment by Usman Haque and Robert Davis is a spatial sound installation made up of multiple agents, each comprising a speaker, a microphone, and a PCB (printed circuit board). Each agent is hung from the ceiling emitting a signal that is either ascending or descending in pitch. Agents listen to each other and analyze the signals around them. If a given agent "hears" too much of one type of signal—say, all descending—, it slowly modifies its behavior, contributing to a more diverse soundscape. At times, the agents "coalesce in an equilibrium where they are all 'content' with the state of pitches in the room" [95]. This equilibrium is disturbed when visitors enter their "space" and generate sounds. The work is described as "a society of devices whose behaviour collectively changes in response to the pitch ascendancy or descendency" by Haque.

Another example that can be considered here is the sound response design of Ken Rinaldo's *Autopoiesis* that was previously discussed in the context of morphology. To reiterate, inspired by the phenomenon of self-organization in nature *Autopoiesis* comprises fifteen agents that demonstrate emergent global behavior through simple rules and interactions. Here, the agents communicate with each other via audible telephone tones that constitute the agents' "language". When an agent locates a visitor, it "calls" other agents in this "language". They respond by repeating this song, and pointing their arms in the direction of the calling agent, which is the closest to the participant. In addition to self-organization, this highly biomorphic system echoes an ecosystem approach. Here, telephone tones were chosen due to their limited spectral bandwidth that does not overlap with human speech, mimicking a sonic ecology in nature as described by *niche hypothesis*.

2.4.3 Roles of Sonic Agency in *Sono-spatial Agents*: *TERRITORY*

In the previous section titled "Agency and Spatial Morphology", I discussed how spatial morphologies can take on an architectural function facilitating the creation of a world, a landscape, or an ecology, in which the viewer and the agents cohabit. Due to its spatiality, sound can take on a similar role. In addition to having spatial cues and carrying spatial information, through projection sound can be a medium for delineating space or establishing spatial relationships between the components of an installation based piece.

On sound, space, and interaction

Curtis Roads remarks "physical architecture colors the virtual sound" [96]. As sound is projected into the space, its aesthetic qualities are immediately modified, colored, and shaped by the spatial qualities of the environment it is projected in. In addition to this, Roads adds that "the experience of projected sound evokes spatial impressions" [96]. That is, sound itself shapes the space via modulating our spatial experience while we move through the diffused space of various aural zones and intensities, some of which we experience as volumetric and enveloping, some of which we experience as directional and trajectory-like, and some of which can be felt in the body through low frequency vibrations. Sound diffusion creates heterogeneities in space through waves, impulses, and rays. Although defined not through a traditional language of architecture—of walls and openings—but through sonic zones, intensities, and trajectories, this notion of space is very akin to a sculptor's or an architect's space.

Sound as a highly malleable "material" with spatial implications and immersive qualities that define, demarcate, and delineate spaces is very well understood and used by many sound artists, such as Maryanne Amacher, Max Neuhaus, Bernhardt Leitner, Michael Brewster, and Bill Fontana. For example, Leitner creates unique sonic experiences through the use of physical objects and space with audio transducers [97]. *Tuba Architecture* (1999) is a sound installation that is made up of several metal panels, suspended parallel to each other in couples forming a series of rooms and corridors. Attached to each panel is a transducer that emits low frequency signals that transform the panels into vibrating resonance boards. As the visitors walk through these spaces that are delineated by the panels, they experience this "acoustically condensed sound space that envelops and fills their bodies" [97].

Spatial qualities of sound, or more specifically the potential of sound diffusion in inscribing space is thoroughly explored in artistic contexts as discussed. However, this potential is arguably underutilized in interactive contexts. While many sound artists use these qualities of sounds in their work in creating sound installations, the majority of this work is not responsive or interactive. Neither does it feature physical bodies, or agent-based attributes. Taking advantage of this kind of spatiality of sound diffusion can be carried over to *Sono-spatial Agents* creating architectures, habitats, and ecologies through interactive sound projection. In other words, through modulating the spatial qualities of sound via interactive processes, we can create rich and powerful aesthetic experiences in which sound inscribes an interactive territory through its spatiality.

Such architectural approaches to sound emitting agents arguably do not have many explicit examples. One example is the author's work HIVE, which will be thoroughly discussed and evaluated in the next chapter. Another example is *Espace Vectoriel* (2002), by Bill Vorn and Louis-Philippe Demers. Also described as a robotic ecosystem, *Espace Vectoriel* comprises eight agents, each equipped with a sonar and a motorized tube with a speaker and a light source within [98]. The motorized tube is approximately 1.25 meter long and has two degrees of freedom: full 360 degree rotation and 170 degree tilt. In response to the participant, each agent can modify the direction of its body, the narrow motorized tube through which light and sound are emitted. As a result of the tubular inner structure acting as waveguides, each agent projects highly directional sounds and light. Through these narrow diffusions, each agent creates vectors that altogether delineate a space with an ever changing geometry that is simultaneously sonic and architectural.

2.4.4 Roles of Sonic Agency in *Sono-spatial Agents*: *ACTUATOR*

Actuators are typically devices that induce motion, such as motors and SMAs (Shape Memory Alloys) and they are one of the most essential components of an agent-based system in that they constitute the "action" part of such systems. Agency is broadly defined as the capacity of action and we need actuators to enable this action in the case of physically embodied agents. But, what is action, in an artistic context and what is actuation?

Action constitutes the output of an interactive or agent-based system. In the context of art, it need not be limited to a visible motion induction, but can be made of any modality that can help express the artistic agenda, because the key concept in such artistic systems is performance. So, in artistic contexts, we can shift our focus from action—that is defined by motion—to performance—that is defined by the relationship between the performer and the audience. And, if we shift the focus from motion to performance in (re)defining agency in the context of art, can sonic behavior constitute a viable way to depict agency in systems that are non-kinetic? Things—objects, products, environments, artworks—can indeed perform through sound and induce actions. This requires us to reconsider the loudspeaker as not merely a sound reproduction device, but also as a performer and actuator, enabling response and action through expressiveness.

One such example is Mark Böhlen's *Universal Whistling Machine (UWM)* (2003–2005). Alluding to an *UTM (Universal Turing Machine)* [99], *UWM* is an agent that uses whistling as a universal mode of communication, an expression that is conceivably common to digital machines, humans, and many animals. Whistling can be very expressive; in humans it can signify pleasure, admiration, warning, cipher and protest [100]. Unlike speech which is exceedingly difficult to analyze and synthesize, a whistle signal is relatively simple, and as such, easier to separate from a noisy background than speech. *UWM* is an agent with a simple body fitted with a camera, microphone, and a speaker. Through the camera, *UWM* can sense the presence of a visitor that enters its field of vision. As soon as the visitor moves outside this field, *UWM* whistles at them. If the visitor whistles back a tune, " it will improvise with some musicality, a response related to, but not the same as, the [visitor's] melody" [31]. In other words, the agent performs through its speaker, which acts as an actuator here triggering action and interaction.

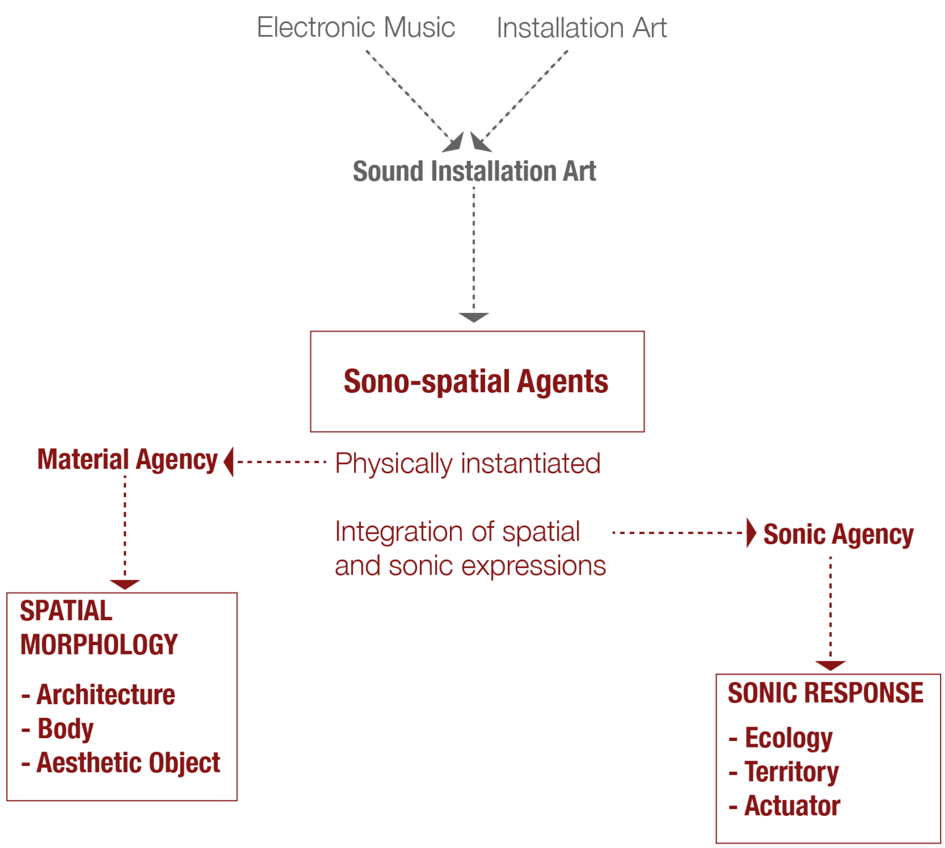


Figure 2.6: The conceptual framework diagram showing the histories and elements of Sonically Actuated Spatial Agents.

2.5 Summary: A conceptual framework for agent-based art

In this chapter, I defined and situated the *Sonically Actuated Spatial Agent* practice. I argued that they are historically related to sound installation art and that their agency is strictly enabled by two primary modalities: sonority and spatiality. In other words, their agency is defined by their sonic response and spatial morphology. I laid out the three roles that a *Sono-spatial Agent*'s morphology can take on as architecture, body, and aesthetic object, and the three roles that a *Sono-spatial Agent*'s sonorities can take on as ecology, territory, and actuator (Figure 5.3).

These histories and elements of *Sono-spatial Agent* practice constitute my proposed conceptual framework through which I will approach agent-based art practice and its broader family, media arts practice.In the upcoming chapters I describe, document, and evaluate my practice that is founded upon this framework.

Chapter 3

Case Study 1: HIVE

This chapter describes the conceptual background, design, and implementation of the agent-based art installation, *HIVE*. The emphasis is on describing the spatio-morphological and behavioral design principles and process of the agent. The design and implementation process is described from ideation stage to fabrication and installation details.

3.1 Introduction

Created via fusing aspects of spatial sound, parametric design, digital fabrication, and interactive methods, *HIVE* is an agent-based art installation that explores the notion of sentience and agency in the sonic medium (Figure 3.1). HIVE is conceived as a speculative organism that belongs to a family of organisms, whose subjective worlds—*umwelts*—consists only of sound signals. In other words, their only mode of sensing and responding to their environment is through sound. By restricting this speculative creature's perception and action mechanisms to a mere sonic modality, we aimed at emphasizing the importance of sonic communication for the survival of many animal species and how soundscape as a finite resource is neglected by us, humans, and consumed

Figure 3.1: *HIVE* at an exhibition at SBCAST (Santa Barbara Center for Art, Science, and Technology) in February 2017. ©Şölen Kıratlı, ©Akshay Cadambi. Photography credit: Joey Armario

and contaminated as a result of our activities.

HIVE was produced in 2016–2018 by the author of this dissertation, Şölen Kıratli, and collaborator Akshay Cadambi, and ReTouch Lab. It was exhibited at ISEA (International Symposium of Electronic Arts) 2020, Currents New Media 2018, ACM SIGGRAPH Asia 2017, and SBCAST (Santa Barbara Center for Art, Science, and Technology), amongst other places. A paper on the piece was also presented and published at the Proceedings of NIME 2017 (New Interfaces for Musical Expression), parts of which are included in this chapter [62].

HIVE was made possible with the support from Interdisciplinary Humanities Center (IHC) of the University of California's Humanities Network and Systemics Artistic

Production Fund (Media Arts and Technology Program, UC Santa Barbara). A video documentation of the piece can be found in the following URL: `https://vimeo.com/215576503`

3.2 Conceptual Background

Vision is the primary sensory modality of humans, and this heavy reliance on our vision overshadows other modalities, such as sound. This is, however, not the case for all animal species. Many species rely heavily on acoustic communication—as much as visual—for activities that are essential to their survival, as discussed in Chapter 2. ”Sound is an important component of the majority of the terrestrial, freshwater, and marine ecosystems and becomes an essential context with which organisms daily interact performing their vital functions” [87].

The quality of acoustic communication in a given environment is determined by the condition of the soundscape ecology, defined as the set of the acoustic relationships between living organisms, and their environment [91]. It is argued that “sound reflects natural and human activities and thus serves as an excellent “universal” variable to consider in any study of a coupled natural-human system” [91]. An understudied field, the study of soundscape ecology can be very crucial to understand and preserve the fitness of a habitat. Bioacoustician Bernie Krause defines soundscape as all of the sounds—biophony, geophony, and anthrophony—present in an environment at a given time and argues that soundscape is a finite resource and that many organisms compete for spectral space. Also called the *niche hypothesis*, species within a given biome have evolved such that their vocalizations are not masked by one another. In other words, spectral space is partitioned between species [88] and parts of the bandwidth are claimed by different species as their vocal territory.

Soundscape is a finite resource, however, especially due to auditory masking. Like all finite resources, many organisms compete for a territory—spectral space—within the soundscape of their environment. Today, human generated noise dominates the sonic spectrum of many ecosystems, even those we consider untouched by our activities, and this condition is widely neglected in environmental research and policy efforts [88]. In reaction to this, the inquiry into this agent-based artwork started with a thought experiment: let us imagine an organism who is entirely bound by sound signals—that is, it can only sense and (re)act via sound. By restricting this speculative creature's perception and action mechanisms to a mere sonic modality, the goal was to emphasize:

- The importance of sonic communication for the survival of many animal species
- How soundscape as a finite resource is neglected by us, humans, and consumed and contaminated as a result of our activities—as previously discussed.

This line of thought was influenced and inspired by two primary notions: the first is creating intricate speculative worlds as a cultural critique, the second is the notion of *umwelt*, introduced by the Estonian biologist, Jakob von Uexküll [60]. What follows is a series of brief discussions on both of these notions respectively.

The notion of creating intricate speculative worlds as a cultural critique is commonly used in art and design, as well as literature. For an example from art and design, we can consider the artist, academician, and Guggenheim Fellow Pınar Yoldaş's *An Ecosystem of Excess* (2014) [101]. As a critique of the excessive consumption and environmental recklessness of our current culture, the artist imagines a future where new lifeforms evolve to thrive in such extreme environments that are marked by the waste of human consumption—i.e. lifeforms with organs for sensing and metabolizing plastics.

> "This project starts in the Great Pacific Garbage Patch. Covering between 700000 and 15 million square kilometers, the site is a monument to plastic

> waste on a global scale... *An Ecosystem of Excess* asks a very simple question: 'If life started today in our plastic debris filled oceans, what kinds of life forms would emerge out of this contemporary primordial ooze?' [102]"

As a literary example for this notion of creating intricate speculative worlds as a cultural critique, we can consider the novella, *Flatland*, by Edwin A. Abbott [103]. The story depicts imaginary beings—polygons who live in the two-dimensional universe of the Euclidean plane becoming aware of a third dimensional universe as a result of a communication with a creature—a sphere—from the three dimensional world. *Flatland* is essentially a satirical commentary on the values of Victorian culture—especially with regards to women and social status.

The second significant notion that informed and heavily influenced our critical line of thought is "umwelt". Uexküll suggested that the world that an organism inhabits is defined by and limited to what it can experience through its specific sensory-motor apparatus [60]. While these subjective environments that are inhabited by different species—*umwelten*—may overlap at certain points, each species has its own *umwelt* as defined by their embodied experience of the world that surrounds them [60]. *Umwelt* is a prominent notion in cognitive philosophy, robotics, and cybernetics due to its focus on a non-human based sentience and consciousness.

Following this thread, our inquiry started with the question: "Can we conceive of an organism that exists in a purely acoustic *umwelt*—an organism whose only way of sensing, observing, reacting, and communicating with the world is through sound?" The design ideas of both the morphology and the response of this organism were guided by the notion of *umwelt* and embodiment. If intelligence is shaped by the perception-action loops that are enabled and guided by the morphology of the body [16]—as I discussed in Chapter I—what should the morphology and behavior of this quasi-biological agent be like? These are discussed in the upcoming sections.

3.3 Design Process

In the light of the conceptual and critical underpinnings that are discussed in the previous section, the research problems that were specific to the design of this agent were:

- How can we reflect the significance of sound as a modality for survival through an agent?
- What are the ways in which this agent-based system can embody the notion of "ecology" and the impact of anthropogenic noise?
- How can an inanimate body depict agency via sound and sonic response? How can sound activate/animate an inanimate body?

These project-based research questions, along with the theoretical framework that is based on *umwelt* and embodiment helped guide the entire design process.

3.3.1 Agent Morphology

The body of the agent consists of two essential parts that are intertwined: the physical architecture—that is the exoskeleton—and the electronic architecture, that are the i/o devices.

The Physical Architecture (the Exoskeleton)

The design of the body of *HIVE* is guided by the embodiment paradigm. As I discussed in Chapter 1, embodiment is not merely about being equipped with a body.

It is about how the body (of the agent) both enables the sensory-motor processes of the agent itself, and enhances the agency of the participant on the course of the interaction. While overlaps exist, the former notion guided mostly the physical design process, and the latter one the behavioral design process.

In mediating sound-based input and outputs via spatial morphology, I started my explorations with tubular geometries, due to their acoustic properties. Tubular structures–especially horn-shaped ones—are commonly used in filtering, amplifying, and guiding soundwaves both in natural and human artifacts. As an example from nature, we can take Mole Crickets. Male mole crickets sing by stridulating underground. They build burrows that are shaped as double exponential horns, which immensely amplify their vocalizations [104]. As examples from human culture, we can see the early sound art (Figure 3.2), and sound reproduction devices, such as the phonograph and loudspeakers, in which the physical shape of the horn acts as an acoustical waveguide shaping the diffusion pattern and amplifying the sound, increasing the overall efficiency of the driving element.

Informed and inspired by this notion of an acoustic waveguide, early experiments on spatial morphology focused on geometries that feature tubular structures (Figure 3.3).

All spatio-morphological explorations, as well as the final design process, followed a parametric approach using the graph-based algorithmic modeling environment Grasshopper [106], a plug-in for the modeling software Rhinoceros[107]. As I discussed in the first chapter parametric design enables the creation of a vast number of instantiations of geometric forms that can be controlled via parameters. In addition to the ease such a procedural approach provides for creating subtle geometric variations, it also allows for an ease in changing more impactful parameters, such as the base geometry. In other words, once a procedure is created, it can be applied to various different surface geometries and topologies in a rapid way. Such parameterization also yields a lot of flexibility

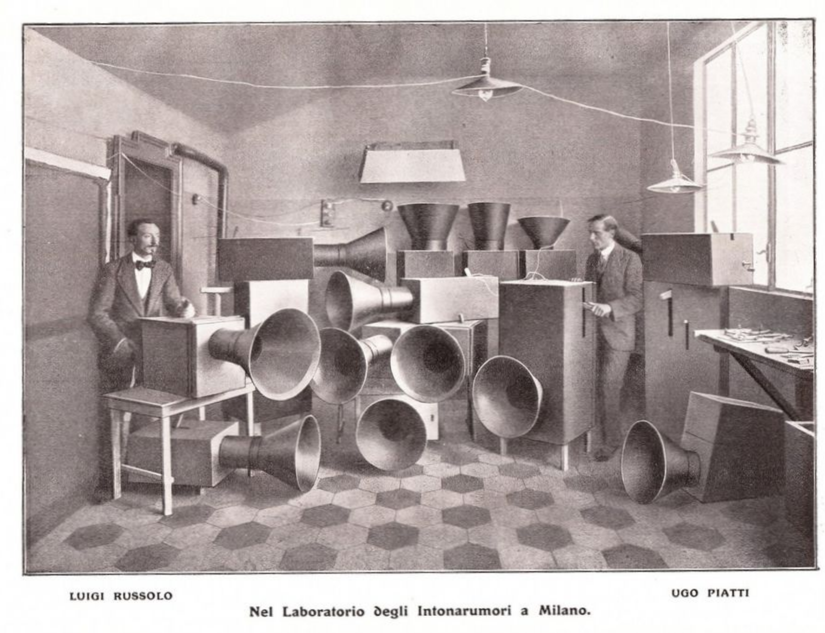


Figure 3.2: *Intonarumori* by Luigi Russolo, photo published in his 1913 book *The Art of Noises* (Public Domain). Russolo built this instrument in conjunction with his Art of Noises manifesto. These purely acoustic "noise machines" use exponential horns to amplify the sounds generated by the mechanisms inside the boxes [105].

in design, since many details of the design (i.e the number, length, diameter, exact shape, and size of the tubes and other structural elements) could be decided upon later in the process. Lastly, as discussed in Chapter 1, parametric and digital design tools, such as Grasshopper, also allow us to implement complex biological concepts in designing and creating agent bodies, such as morphogenesis, genotypic or phenotypic variations, mutations, growth, etc.

The biomorphic appearance in the design experiments in Figure 3.3 are not just the post-factum effects of using parametric design tools, however. Here, biomorphic features are deliberately chosen and emphasized both as a result of mimicking concepts of form, growth, and efficiency from nature, and at the same time to enhance the attribution of agency, as also discussed in Chapter 1. Here, this notion led to geometric design experimentations with hexagonal lattices and honeycomb structures. It has been known

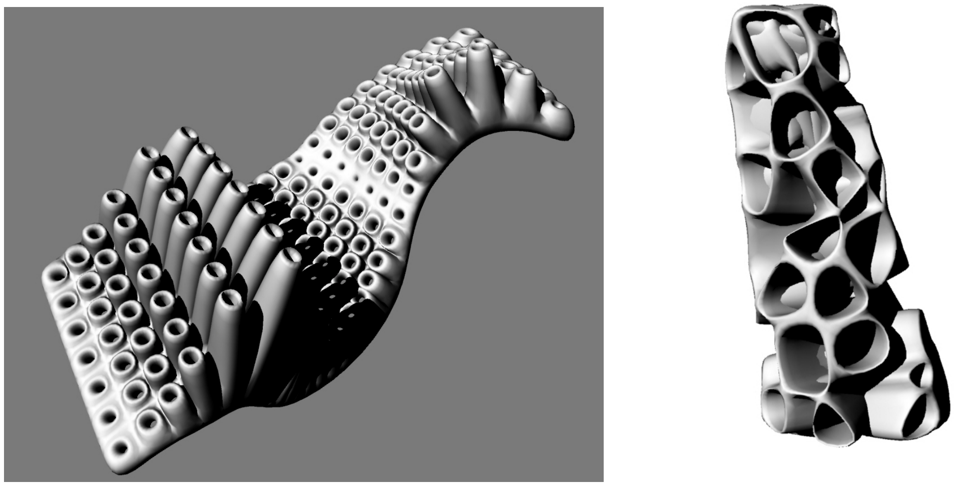


Figure 3.3: The figure to the left is a rendering of a surface that is subdivided and includes several tubular geometries of different lengths as determined by their distance to a random attractor point. The figure on the right is a rendering of a cylindrical geometry divided into voronoi-like irregular cells. Both are early geometry experiments on geometries with multiple tubular structures.

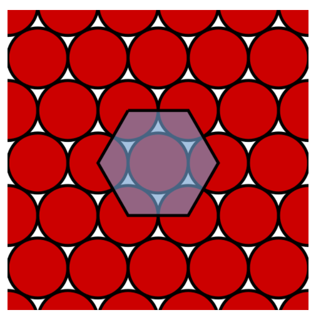


Figure 3.4: A hexagonal lattice allows for the densest packing of circles on a plane [108].

for millennia that such structures provide efficient use of space and material, both in human-made and natural structures. For example, it has been argued that a honeycomb is composed of hexagons, rather than any other shape due to efficiency; hexagonal grid is the best way to divide a surface into regions of equal area with the least total perimeter [109]. Furthermore, a hexagonal lattice allows for the densest packing of circles on a plane [108] (Figure 3.4. Since I was working with tubular inner structures due to their aforementioned acoustic properties, a tight packing of these structures would behave

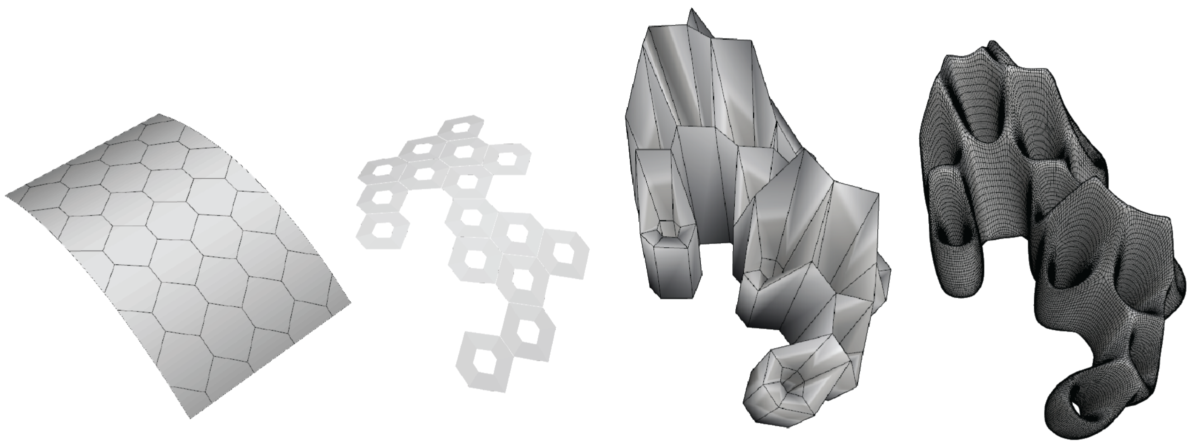


Figure 3.5: The final design procedure I developed can be condensed to four essential steps. The first step was to hexagonally tile an arbitrary curvilinear surface. The second step involved the exclusion of all peripheral cells that did not constitute complete hexagons. Random cells were also seeded in order to create variations in density. In the third step, we used a mesh thickening algorithm to create a non-linear extrusion of this surface that uses the hypotenuse average based trigonometrical offset for computing a new mesh that is a closed solid. The final step employed Catmull-Clarke subdivision algorithm to smoothen the mesh, resulting in a curvilinear cross section approximating an exponential-horn-like inner structure. The resulting geometry visually and structurally retains the qualities of a honeycomb pattern while packing horn-like inner cells.

as an array of acoustical waveguides, allowing for spatial sound. The combination of hexagonal structure with tightly packed tubular inner structure became the final concept for the "exoskeleton" that would allow for a dense array of speakers to be attached to tubular inner structures.

The final design procedure I developed can be summarized in four essential steps, as depicted by Figure 3.5. The first step was to hexagonally tile an arbitrary curvilinear surface. The second step involved the exclusion of all peripheral cells that did not constitute complete hexagons. We also seeded random cells in order to create variations in density. In the third step, we used a mesh thickening algorithm [110] to create a non-linear extrusion of this surface that uses the hypotenuse average based trigonometrical offset for computing a new mesh that is a closed solid. The final step employed Catmull-Clarke subdivision algorithm [110] to smoothen the mesh, resulting in a curvilinear cross section

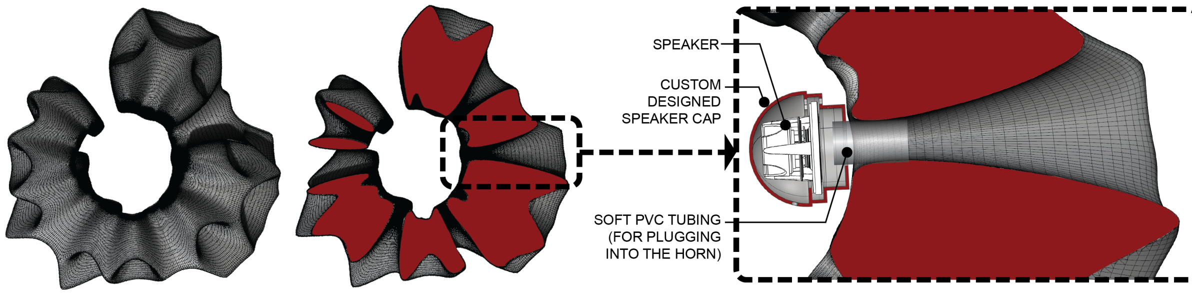


Figure 3.6: The exoskeleton of *HIVE* features an inner structure of horns intended to diffuse and filter the sound emanating from the attached speakers.

approximating an exponential-horn-like inner structure. The resulting geometry visually and structurally retains the qualities of a honeycomb pattern while packing horn-like inner cells.

To summarize, the "exoskeleton" was designed with the intention of housing a dense array of speakers, as well as an intention of diffusing and filtering the sound emanating from these speakers (Figure 3.6). We had two primary inspirations for the physical design of the artifact. First is the horn loudspeaker design, in which the physical shape of the horn acts as an acoustical waveguide shaping the diffusion pattern and filtering the sound. This shape has been shown to have an impact on the spectrum, creating a so-called "presence effect" [111]. The second inspiration was the use of honeycomb patterns as a means to achieve tight packing of these tubular inner cavities inside the sculpture. Honeycomb geometries, as often seen in nature, have been shown to present spatial advantages in this regard.

Once the procedure for the general structure was created, the next design decision to be made was the overall shape of the agent, which is determined by the base geometry of the procedure. This is significant much beyond aesthetic concerns, because it would determine the architecture of the agent and the installation, that is, the experiences and interactions it would afford via its spatial and material configuration. The overall form of the agents directly determines the organization of both the architectural space and

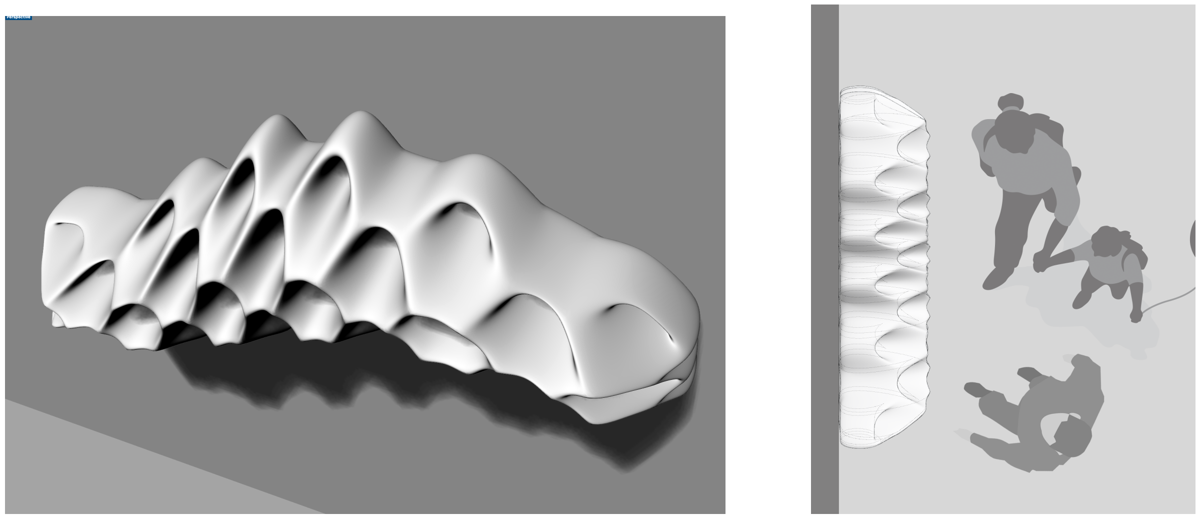


Figure 3.7: A planar base geometry affording one to stand in front of the agent and listen.

the soundscape around itself, especially in this case, where the agent is inanimate. For example, a planar base geometry, as seen in Figure 3.7, would afford one to stand in front of the agent and listen, whereas a curvilinear or conic base geometries would allow for one to walk around the agent and explore the agent and the soundscape from different viewpoints. In other words, a planar base geometry would diffuse the sound forward, allowing us to create a spatial sound image in front of the object, whereas a circular and centripetal projection pattern would create a 360 degree divergent soundscape and an image could move within this space, creating a sonic layer around HIVE, extending its physical boundaries (Figure 3.8). As such, this latter approach would also lend itself better for explorations on sonic territoriality, also described in Chapter 2, as a part of the conceptual framework. Furthermore, such architecture would allow for the audience to explore the architectural and sonic field around the object. For these reasons, I chose a truncated cone as a base geometry and the overall topology of the agent is a toroid (Figure 3.10).

I also experimented with parametric variations and notions of a "family" of "creatures" further enhancing the biomorphic design concept. Applied to a variety of base

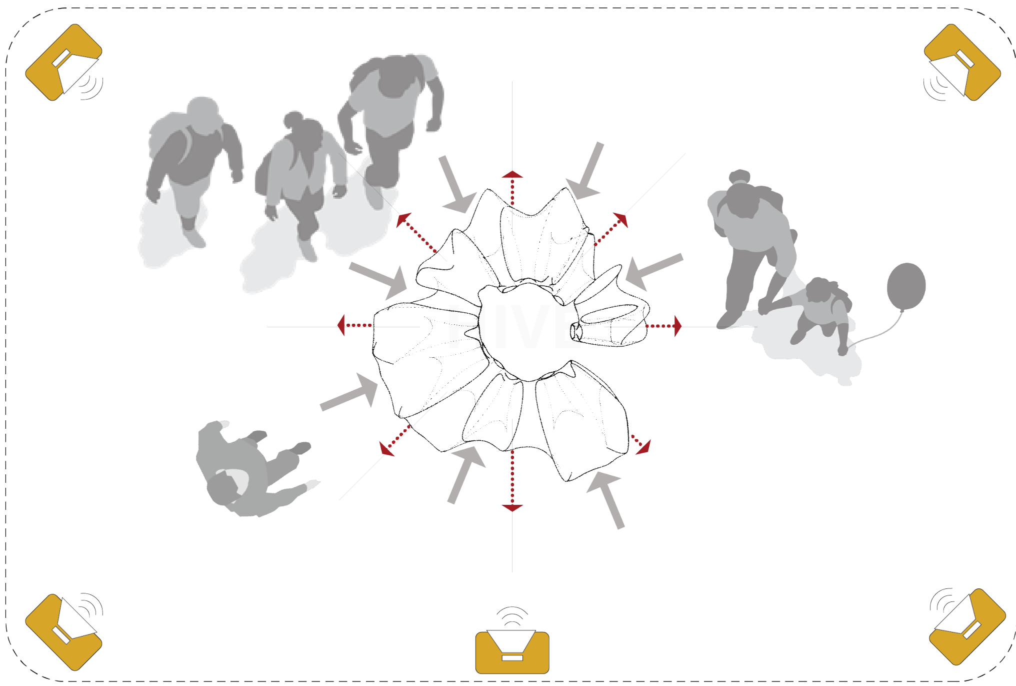


Figure 3.8: *HIVE* installation architecture. A curvilinear or conic base geometries would allow for one to walk around the agent and explore the agent and the soundscape from different viewpoints.

geometries, and with different parameters, the principal procedure I created generates an entire family of artificial organisms that include HIVE (Figure 3.9).

Fabrication

Additive manufacturing was chosen for the fabrication of the exoskeleton, given the complexity of the shape. However, since the overall size of the object was larger than the maximum printing area of most commercially available 3D printers at the time (2016), the model had to be printed in multiple segments. (Figure 3.11) The geometry processing software *Netfabb* [112] was used for segmentation of the model. After printing the pieces using ABS (acrylonitrile butadiene styrene), the interlocking parts were attached using

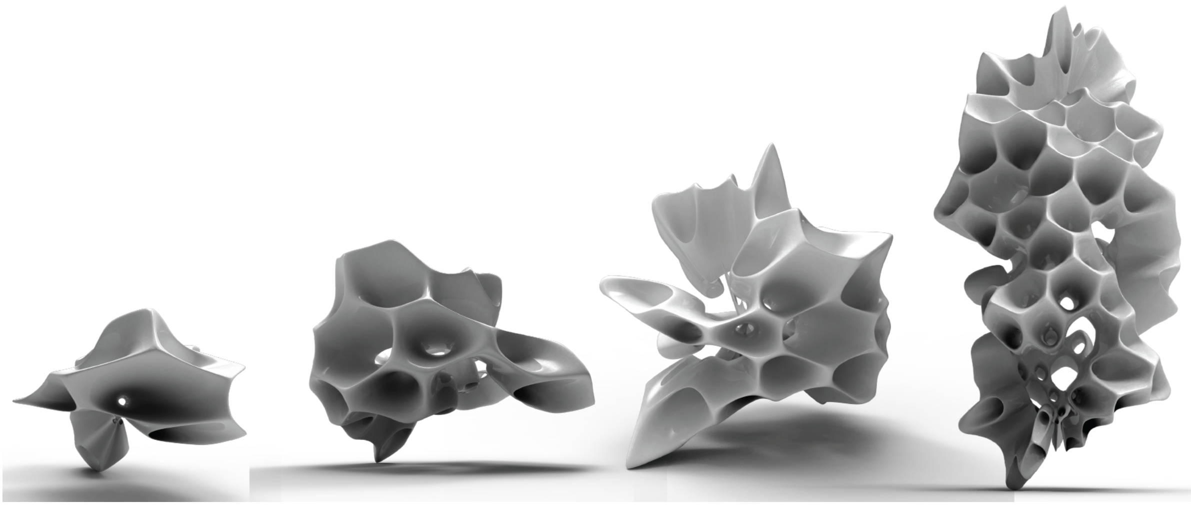


Figure 3.9: Experimentations with parametric variations and notions of a "family" of "creatures" were made in order to further enhance the biomorphic design concept.

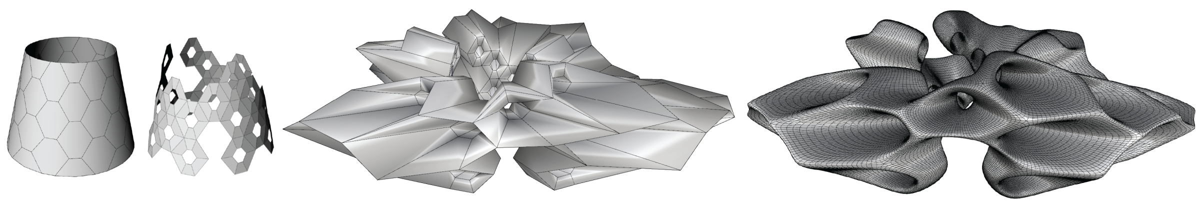


Figure 3.10: For the base geometry, a truncated cone was chosen and the overall topology of the agent is a toroid.

two-part epoxy glue. Automotive body filler was used to cover the seams, which were then sanded down in order to prepare the structure for painting.

The Electronic Architecture (Organs)

While the first iteration of the project used piezoelectric sensors, in the latter iterations, we used ultrasonic proximity sensors and microphones, following the concept of a sonic *umwelt*. The final version includes three microphones and six ultrasonic proximity sensors, as the sensory network of *HIVE*, and sixteen small transducers allowing for spatially localized audio output that constitutes *HIVE*'s response network—that is, its vocalizations. The speakers are plugged into the inner holes of the exoskeleton whereas

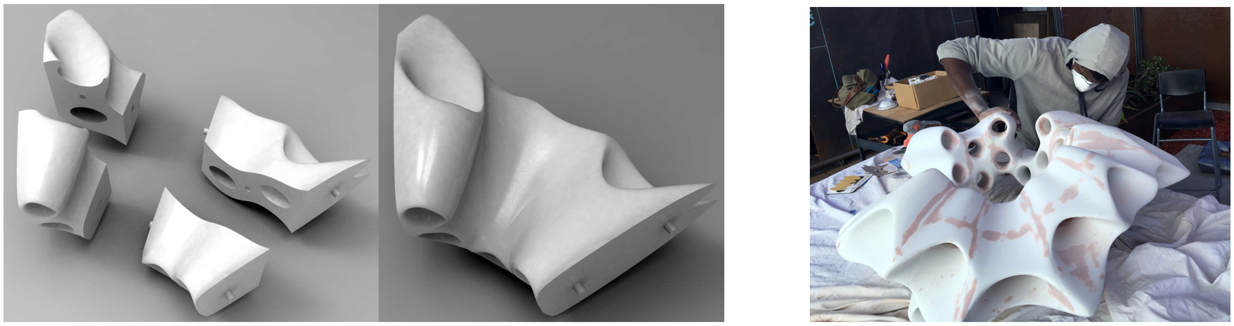


Figure 3.11: To the left: After printing the pieces using ABS plastic, the interlocking parts were attached using two-part epoxy glue. To the right: Automotive body filler was used to cover the seams, which were then sanded down in order to prepare the structure for painting.

the input devices are embedded in them (Figure 3.12). The speaker caps were designed such that they inhibit the projection of sound from the driver in the backward direction and allow for coupling the driver to the horn throat. These caps that house the speaker drivers were fabricated using the same material as the rest of the exoskeleton: ABS. The sensors are embedded in a flexible silicone rubber (*Smooth-on, Ecoflex^{TM} 00-30*) that is in a two-part liquid form prior to curing. These encasing (Figure 3.13 were fabricated via pouring the silicon into a 3D printed mold.

HIVE used sixteen speaker drivers (model NE65W-04 2", Tymphany Inc., Sausalito, CA), driven by eight class-D stereo amplifiers (model DTA3116S, Dayton Audio, Spring-boro, OH) yielding 16 channels of audio. The audio signal was produced by a multichannel digital audio interface (model Ao24, MOTU, Cambridge, MA) connected to a computer running the custom synthesis software. In the first iteration, piezoelectric sensors were placed under the carpets in the space around the sculpture whose output was fed into the audio system. In the latter iterations, however, as inputs, we used ultrasonic proximity sensors (HC-SR0) and electret microphones (Figure 3.14). The microphone inputs were connected into the audio interface, whereas the signals for the sonars were controlled by the microcontroller. The input values that are detected by the microcon-

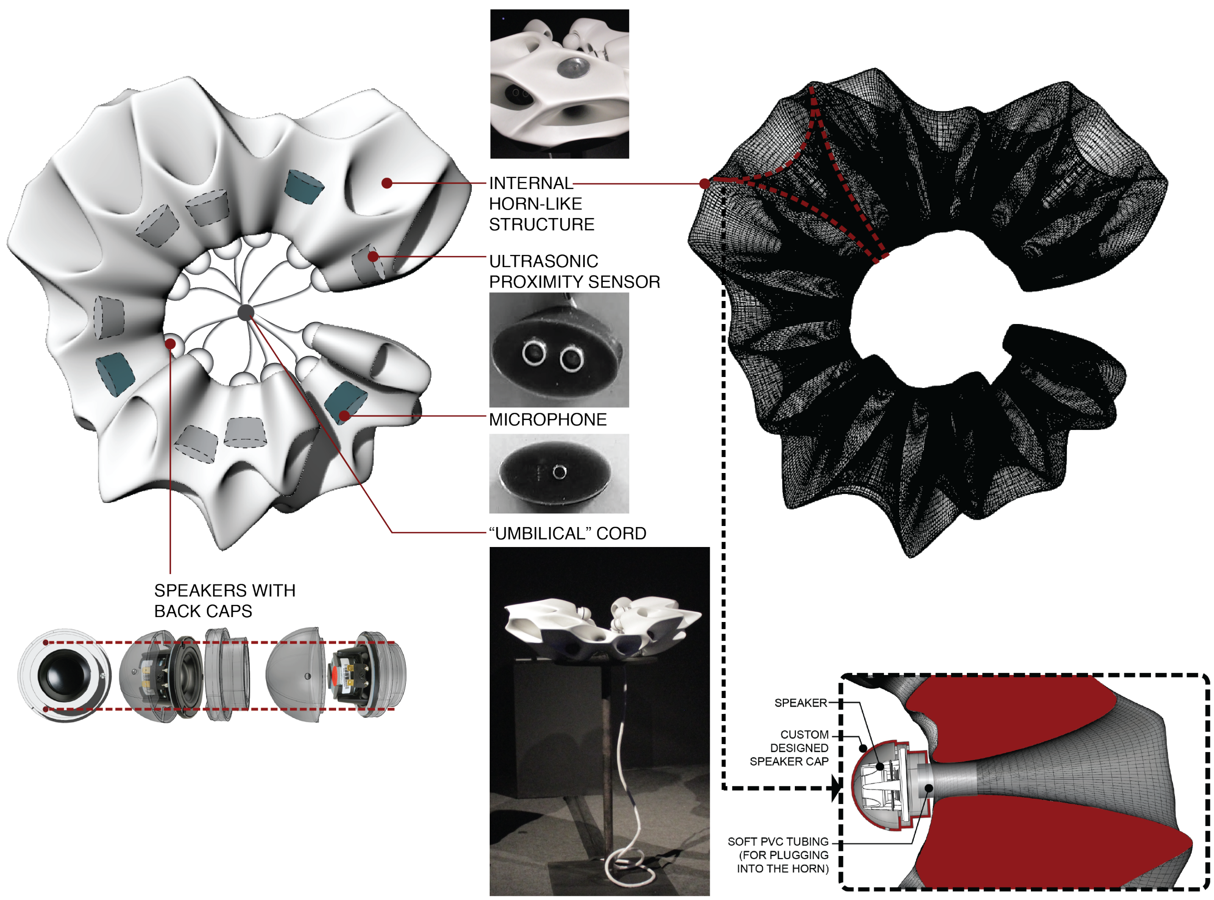


Figure 3.12: The figure shows *HIVE* agent architecture.The body of the agent consists of two essential parts that are intertwined: the physical architecture—that is the exoskeleton—and the electronic architecture—that are the i/o devices.

troller were fed into the custom software *Lithe* [113], in which we have rendered the entire sound design of *HIVE*, which is discussed in the next section.

3.3.2 Behavior

Our project-specific inquiries were to reflect the significance of sound as a modality for survival through an agent, reflect the notion of "ecology" and critique the impact of anthropocenic noise, and finally use sound to activate and "animate" an otherwise

Figure 3.13: Left: shows the speaker caps and the sensors that are embedded in silicon forms. Right: shows the 16-channel output system with the amplifiers and the audio interface device.

inanimate body. The expressiveness of sound as an artistic medium can be powerful to convey such complex notions as space and territory, ecology, and movement, as I discussed in Chapter 2. Moreover, these notions are a direct part of the conceptual framework that is designed to guide the current and future endeavours in agent-based art.

Territory and Actuation

Taking advantage of the spatial properties of sound was a focus from the start. For example, the exoskeleton was designed to house a dense array of speakers for this reason. It allowed us to design *HIVE*'s vocalizations such that, akin to a defense mechanism, the agent could use and animate localized source points, creating the impression of movement and territory around itself, further enhancing its agency.

In an effort to avoid predictability in interaction and enhance the engagement of the human agent, we intended for *HIVE* to go beyond a simple-reflex style interaction, where the inputs are mapped to the outputs with a very simple function. Behavioral complexity can be achieved via software in several ways. Since the only modality for response here is sound, we focused on the complexity of the sound design—as *HIVE*'s vocalizations—and

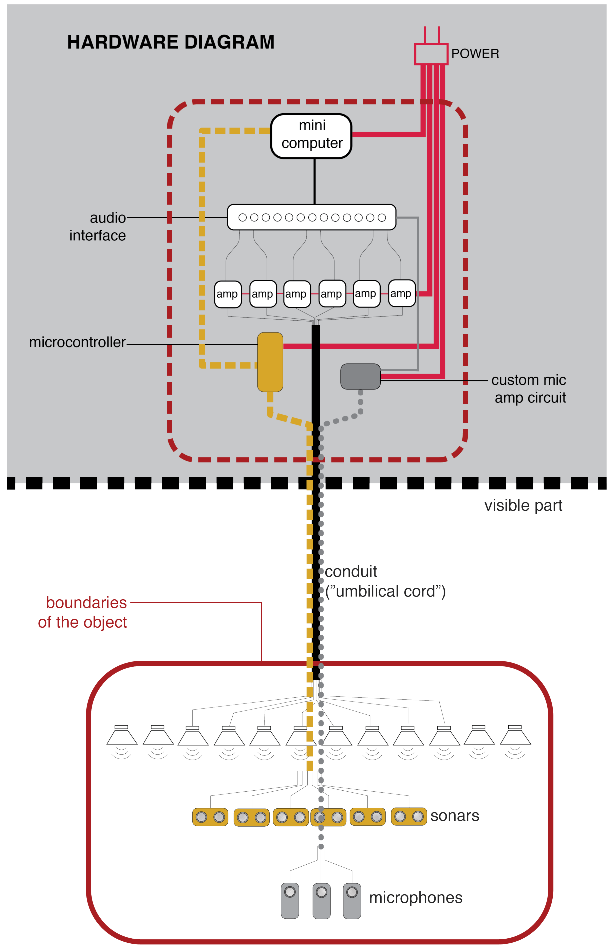


Figure 3.14: System architecture.

how it may change over time and in response to input devices that are triggered by the viewer's presence and movement.

The complexity and the territoriality of *HIVE*'s vocalizations and response were achieved by a combination of manifold mapping (a kind of spatial trajectory processing via the use of manifolds), layering and looping several different sound sources, and modular synthesis, where the triggers of certain modules are controlled by the sensor input—that is the human proximity to the agent and the human generated sounds.

Sound Design Strategies

Custom software, *Lithe* [113], was developed for sound synthesis and spatialization by Akshay Cadambi, partly for this project. *Lithe* uses u-gens (Unit Generators) with a graph-based workflow. *Lithe*'s ability to "manipulate sound-objects (sound + real-time trajectory) at each node allowed for the creation of novel spatial effects [113]". Lithe allowed us to:

1. Render spatial sound effects precisely for the irregular geometry of *HIVE*, in which the speakers were embedded using DBAP (distance based amplitude panning). The trajectory processing via the use of manifolds allowed us to generate and orchestrate the positions, movements, and textures of the spatial sound objects, enabling them to move in virtual space inside and around the agent.

2. Create complex and unpredictable soundscapes and spatial textures as a result of looping and layering, in combination with *Lithe*'s modular synthesizer-like sound generation system where sound synthesis graphs of both sounds and their trajectories could be synthesized using a procedural workflow.

3. Alter *HIVE*'s vocalization in response to human interaction—sometimes immediately, and sometimes in larger timescales—via the use of external input devices like microphones or sensors to trigger both sonic and spatial events. These events include motion along a trajectory or modulation of velocity or position of sound objects.

HIVE's vocalizations are based on field recordings by Akshay Cadambi and the author of this dissertation. These recordings are spatially and sonically manipulated, layered and are running in continuous loops, tailored spatially for *HIVE*'s geometry via manifold mapping.

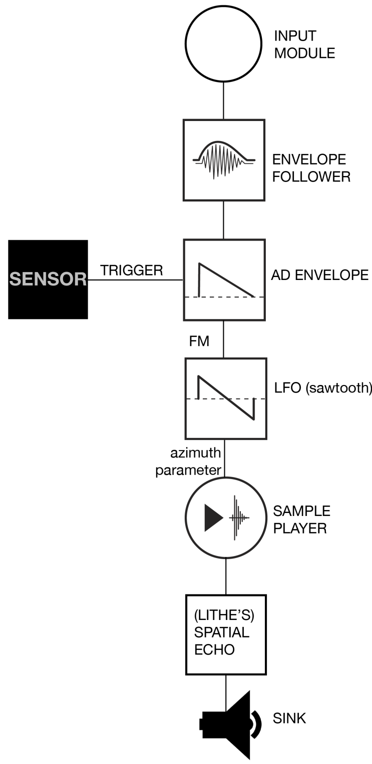


Figure 3.15: Shows Lithe uses u-gens (Unit Generators) with a graph-based workflow. Lithe's ability to "manipulate sound-objects (sound + real-time trajectory) at each node allowed for the creation of novel spatial effects [113].

Play-rates were manipulated to conceal the source sound (from the field recordings) using a network of inter-modulated LFOs (low frequency oscillators) and AD (attack-decay) envelopes (Figure 3.15). These sounds panned in circular paths around the sculpture at different rates and by experiment we found that this yielded the perception of rhythms. These panning rates were further modulated using another network of LFOs and AD envelopes, with some connected to those that modulated the play-rate. This patch effectively created a swirling texture of sounds around the object with an irregular ebb and flow.

The input from the sensors was processed by the audio-graph to trigger sonic and spatial events based on a simple probabilistic algorithm.

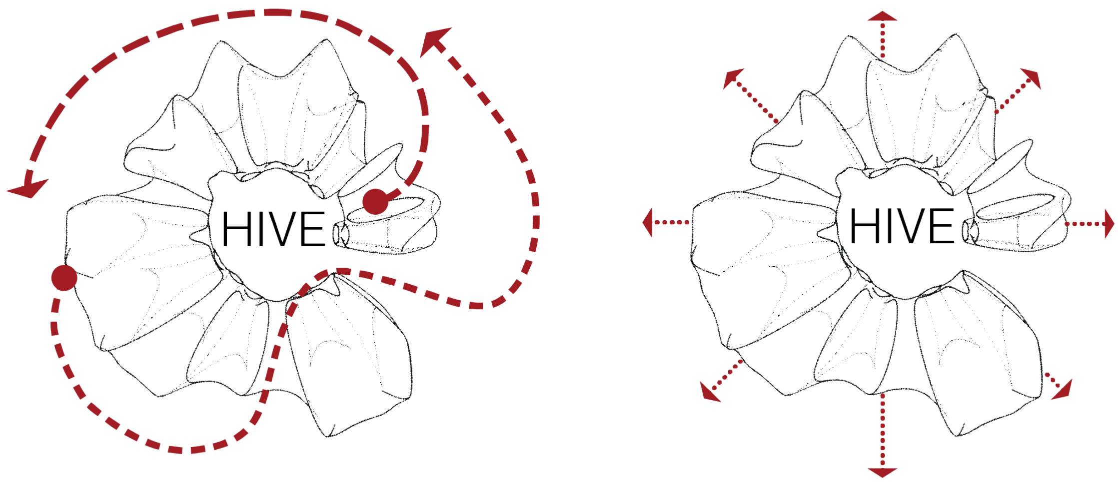


Figure 3.16: Left: The trajectory for the spatial ‘sound object’ that moves in a circular fashion and goes in and out of the exoskeleton of HIVE. Right: ....

Sonic events involved sharp or subtle rises and falls in the play rate, or the triggering of echoes. The source clips are field recordings that were timbrally rich and rhythmically and harmonically irregular. They were played in a loop and another distinct LFO controlled the play rate modulation. This allowed us to stretch, shrink, reverse the playback of these already irregular sounds, resulting in change and variety in the audio output. In the manipulation of these source audio clips envelopes, delay, and envelope followers are used in addition to LFOs.

Spatial events involved modulations on the velocity of movement of the sound sources, controlling the trajectory for the spatial ”sound object” that moves in a circular fashion and spirals in and out of the exoskeleton of *HIVE* (Figure 3.16). Modulation of the spatial aspects of sounds allowed us to control the trajectory for the spatial ‘sound object’. For example, the azimuth parameter is controlled by a dedicated LFO. The range of the azimuth signal [-1, 1] was mapped to [-180, 180] for a spherical manifold. Using a sawtooth waveform for the azimuth signal created circular motion of the source point. There is a separate LFO controlling azimuth, elevation, and distance. Since the frequencies of the

LFOs were harmonically not related or synced in any way they combine in a non-periodic manner resulting in a continuously changing but somewhat regular trajectory. When we add the spatialized-echoes and echo-shifts to these sound objects, we get a continuously changing spatial texture [62].

Care was taken to make the effect of the sensor input less predictable; the intention was to implore the audience to be more spatially and acoustically aware of the environment. To this end, the response of the agent is not always immediate, and it changes over time. This is achieved via the sensors probabilistically triggering given actions, as well as the context dependency of the audibility of these changes. For example, if *HIVE* is in a relatively "quiet" period with its vocalizations, the audience does not hear a reaction/ response, because the speed of motion will not impact this state.

The Ecosystem

A quadraphonic sound projection surrounds and envelopes *HIVE* (Figure 3.8). This, along with human generated sounds and activity, constitutes the sonic environment (habitat) *HIVE* inhabits. The sound emitted by this system creates a contrasting sound space to that of the agent. This kind of background and foreground dichotomy is further emphasized via contrasting register, texture, and motion. The external quadraphonic system emits droning, sustained, volumetric, non-directional field of low frequencies creating a directionless but enveloping sound space that is more or less static; creating a container, in which the object vocalizes in. The sound material emanating from the agent has higher frequency transient sounds that are in circular motion. The bright, transient, and dynamic nature of these sounds clearly marks this space as a foreground space. Such contrast in sound material also allows for the sensors on *HIVE* to pick up stimuli from the audience walking around and interacting with it.

Here, the external quadraphonic system is designed to enhance the reflection of an

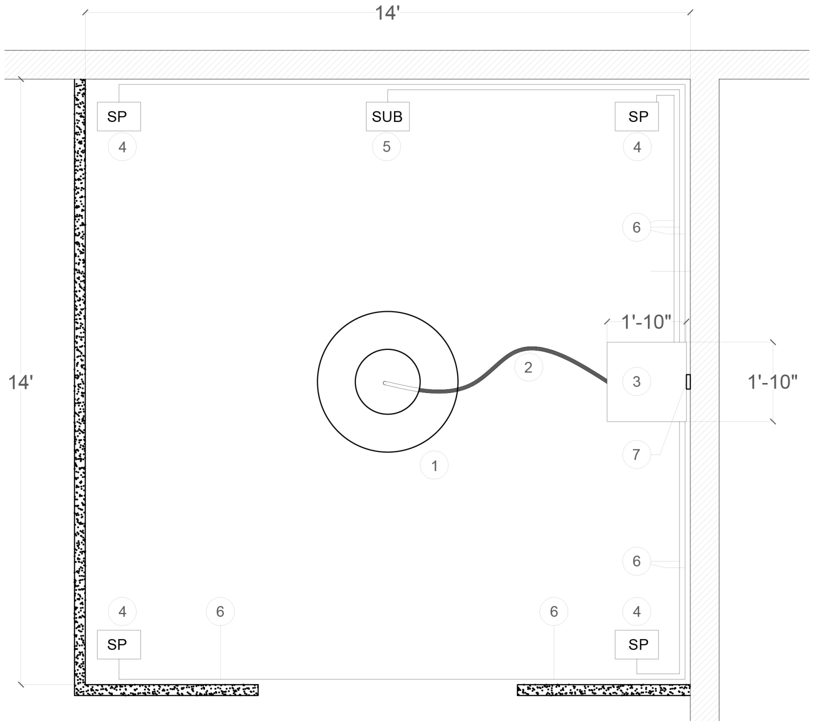
Figure 3.17: Left: Photo from the SBCAST exhibition in 2016. Credit: Joseph Armario, Right: Photo from SIGGRAPH Asia 2017 Art Gallery. Credit: Şölen Kıratlı

ecosystemic concept. *HIVE* has its own “niche” as its vocal range, which does not overlap with its environment. It is only when humans are present and their voices and activities bleed into the environment that *HIVE* starts altering its vocalizations —sometimes immediately, and sometimes in larger timescales. In some cases, the sounds emitted by *HIVE* bleeds faintly into the environment speakers. At the times of overwhelming human activity, *HIVE*’s vocalizations might get more erratic (i.e. higher rate of moving source point), acting as a defense mechanism.

3.4 Installation

HIVE was exhibited at ISEA (International Symposium of Electronic Arts) 2020, Currents New Media 2018 (Figure 3.19), ACM SIGGRAPH Asia 2017 (Figure 3.17), and SBCAST (Santa Barbara Center for Art, Science, and Technology) amongst other places.

In the first version of the project exhibited in SBCAST, as mentioned before, we used piezo-electric sensors as the inputs. These were hidden under a rug beneath HIVE that the audience was walking on. The primary means of interaction were through the footsteps of the audience around that sculpture, picked up by sensors in the floor.



1. The exoskeleton
2. The "umbilical cord"
3. The audio rack + concealing structure (i.e. podium)
4. Speakers on stands
5. Subwoofer
6. Audio Cables w/ concealers
7. Power outlet on the wall.

Figure 3.18: The figure shows the installation plan from the Currents New Media exhibition. The exoskeleton (1) is approximately 38.8 inches by 39.7 inches by 12.43 inches and weighs 30 lbs including the embedded speakers and sensors. It is suspended from the ceiling using filaments. The "umbilical cord" (3) is made up of the input and output cables wrapped with a plastic concealer. It connects to the audio rack, which is concealed under a podium.

However, during the exhibition of the installation, we observed that the audience had a strong and intuitive tendency to attempt to interact with the object gesturally: by moving their hands and bodies around the sculpture. The system however, only responded to the footsteps of the audience in indirect and subtle ways by triggering both sonic as well as spatial events like sudden changes in the velocity of moving sounds within the sculpture. This, therefore suggested considering a more gesture based means of input for interacting with the sculpture, for the future efforts. In addition to this, using sonic inputs would more coherently follow the theme of sonic agency and *umwelt*.

We implemented this in the latter iterations, in Bangkok for SIGGRAPH Asia and Currents New Media (Figure 3.18). In both exhibitions, we incorporated a sensor system

Figure 3.19: Photo from Currents New Media exhibition in 2018. Credit: Şölen Kıratlı.

consisting of six proximity sensors and three microphones. Not only were there more input devices with a higher resolution than the previous rendition, but also more spatial and sonic events were triggered based on more crowds of people. They were able to use their hands to get closer to the agent's body and sensors and were able to get a response, sometimes immediately. It is my observation that the audience showed more signs of engagement than the previous versions. Anecdotally, on an average people, spent more time at the installation, taking their time to walk around and explore the installation.

The ISEA exhibition took place virtually via online videos and discussions due to the ongoing pandemic of Covid-19.

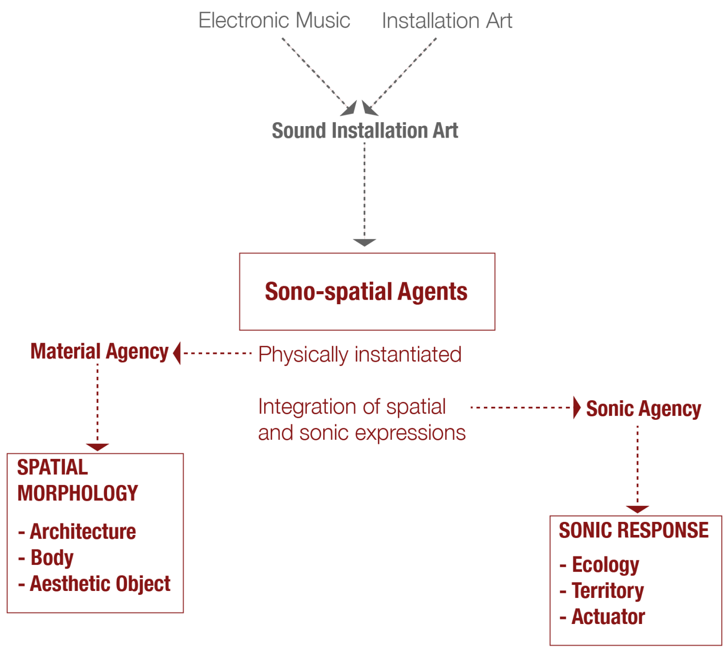


Figure 3.20: The conceptual framework of *SAMA*, as introduced in Chapter 2.

3.5 Evaluation and discussion

This section is a discussion of this work, *HIVE*, within the conceptual framework that I presented in Chapter 2: *Sonically Actuated Morphological Agents (SAMA)*. As a part of the evaluation, I also offer a list of the work's public dissemination at the end.

HIVE explores the notion of sentience and agency in the medium of sound. The piece is aimed at bringing attention to the importance of sonic communication for the survival of many animal species, and how soundscape as a finite resource is neglected by us, humans, and consumed and contaminated as a result of human activities. Following this thread, *HIVE* is conceived of as a speculative organism that lives in a sonic *umwelt*. By limiting its i/o to sound signals, we emphasize the importance of acoustic communication for the survival of certain organisms. Furthermore, via having the viewer activity impact on *HIVE*'s responses and the soundscape around it, we show how humans impact this soundscape.

In Chapter 2, I tied the importance of morphology to material agency and described its components as consisting of architecture, body, and aesthetic object. I also discussed sonic response as a powerful way to depict agency, through three primary aspects: actuator, ecology and territory (Figure 5.3). In *HIVE*, both the morphology and the sonic response work in tandem in affording its attributed agency.

First, let us discuss **'body'**. In Chapter 2, I argued that an agent's body can be designed to not only house its sensory-motor systems, but also can work in tandem with electronic or computational elements to determine its agency. In *HIVE*, The exoskeleton (body) operates both as an acoustic object, enabling *HIVE*'s vocalization (spatialization and timbral transformations) and also as an **'aesthetic object'** in its own right with a biomorphic appearance, reinforcing *HIVE*'s status as a pseudo-being. As mentioned in Chapter 2, formal aspects of agents directly impact how we attribute agency to them. The third element of morphology, architecture and related approaches, helps facilitate the creation of a world, a landscape, or an ecology, in which the viewer and the agents cohabit. The essential parts of *HIVE*'s **'architecture'** are the configuration of its body, as it affords radial sound projection, and the space that is created between the exoskeleton and the quadraphonic sound system on the periphery. The former enables the formation of a spatial sound image around the object, as a **'territory'**, allowing for the audience to walk around and explore both the soundscape and the object from different positions. The latter acts as a habitat containing the audience and the anthropogenic sounds that they introduce into this environment. Its status as the environment that *HIVE* inhabits is further enhanced by the sound design that is projected by the quadraphonic system. As mentioned previously, the external quadraphonic system emits droning, sustained, volumetric, non-directional field of low frequencies creating a directionless but enveloping sound space that is more or less static, acting as a container, in which the object vocalizes.

Here, the external quadraphonic system also enhances the **'ecology'** concept. HIVE has its own "niche" as its vocal range, which does not overlap with its environment. It is only when humans are present and their voices and activities bleed into the environment that HIVE starts altering its vocalizations —sometimes immediately, and sometimes in larger timescales, akin to the anthropocenic destruction of the natural environment and resources. At the times of overwhelming human activity, *HIVE*'s vocalizations might get more erratic (i.e. higher rate of moving source point), creating a cloud of sound around itself, using spatial sound as a defense mechanism; like a sonic structure, a sonic fort that *HIVE* builds around itself—a mound in sound. Here the sound system acts as an **'actuator'** animating this otherwise inanimate body. Sound creates motion and animation around this inanimate object, bringing it to life, prompting the audience to move around, interact, and listen.

As mentioned before, *HIVE* was exhibited in several venues, both nationally and internationally, so we were able to observe audiences in multiple cases. Viewers were usually intrigued by the agent, walking around it and interacting with it. I have also witnessed *HIVE* acting so erraticaly (sonically, of course) that it pushed the audience away;one audience member told me that it was impossible to be around it at times. Well, that was exactly the point! The criticism came from a person who believed that an artwork should appear pleasant at all times. Art, of course, has no such mission. Here, I cannot help but think that our branch of art is arguably found upon works like Jean Tinguely's *Homage to New York* (1960) (mentioned in Chapter 1), a machine that self-destructs in order to make a larger point.

One limitation we observed in our design is that the audience did not always get that they had an impact on *HIVE*'s vocalizations and the entire soundscape; ironically so. The anthropogenic impact is sometimes immediate and sometimes happens over larger time spans. The interaction we designed mimicked this notion. *HIVE*'s response was probabilistic and context dependent, as it was based on triggers that may or may not impact the soundscape right away. Due to the nature of the sound design, constant looping of some sounds, and certain events being triggered by sensors, it kept evolving. But, the audience were not always able to see the results of their actions right away, which could be frustrating to them.

In an ideal interaction design environment, one has to have the perfect balance of transparency and playfulness. Perhaps, our project did not strike this balance. In its defense, though, it is an art piece, and as such we are more concerned with the way it conveys the concept in a meaningful way, whether it is optimized for an easily perceivable interaction or not. I would like to once again remind us of Jean Tinguely's work and works of many other artists like that.

As a summary, *HIVE* can be thought of as an acoustic inanimate (static) object and the installation around it an entire architecture. As such, it is neither robotic art—since it is static—, nor A-life art—since it does not incorporate notions of complex biological processes or evolution. It then falls into the category that we created here: *SAMA*. It relies on a combination of spatio-material and sonic agencies, as was described in the conceptual framework above (Figure 5.3), that I introduced in Chapter 2. While Chapter 2 is a discussion of the elements of *SAMA* in discrete artworks, here all the elements are synthesized and altogether embodied within the artwork.

3.6 Public Dissemination

Below are the achievements of *HIVE* in reverse chronological order.

- Exhibition and talk: ISEA Art Gallery, 2020
- Exhibition: Currents New Media, 2018

- Media Coverage: “Sonic symphony: Sölen Kıratlı and Akshay Cadambi's HIVE”, by M.W. Simpson, in Pasatiempo, Santa Fe, NM, 2018, https://www.santafenewmexican.com/pasatiempo/art/sonic-symphony-s-len-k-ratl-and-akshay-cadambi-s/article_0c88be9e-2846-5b83-bae9-6d0a0b8e8a3b.html

- Exhibition, talk, and proceedings publication: ACM SIGGRAPH Asia Art Gallery, 2017 [62]

- Publication: NIME 2017 Proceedings, “HIVE: An Interactive Sculpture for Musical Expression”, [61]

- Exhibition and publication: ”White Noise”, MAT End of the Year Show Exhibition Catalogue (pp 82-83), 2016

Chapter 4

Case Study 2: *Cacophonic Choir*

This chapter describes the design,implementation, and conceptual background of the agent-based art installation, *Cacophonic Choir*. The emphasis is on describing the spatio-morphological and behavioral design principles and process of the agent. The design and implementation is described from the ideation stage to fabrication and installation.

4.1 Introduction

Cacophonic Choir is an agent-based interactive art installation aimed at bringing attention to the firsthand stories of sexual assault survivors. The work reflects the way sexual assault survivors' tales are obscured and distorted in online public discourse. *Cacophonic Choir* comprises nine self-contained, embodied "agents" distributed in space (Figure 4.1). The main form of interaction—the physical distance between the visitor and an agent—is a metaphor for the distance between the listener and the original source of the story. This represents the difference in accuracy between the original testimony and the versions of it told in various forms of mass media.

Agents are fitted with ultrasonic proximity sensors and respond to viewers' proxim-

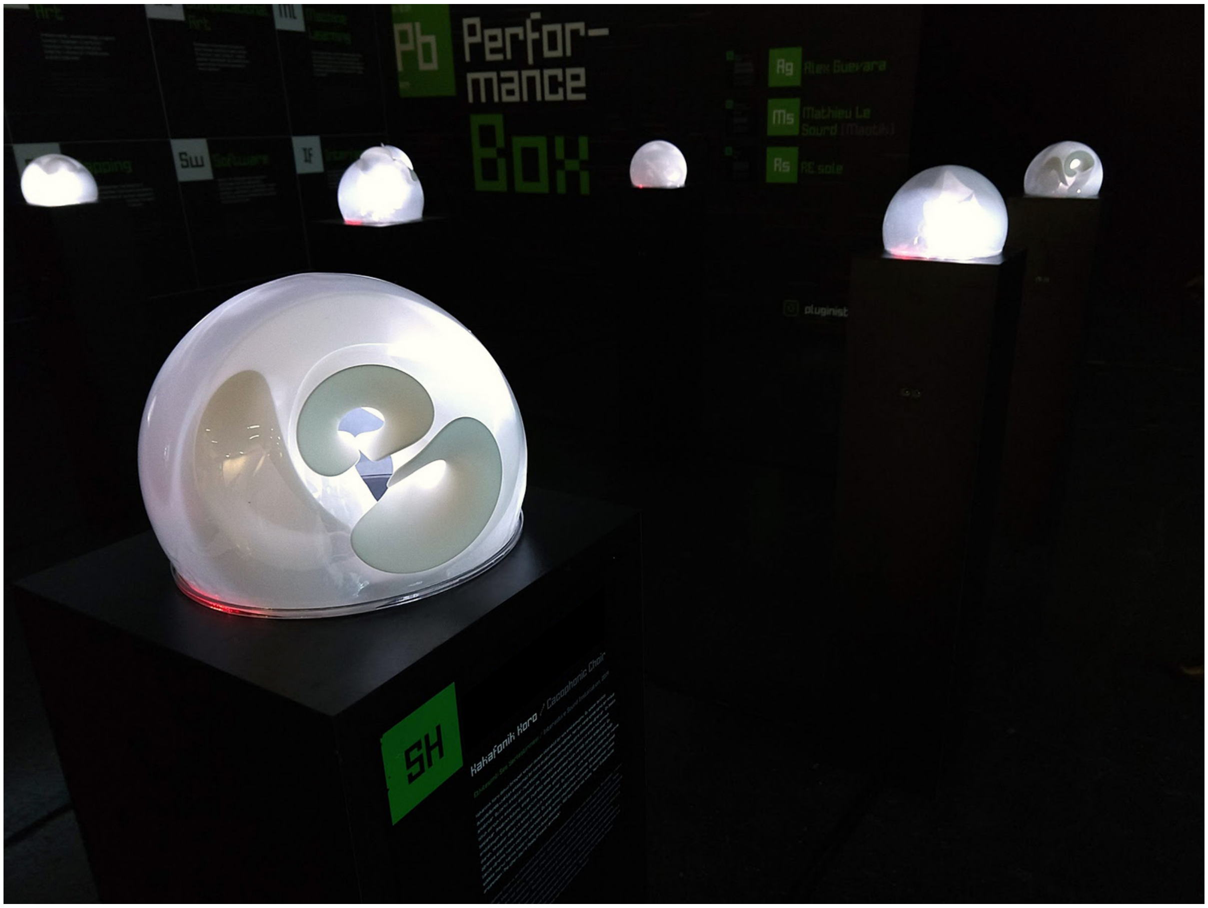


Figure 4.1: *Cacophonic Choir* (2019) is an interactive installation comprising of nine self-contained, embodied "agents" distributed in space.©Şölen Kıratlı, ©Hannah E. Wolfe. Photography credit: Hannah E. Wolfe

ity. An agent responds in three ways as a viewer approaches it. First, the narrative becomes more coherent, with the original testimony heard only when the viewer is in close proximity to the agent. This is achieved by adjusting the accuracy of a generative, machine learning algorithm that we designed and trained on the anonymous accounts of sexual assault survivors. Second, the voices are treated by a granular synthesis algorithm that generates a stuttering and halting effect that decreases as the viewer approaches the agent. Third, the individual form of each agent becomes revealed as the result of it illuminating itself from within, enabling the viewer to see through the soft silicon shell to the digitally fabricated organic form inside.

The stories the agents tell are taken from the *When You're Ready* website, "a community for survivors of sexual violence to share their stories and have their voices heard, finding strength in one another" [114]. The site is an exemplar of the dual nature of social media platforms: They empower survivors by allowing them to share their stories widely and anonymously, yet also expose those stories and their authors to the doubts and distortions that occur in social media. The demographics of the community are unclear due to its anonymous nature, and the work respects the authors' privacy by using anonymized stories.

Cacophonic Choir was produced in 2019 by the author of this dissertation, Şölen Kıratlı, and collaborators Hannah E. Wolfe, and Alex Bundy. It debuted in the sub-exhibition titled *Plug-in* '19, within *Contemporary Istanbul*, an international contemporary art fair. *Cacophonic Choir* was also exhibited in SIGGRAPH '20, which took place virtually, and won SIGGRAPH Art Gallery's "Best in Show" award. For this exhibition, we developed a virtual version of the work (`https://cacophonic.cs.colby.edu/`) using *Unity*, which we then also exhibited in IEEE Visualization Conference's Art Program '20. A paper on the piece was presented in the SIGGRAPH '20 art papers track, and published in the Leonardo Journal, parts of which are included in this chapter [63].

Cacophonic Choir was made possible with support from the *Systemics Artistic Production Fund* (Media Arts and Technology Program, UC Santa Barbara). Video documentation of the piece can be found at the following URL: `https://vimeo.com/364662275`

4.2 Conceptual background

Social movements use social technology as a way to empower people. Many movements have utilized platforms such as Facebook and Twitter to organize and give voice to their members. The *MeToo* movement in particular has succeeded in motivating many people by using social media platforms as places to share their stories and express solidarity with one another. However, these platforms have proven to be far from ideal places to share personal stories like this. Between Twitter users who engage in victim blaming and those who support sexual assault survivors, it has been found that those who blame victims get retweeted more [115]. In such an environment, instead of giving voice to sexual assault survivors, social media platforms reinforce the narratives of news media where rape myths are perpetuated and sexual assaults are trivialized by being treated as isolated cases of pathology or deviance [116] [117].

Media coverage of sexual assault, especially combined with the hostility and distortion that one often finds in these platforms, can be overwhelming to the survivors. *Cacophonic Choir* is aimed at both reflecting these feelings of being overwhelmed, and encouraging people to step away from these arenas to listen to individual survivors' accounts. While sexual violence is a systematic problem, the experiences of those who have survived it are all different and deserve to be heard. The installation is designed to embody and reflect this feeling of inundation in the face of hostility and distortion, while highlighting the first-hand stories of the sexual assault survivors. Given these goals, we aimed at creating an artistic system that can reflect this situation and translate it into an embodied experience using agent-based art and interactive strategies. The work follows the embodiment paradigm. If interaction is defined as "two (or more) agents engaged in ongoing, dynamical exchange" [3], the condition of distortion, as well as the severeness of the stories needed to be translated into the mechanics and aesthetics of this dynamic exchange.

4.2.1 Qualitative data and embodiment

The project is data-driven. Our data consisted of personal accounts of sexual assault survivors taken from the online platform, The When You're Ready Project. We picked this platform, because at the time—early 2019—this was the only extensive platform we could find where people safely and anonymously shared such stories. From this site, we scraped over 500 self-reported stories using the Beautiful Soup Python library. Contrary to the prevailing data visualization or sonification practices in media arts today, the data that we are translating into sensory modalities here is qualitative. It possesses semantic and emotional qualities in its "raw" form. It would follow that the design considerations in the translation of such qualitative data would be different than the quantitative one. This would render embodied ways of interaction—as discussed in Chapter 1—even more crucial, as this type of interaction can offer an immensely powerful way to critically and intimately engage with information.

With the initial goal of having the survivors' voices heard and at the same time critically reflecting the media coverage and distortion of these voices, the primary question was translating this situation into an artistic system that would enable an embodied experience. To this end, we needed to create a physical experience where we wanted the viewer to engage with not only the original qualitative data in its "raw" form, but also its distortion in an embodied and visceral fashion. This necessitated the notion of modulation. Here, instead of reflecting the data in different modalities and accessing it via a practical interface, our approach was to 'modulate' the data by sensory inputs. In other words, in an effort to reflect a notion of distortion we had to generate different versions of the data that could allow us to modulate the narratives by some sensory input, creating an interactive experience.

To this end, we pre-trained LSTM (Long Short Term Memory) recurrent neural network models on the stories. We used the library *TextGenRNN*, which uses *TensorFlow*, to train the neural network. The idea was to capture the system at various levels of training, so that we could modulate the original narrative, generating semantically incoherent or 'distorted' versions of it. This would allow us to create a system that generates words based on previously played words, rendering text generation in real-time based on some kind of sensor input. To generate text at different levels of semantic clarity, the neural network model was trained to 199 epochs and saved at different levels of training along the way. Next, we needed to decide on how to modulate this data and turn it into a meaningful embodied experience.

4.2.2 Structuring the space: distance as metaphor

"The meaning of information is not simply what the system conveys, but how it fits into a wider pattern of practice. The medium is not simply the representation that is conveyed, but how that representation becomes active in practice [12]"

In translating the human condition that is our subject matter into an embodied experience, I introduced the notion of modulation in the previous section. Modulation would allow us to create different 'versions' of the narratives, whose projection could be controlled by some sensor input. This sensor input, as the cause of the modulation, would determine the primary interaction modality. Following Dourish's statement "the modulation is the actual carrier of information—in terms of embodied interaction, the carrier of meaning" [12], the question was what sensory modality would be the most appropriate in interacting with these surrogate bodies. In other words, what is the modality in which we modulate the response (the behavior) of the agent?

The reason behind our choice of proximity based interaction to guide the entire experience is twofold. First is the significance of (physical/architectural) space as a medium in its own right, the second is using spatial distance as a metaphor for the "distance" between the original stories and their renditions filtered and distorted by the digital and mass media.

The former is based on aforementioned material agency. Physical space is an immensely powerful agent for embodied experience. Configuration and structuring of space via both material and computational means is especially important for any kind of (non-screen based) interaction. Here, let us regard space as not simply a container in which objects exist and events take place, but rather a series of relationships, a kind of continuum that includes the objects and affordances. Following this notion, (in the context of media arts) we can consider space within two major categories: static (material) and dynamic (computational) relationships. The static relationships that define the space are the architectural aspects of space, such as how the space is physically configured and organized, the objects in it and the relationship between them and how we move through this configuration; in other words, what kind of movements this static configuration induces. We can describe the dynamic relationships, on the other hand, as the relationships that are enabled by computational media processes, such as how the elements of space change over time automatically or in response to the viewer. In this category, the space can be directly or indirectly, actively or passively reconfigured with computation. The relationships can be composed of kinetic objects that can reconfigure themselves and hence the space around them, or the change can take place in other modalities, such as light or sound based, or haptic output. In each case, space is a medium that is significant in determining the nature of interactive aesthetic experience. Yet, in media arts practice, I argue that in most cases, space is taken merely as the container in which the modulation of media takes place. Instead of this passive position, we aimed at giving space a more active role, making it become the forefront agent in interaction—spatial parameters modulating or guiding the entire experience. Using the proximity sensors, and creating a proximity based interaction we structured the space. Space, here, is not homogeneous anymore, it is digitally 'heterogenized'.

The latter reason for the distance sensor based interaction is based on using space as metaphor. Considering the conceptual background of the project, it can be argued that what lies at the heart of the problem is a gap between the original story as told by the survivor and the way it is distorted, twisted, and turned in various media outlets. We decided to focus on this gap and to translate it into an interaction strategy within an agent-based system. We are representing this gap as an actual physical distance that impacts the narratives. In other words, we are using the physical distance between the agent and the viewer as a metaphor for the 'distance' or 'accuracy' between the original story and its coverage. This concept helped guide the entire work.

We implemented this concept—distance as a metaphor—as a response design in three fundamental modalities: semantic, sonic, and morphological. The semantic response uses neural net based text generation. The sonic response employs text to speech synthesis and granular synthesis. And the morphology was designed using parametric modeling and uses light-based response. All three components respond to the observer's proximity in different ways as defined by their modality. The following sections present a more thorough discussion on these components, focusing on the design processes.

4.3 Design Process

In the light of the conceptual and critical underpinnings that are discussed in the previous section, the following questions became the main points of our inquiry and steered the development of the project:

- How can we reflect this condition of distortion through an agent-based system, in which the agents represent survivors and their voices?

- What are the ways in which this agent-based system can embody the notion of the mediated content, as well as the true voices of the survivors?
- How can this agent-based system represent survivors as individuals and at the same time as a part of a larger systemic condition?

Given these questions, this section focuses on the development processes of design and fabrication, from early ideas and prototypes to the final design and implementation. It constitutes a valuable contribution to media arts and agent design practice due to an in-depth discussion of the design development, the tools and strategies used, and the conceptual, as well as practical reasoning behind the design decisions made.

4.3.1 Preliminary systemic design decisions

As a result of the aforementioned deliberations, the preliminary decisions made early in the conceptual design process were:

- To use text-to-speech synthesis to create multiple audio sources distributed in space, each projecting a narrative., From a distance the voices would collapse into a collective "murmur" where it would be hard to differentiate one narrative from another
- To use proximity sensors to control and modulate the semantic and audio qualities of the narratives and the response in close proximity designed in a way to help promote the viewer's engagement with the narrative
- To render each agent with a physical body that goes beyond a mere electronic assemblage; in other words, visually represent the agents by some kind of sculptural form

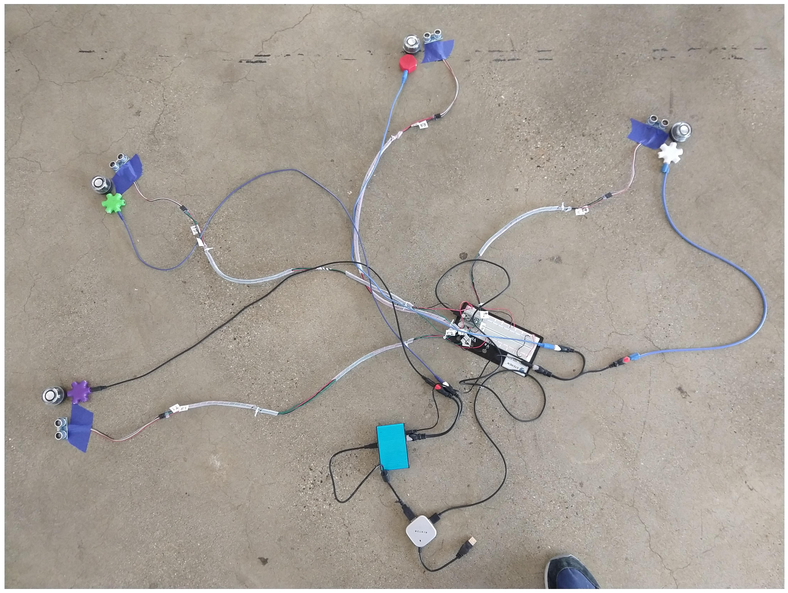


Figure 4.2: The figure shows the early prototype with four sensors, four speakers, and a microcontroller.

Given these preliminary decisions we steered the project in three parallel tracks: interface design, behavior, and sculptural morphology. The following sections discuss the project development based on these three main tracks.

4.3.2 Interface design

Preliminary prototype

Our first prototype consisted of four loudspeakers and four ultrasonic range finders (HC-SR04) controlled by a microcontroller, teensy 3.0. (Figure 4.2). We had designed the RNN (Recursive Neural Network) and converted all words into audio files usingApple text-to-speech synthesis. We wrote a simple MaxMSP patch (see Appendix) for signal processing and data flow. The patch received the sensor values from Teensy via serial protocol, smoothing these noisy values with a low pass filter and mapping them onto a range between 1 and 5. As soon as this value was determined, the patch would do two things simultaneously: send this value to a python script asking for the next word from

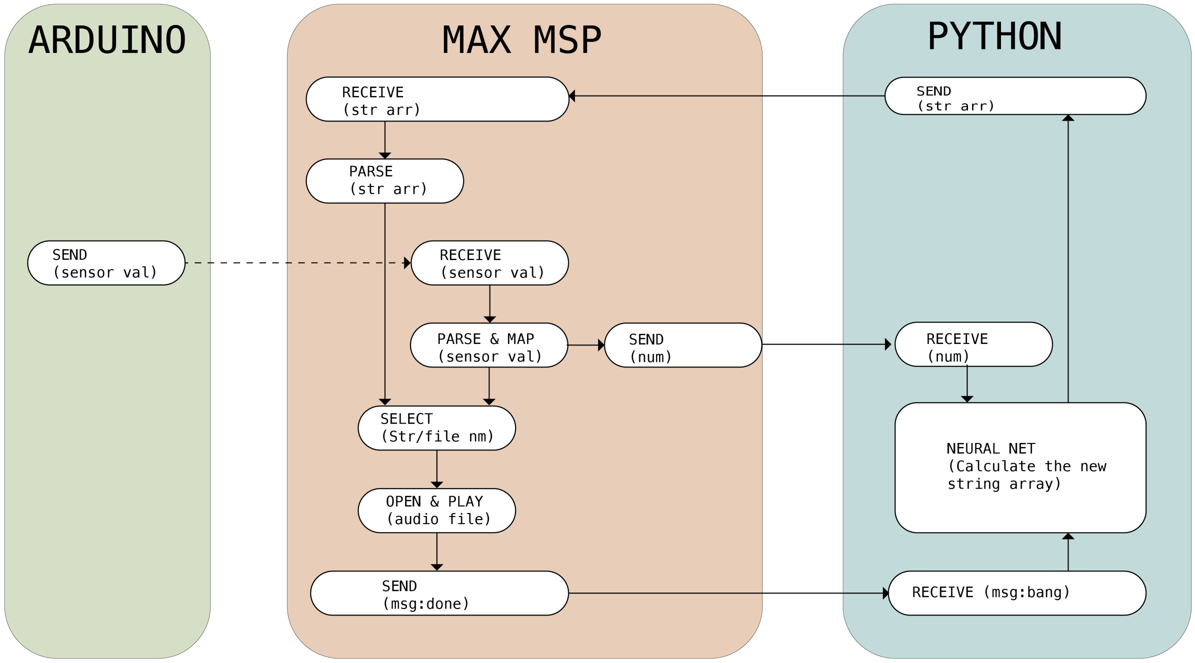


Figure 4.3: The figure shows the system architecture of the early prototype.

the RNN, and pass this value to the audio filter as a parameter triggering the playlist object. At this time, the object would have received the next word as a string and the system would play the corresponding audio file back. As soon as the playback is done, the playlist object sends the message "done" to the Python script and the next loop begins. (Figure 4.3)

The preliminary audio filtering process we chose to be modulated by distance was a simple low pass filter. The filter was fully open in the closest distance (level 1) and fully closed in the furthest distance (level 5) and everything in between was continuously mapped. The basic low pass filter was chosen for the prototype in the anticipation that this would be the simplest way to render a "muffled" effect when a subject was far, that would get clearer as the subject approached the sensor. However, this did not quite work.

Instead the effect we experienced perceptually was a mere modulation in loudness, as in when we were further, we experienced audio as more attenuated than 'muffled'. This can be due to the factor that our perception of audio is much more sensitive when it comes to human speech, so special filters that deal with phonemes are needed.

With this system, we also encountered latency problems resulting from dealing with several inputs and outputs simultaneously, due to the processing limitations of the microcontroller.

Design Development

The early prototype was a centralized system. In other words, all of the i/o was connected to and controlled by a single computer (mac mini). Moving forward, we decided to design the system as composed of multiple independently operating agents. Each of the agents' input and output elements would be controlled by their own computational unit. There are two primary reasons for this: one is practical and the other is conceptual. First, due to modularity, the level of flexibility enabled by distributed agents is higher than centrally controlled ones. This way, the system can be arbitrarily expandable and scalable, regardless of the computational power of the centralized control unit or the physical and spatial limitations of the system. Second, instead of designing and implementing a global behavior in a top-down fashion, we wanted the collective behavior to emerge from the behavior of the individual following a bottom-up approach, reminiscent of a self organizational structure. In this final design, as described in the next section, each agent is equipped with its own single board computer and therefore is completely independent from other agents.

Final Interface

The interface elements are chosen such that the agent can sense the proximity of

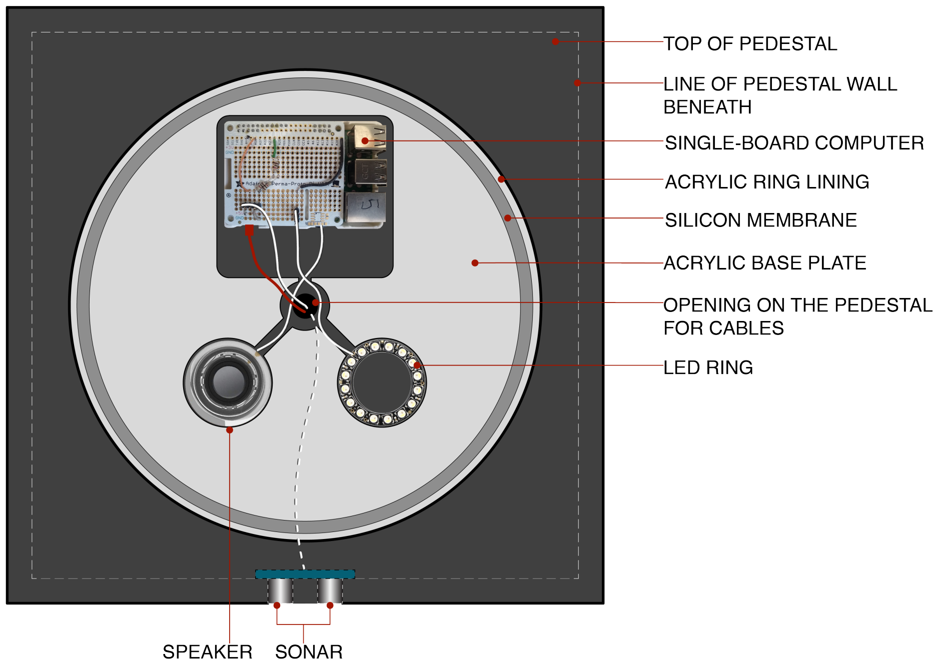


Figure 4.4: Planar view of the agent, showing the interface elements.

the viewers and it is able to respond via modulation of sound and light. The single board computer is the main controller of the input and output elements (Figures 4.4, 4.5). The system architecture and signal flow is described in the following section. We used a Raspberry Pi 3, Model B board for the single board computer. The primary input element that we used is an ultrasonic range finder *HC-SR04*. The Module sends eight 40 kHz sound signals automatically and detects whether there is a pulse signal back. The beams are narrow, with an effective angle of less than 15°. The detection zone is between 2 cm and 500 cm. There are two output elements. The first one is a small 8-ohm loudspeaker, 4 cm in diameter, with a built-in amplifier with 3W output power. It is connected to the single board computer via a standard 3.5 mm auxiliary connector andis powered by USB. According to the manufacturer, it has a full frequency range (20Hz-20KHz), however, probably due to the size, we have experienced poor low

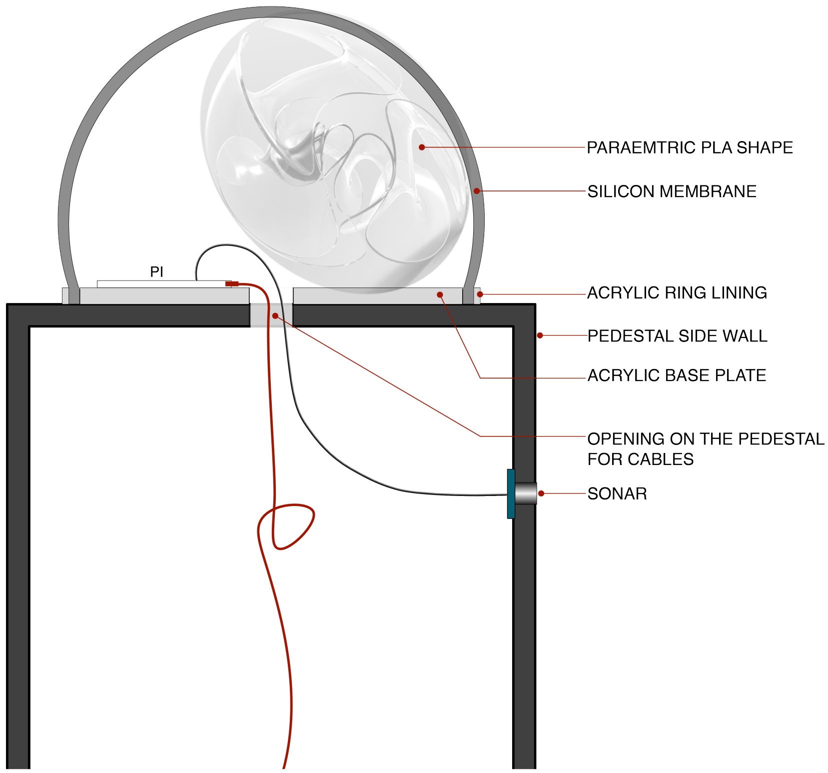


Figure 4.5: The agents' morphology is comprised of the computational and interface components (sensor, speaker, single-board computer, and an LED ring) along with a parametrically designed and digitally fabricated sculptural form encased within a soft translucent silicone-based membrane.

frequency response. The second output element is a 16-pixel WRGB (White Red Green Blue)LED ring. In addition to the standard RGB LEDs, these pixels can independently produce white light in addition to color, ensuring the representation of more pastel tones that cannot be accurately depicted by a standard RGB LED.

4.3.3 Agent behavior

An agent responds in three ways as a viewer approaches it. First, the narrative becomes more coherent. This is achieved by adjusting the accuracy of a generative, machine learning algorithm that we designed and trained on the anonymous accounts of

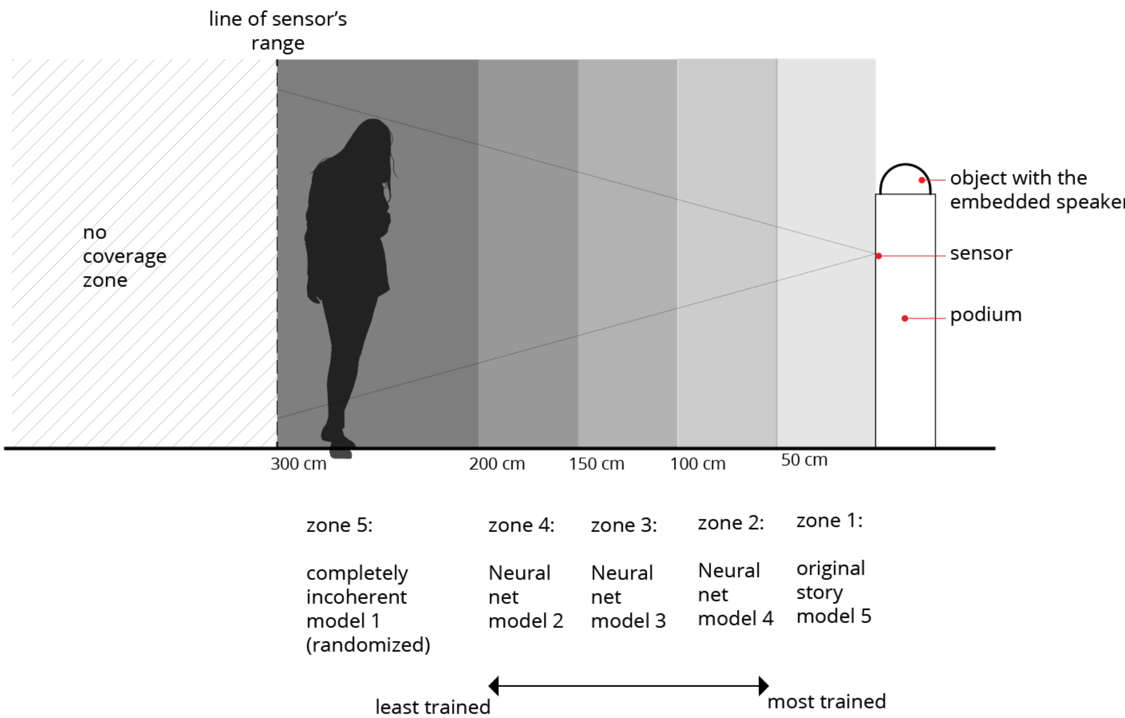


Figure 4.6: This figure shows how distance modulates the word choice of the agent and therefore the narrative. The agent chooses random words in zone 5. If a visitor is sensed within zones 2-4, pre-trained neural networks are used to choose the next word, with networks that were trained over more iterations being used in closer zones. If a visitor is sensed within zone 1 the agent reads the unaltered testimonial of a sexual assault survivor.

sexual assault survivors. Second, the voices are treated by a granular synthesis algorithm which generates a stuttering and halting effect that decreases as the viewer approaches the agent. Third, the unique form of each agent becomes revealed as the result of it illuminating itself from within, enabling the viewer to see through the soft silicon shell to the digitally fabricated organic form within. The following subsections discuss the design and implementation principles in detail.

Semantic response

The stories that the agents tell are manipulated using a generative algorithm, with the degree of manipulation being based on the visitor's proximity to the agent (Figure 4.6). When the agent does not sense any people nearby, the word choice is random. As a visitor approaches, a set of neural network model weights, trained to different levels of accuracy, are used to produce a range of words from more random to more coherent. When a visitor is within 40cm of an agent, an actual account is heard.

To generate text that reflected these stories, Long Short Term Memory (LSTM) recurrent neural network models were pre-trained on over 500 stories of experiences of sexual assault from The When You're Ready Project website. The stories were scraped from the internet using the textit Beautiful Soup Python Library, saving the title of the account, the date it was published, the URL, the tags associated with the story and the story itself. The library *TextGenRNN*, which uses *TensorFlow*, was used to train the neural network. To generate text at different levels of semantic clarity, the neural network model was trained to 199 epochs and saved at different levels of training along the way. The original implementation of the system chose the next word in real time, with the program loading the required pre-trained model, and generating a word based on the previously played words. The program seeded the request with fewer previous words at further distances and more words at closer distances. This process was too slow on a Raspberry Pi, so for the final installation the python script chose the next word from text that we had pre-generated using the neural network models saved at different levels of accuracy.

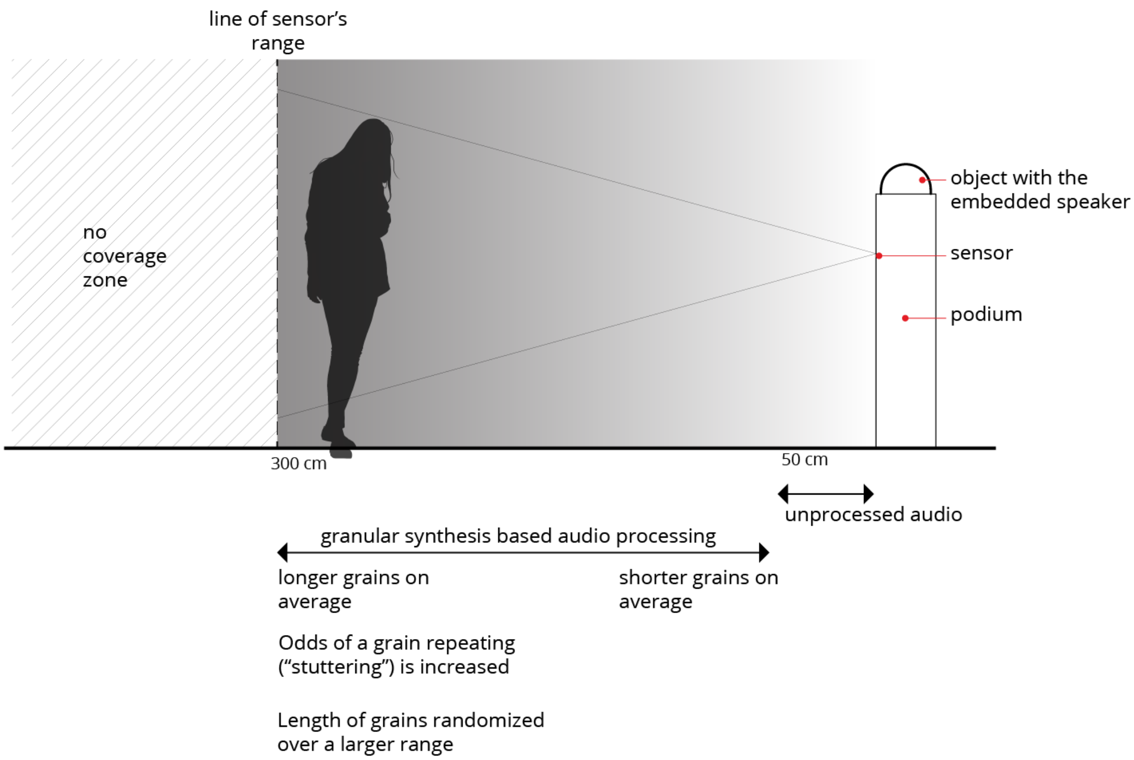


Figure 4.7: The figure shows how distance affects the granular synthesis parameters of the audio processing subsystem.

Sonic response

In addition to applying 'semantic' processing to alter the coherence of the stories, audio processing is applied to the voices to create a stuttering and halting effect that is increased the further the viewer is from the agent (Figure 4.7). This effect is meant to reflect both the distorting effect of media representations of sexual assault, and the fear and self-doubt sexual assault survivors may feel in the face of those representations. Granular processing is used to achieve this effect. Grain sizes are random, but in general relatively large (between 0.13 and 1 second) and with very little overlap (grain retriggering occurs between 2 to 15 times per second). These parameters were chosen to create an effect whereby some phonemes in the sound files are repeated or skipped. Whether any grain is skipped or repeated is determined randomly, with the odds of a skip or repeat increasing as the viewer's distance from the work is increased. The amount of processing and degree of randomization of the granular parameters are calculated throughout the playback of the words, so that the amount of processing may change mid-word. Experiments with other forms of audio processing were made, including distortion and frequency-domain filtering. It was determined that such processing was unnecessary; the natural filtering effects of distance, as well as the "cacophonic" effect of all nine agents speaking, was sufficient to achieve the aesthetic and conceptual effect desired.

The playback of the words was achieved by using audio files that were pre-generated using Apple's Text-to-Speech (TTS) program. Word-by-word playback like this was chosen because it allowed us to alter sentences 'mid-stream', which would not be possible by providing a speech synthesis program full sentences to generate. A side-effect of this approach is that the voices did not sound as natural as they could have, since TTS programs often adjust the inflections of words based on their position in a sentence.

Optic response

The input from the proximity sensors also modulate the light source inside the membrane of the agent, therefore rendering the membrane more transparent, and revealing the structure inside the membrane. This is discussed more thoroughly in the upcoming sections.

4.3.4 Agent morphology

On the body morphology

Instead of having disembodied voices distributed in space, we leaned towards representing the survivors via physical sculptural form. These forms, or assemblies, would act as surrogate bodies, embodying the voices of the survivors. In an effort to follow similar design principle as the semantic and sonic responses, and taking advantage material and visual properties of objects while doing so, we came up with the following design idea: We could design the interaction such that the light inside a transparent object could be modulated by the viewer's proximity, gradually revealing a unique form, just like revealing the individual story of a survivor. This brought about the idea of a translucent membrane and a form either embedded in it, or rupturing outwards from it, following biological undertones. This way, the idea of the gradual unveiling of the narrative would be repeated to reveal the details of a unique sculptural form embedded in a membrane.

The form inside needed to have some kind of three-dimensional complexity. To this end, I worked in a parametric design environment. As mentioned in Chapter 1, parametric design would allow us to create variations on the same theme, allowing similarities between the surrogate bodies, while maintaining differences and individuality.

At this time, I developed an interest in the mathematical idea of *minimal surfaces*, defined as surfaces that encompass the minimum area given a wire frame. Soap films that form over a wire frame are good examples of such surfaces. For the design of the forms inside the membranes, I experimented with minimal surfaces, as they presented opportunities in the direction of my aesthetic goals. First, they are continuous surfaces that can wrap or curve onto themselves, as opposed to solid enclosed objects, allowing three-dimensional complexity. Second, they are mathematically well defined, and therefore very suitable for digital design and parameterization. The next section explains the parametric design and experimentation process further.

Design process of the parametric form

Through a series of experiments on soap films, Joseph Plateau, the 19th century Belgian physicist and mathematician, studied the phenomena of capillary action and

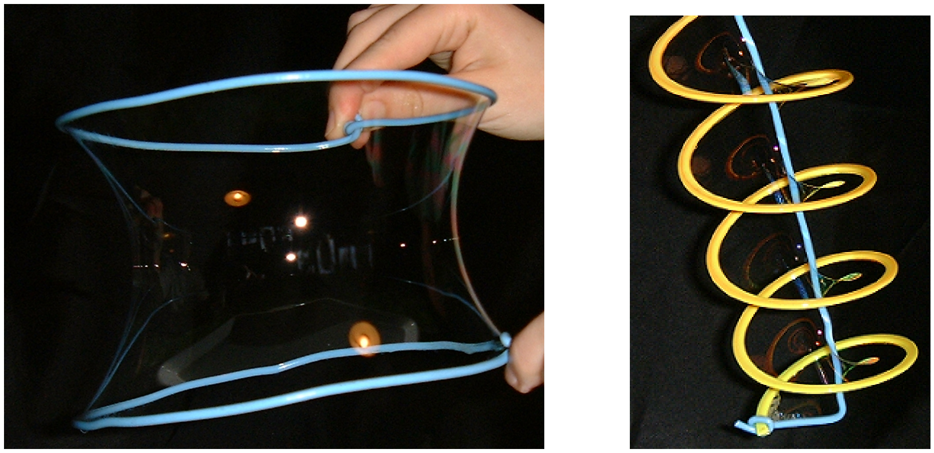


Figure 4.8: (Licenses: CC BY-SA 3.0) Shows soap bubbles forming minimal surfaces, a helicoid (left) and a catenoid (right). Catenoid was formulated by L. Euler (1774) and J. Meusnier (1776) [118].

surface tension. He formulated laws describing the structures and geometry formed by such films in foams [119]. He observed that when a wire frame is dipped in a soap solution, the film that is formed occupies the minimum possible continuous surface area (Figure 4.8). This is because, among all possible surfaces, soap film finds one with the least surface area in order to minimize surface tension and reach equilibrium.

The problem of finding a surface of a minimal area pulled over the given contour was first defined and formulated from a purely mathematical viewpoint by Lagrange (1760). In mathematics, a minimal surface is defined as a surface having the mean curvature H equal to zero at all points. Hence, minimal surface is a surface of negative Gaussian curvature [118]. A plane is a trivial minimal surface [120], and amongst the nontrivial examples, I chose Enneper's surface, formulated by Alfred Enneper in 1864, as a starting point for experimentation. This is due to the relatively simple parametric definition of the surface, as well as its aesthetic qualities. For the implementation, I used the Weierstrass-Enneper parameterization. This was not only easy to implement, but also allowed me to create higher-order variations of the Enneper surface, which yielded visually interesting results. Higher order implementations visually manifest as higher

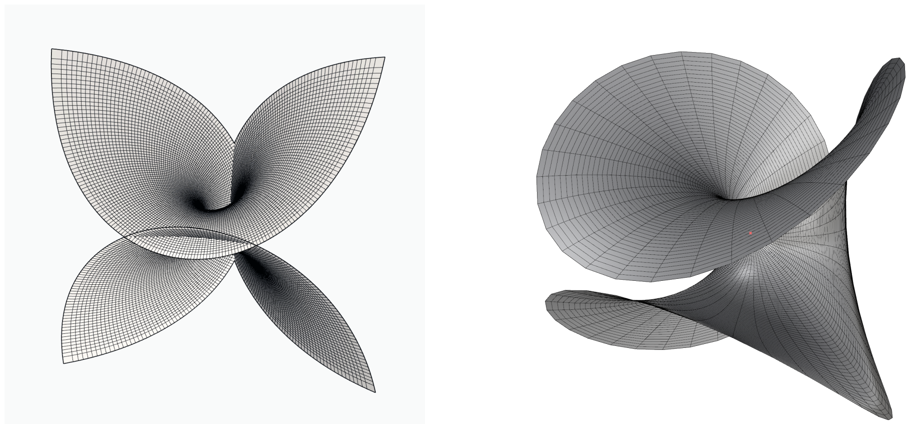


Figure 4.9: Left: Shows a generic Enneper's surface generated in Grasshopper 3D, using the Weierstrass-Enneper parameterization. Right: Shows a generic Enneper's surface generated in Grasshopper 3D, using polar coordinates, with the Weierstrass-Enneper parameterization.

fold curvature symmetry as can be seen in figure 4.10.

The parametric form of the surface $E1$, in (u, v) coordinates is (Figure 4.9, left):

$$E1(u,v) = \begin{pmatrix} -\frac{1}{3}u^3 + uv^2 + u \\ -u^2v + \frac{1}{3}v^3 - v \\ u^2 - v^2 \end{pmatrix} \tag{4.1}$$

where $u, v\ \epsilon \mathrm{R}$

In polar coordinates, Enneper's Minimal Surface $E1$ can be described as (Figure 4.9, right):

$$E1(r,\theta) = \begin{pmatrix} r\cos(\theta) - \frac{1}{3}r^3\cos(3\theta) \\ -r\sin(\theta) - \frac{1}{3}r^3\sin(3\theta) \\ r^2\cos(2\theta) \end{pmatrix} \tag{4.2}$$

where $r\epsilon[-1, 1]$ and $\theta\epsilon[0, \pi]$

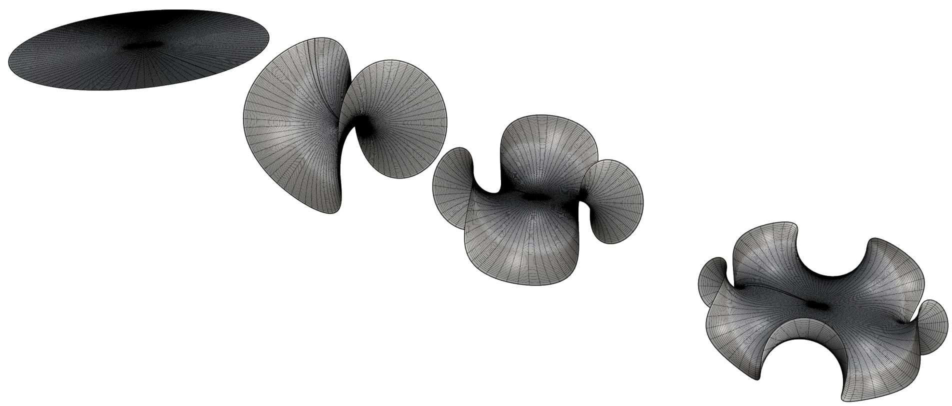


Figure 4.10: The figure shows the higher order Enneper's surface. The order of the original function determines the number of rotational symmetries. I.e. (from left to right), the first geometry is a plane, which is a "trivial" minimal surface. The ones next to it are first order, second order, and third order respectively.

Enneper Surface can be generalized to higher order rotational symmetries by using the Weierstrass–Enneper parameterization. (Figure 4.10)

$g(z) = z^n$ where $n \epsilon \mathrm{N}$

$$E1(r,\theta) = \begin{pmatrix} \frac{r\cos(\theta)+2n\cos(\theta)-r^{2n}\cos(\theta+2n\theta)}{2+4n} \\ -\frac{\sin(\theta)+2n\sin(\theta)+r^{2n}\sin(\theta+2n\theta)}{2+4n} \\ \frac{r^{1+n}\cos((1+n)\theta)}{1+n} \end{pmatrix} \quad (4.3)$$

where $r \epsilon [-1, 1]$ and $\theta \epsilon [0, \pi]$

For the implementation of these geometries, I used the parametric design environment Grasshopper 3D, described in the previous Chapter. The translation of the various versions of the equations into Grasshopper 3D patches (Figure 4.11) was followed by a series of formal experiments that were done in a less systemic but highly intuitive way. As a result of these, I used the higher order (3-fold symmetry, 4th order) version of Enneper's surface. I morphed this onto a sphere using the "surface morph" function, which morphs

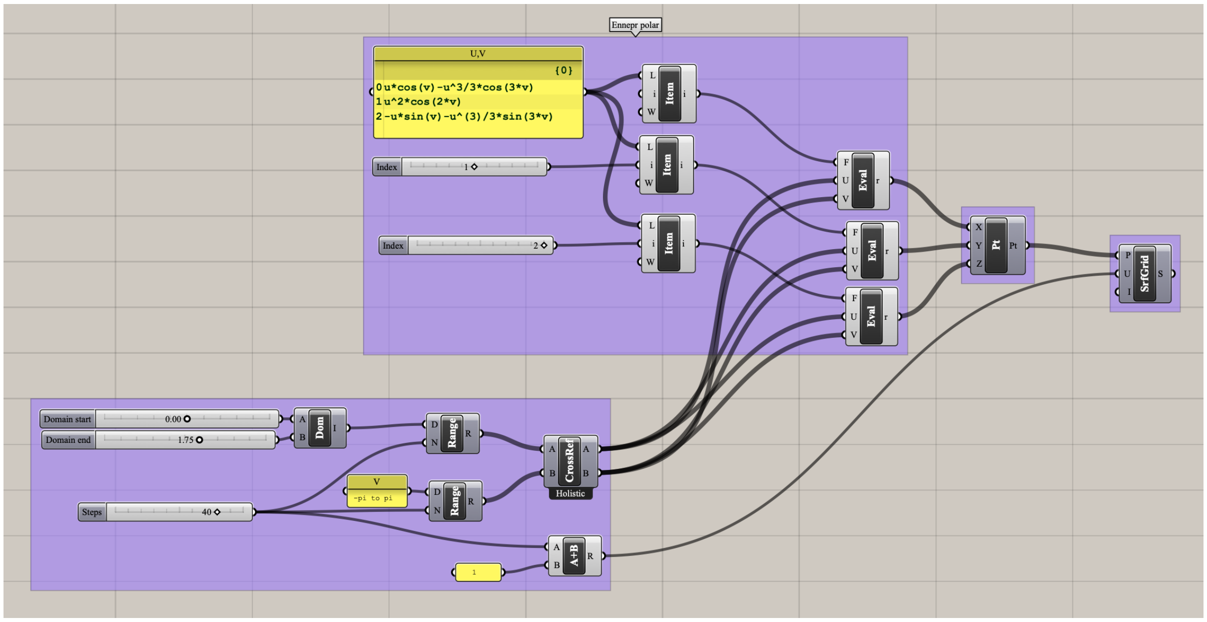


Figure 4.11: The figure shows the Grasshopper patches for the polar implementation of the Weierstrass-Enneper parameterization. Using the respective formula, I created a set of points within a given domain, then turned these points into a surface using Grasshopper's Surface Grid component

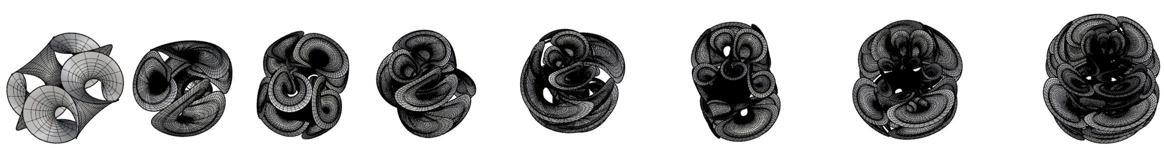


Figure 4.12: The figure shows the Enneper Surface morphed onto a sphere with varying UV parameters.

a given geometry into surface UVW coordinates. Here, the UV parameters of the surface morph component determine the complexity and order of curvatures. (Figure 4.12)

To sum up, after a period of experimentation with various mathematically defined surfaces for the final form, we chose variations on a fourth-order Enneper Surface morphed on to a generic elliptical surface. The resulting form (Figure 4.13) is as a continuous complex surface that can wrap or curve onto itself, as opposed to a solid enclosed object. Instead of having boundaries that enclose a well-defined abstract negative space, such as a sphere, the form here is reminiscent of an organic shell-like surface that creates a three-

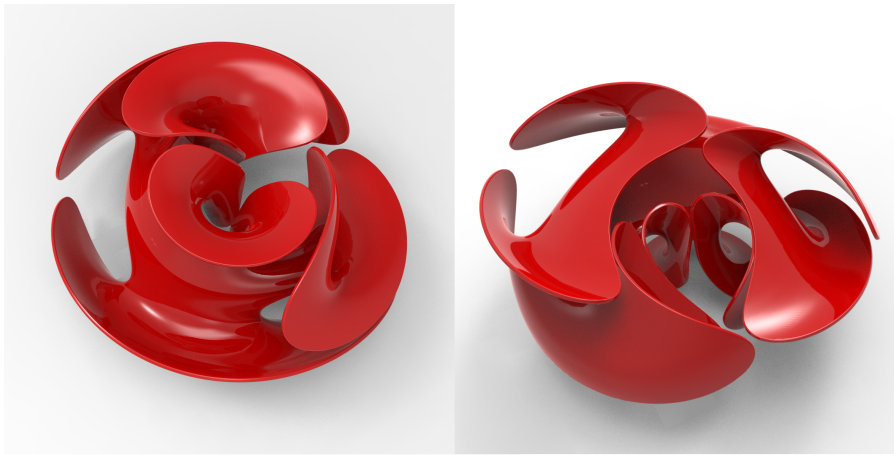


Figure 4.13: Computer rendering of the final geometries with chosen parameters.

dimensional negative space without a clear boundary between its inside and outside. This complex negative space with a series of semi-open and semi-enclosed subspaces projects the tension between privacy and publicness into the geometric realm.

Fabrication process

The final versions of the parametric forms (Figure 4.14) were 3D printed in PLA (polylactic acid) by Shapeways, an on-demand 3D printing service.

As for the fabrication of the membrane, I experimented with several different silicone rubbers. These usually come in two-part liquid form and cure within forty minutes to four hours after being poured onto a mold. I experimented with silicons with different transparency levels, as well as hardnesses. The criteria was that it should not be too opaque and that we should be able to control the transparency with a white dye if need be. The other important criteria was the hardness of the material. It should not be too soft that it would collapse when in a spherical form, but at the same time soft enough for the PLA forms to rupture through. After a series of experimentation with different silicone rubbers, I chose *Smooth-On*^{TM}'s *SORTA-Clear*^{TM} 37, which is a type of translucent silicone rubber that cures at room temperature with negligible shrinkage. It

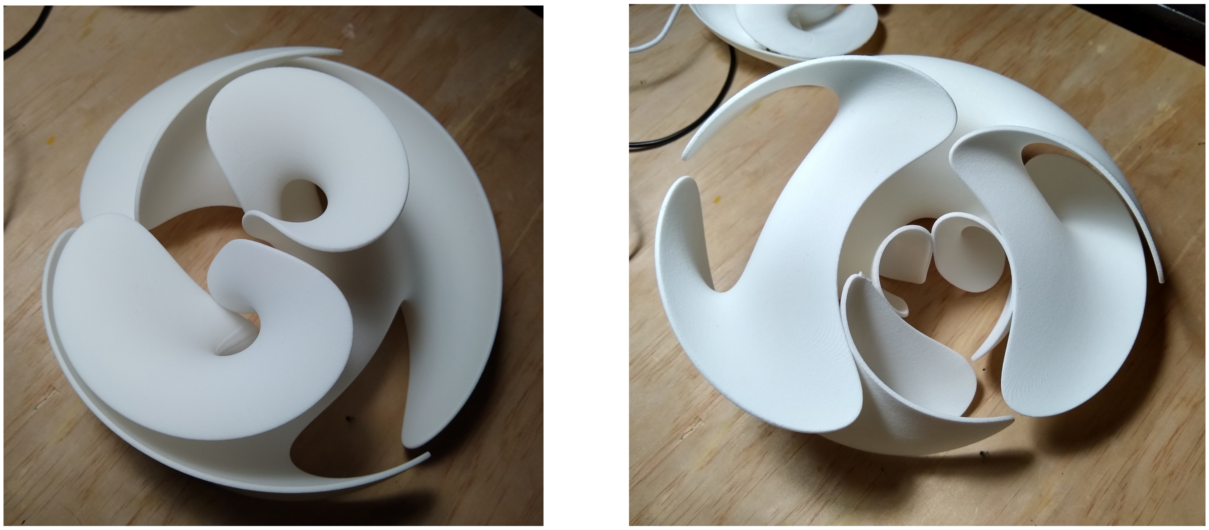


Figure 4.14: The figures show one of the parametric forms 3D printed in PLA.

has *Shore 37A* hardness and features high tensile (600 psi—pounds per square inch) and tear strength.

The idea was that these membranes would approximate a semi-sphere and sit on a near-ear height stand and encapsulate the parametric form, as well as the electronic interface elements (such as the single-board computer, LED ring, etc.).

I devised the following method (Figure 4.16) to create such shapes from relatively soft silicone: I obtained a glass sphere of the size I wanted. I prepared a stand for this using foam core, as seen in the picture. I lined the edge where the sphere meets the stand with fabric, in order to reinforce the edges so they would not tear. Then I poured a thin layer of the silicon (Figure 4.15), let it be hardened to the touch (but not cured), then poured another thin layer. I used a canned air spray to eliminate the bubbles as much as possible. The best way to completely eliminate bubbles would have been to use a vacuum chamber, which was not available to me at this time. As a result, one can observe air bubbles in some of the agent's membranes.

In order to give the ruptured look, I cut a small slit in some of the membranes and

Figure 4.15: The figure shows pouring of the silicon for the agent membranes.

pushed the form through, as seen in Figure 4.17. The form would also help the membrane stand stiff.

Summary of the morphological elements

As a summary, the body of these agents are conceptualized as surrogate bodies representing the survivors and embodying their voices. To this end, each agent is composed of a soft translucent silicone-based membrane encasing a parametrically designed and digitally fabricated form, along with the interface elements. Each agent contains a variation of the same parametric form. Some of these forms are fully contained within the membrane, while others burst outward. This allows for individual differences between the agents, while maintaining a formal coherence. Proximity of the visitor modulates the light source within the membrane. As a result, the translucent membrane gets gradually

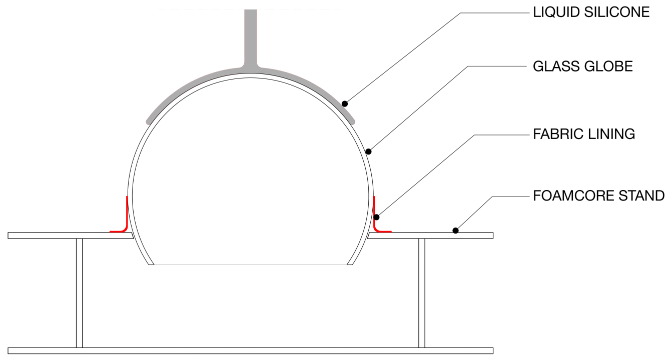


Figure 4.16: Shows the method I devised in order to create hemispherical shapes from relatively soft silicone.

more transparent as one approaches the agent, revealing the intricate geometric form within. Here, our intention was to reflect the condition that the individuals and their voices may look and sound alike from a distance, but each is found to be complex and unique when one makes an effort to focus on it. This simple light-based interaction, coupled with the material properties of the sculptural elements (i.e. transparency) also allowed us to reflect the inherent tension in the public coverage of private events—since opaqueness and transparency have strong connotations of privacy and publicness in many cultures.

4.3.5 System Architecture

Each agent contains a single-board computer with a proximity sensor, an LED, and a speaker. The single-board computer has three processes running an input/output (i/o) controller, a Digital Signal Processing (DSP) server, and a "word server" (Figure 4.19). The i/o controller is a Python script that reads the proximity sensor, shares the proximity data with the DSP server using Open Sound Control (OSC), and controls the brightness of the LED. The DSP server is written in SuperCollider and is responsible for the playback and processing of the audio files, and the word server is a Python script that

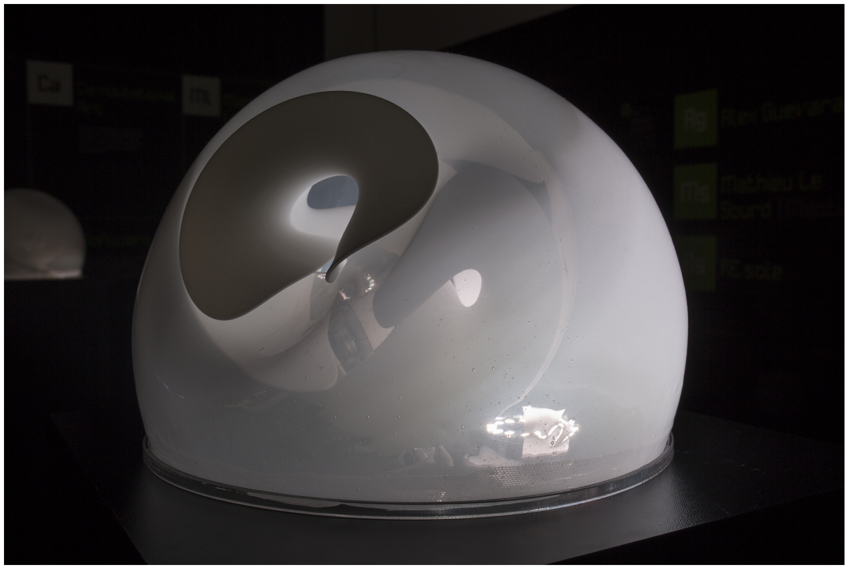


Figure 4.17: In order to give the membranes a ruptured look, a small slit was cut on some of the membranes and the parametric form was pushed through.

is responsible for choosing the words to be played. When the word server has initialized, it sends the first word to the DSP server to be played. The DSP server plays back the word, applying real-time processing that is proportionate to the current reading of the proximity sensor. When SuperCollider is finished playing a word, it sends a request to the word server for the next word. This request includes the current distance readout from the proximity sensor. The word server then chooses a word using the algorithm described previously, the accuracy of which is determined by the distance reading. Once a word is chosen it is sent to the DSP server to be played back, thus closing the loop.

4.4 Installation

Cacophonic Choir debuted in the sub-exhibition titled *Plug-in '19*, within *Contemporary Istanbul*, an international contemporary art fair. The piece was located in a fairly noisy environment that caused an unintended interaction between the visitors and the work. To hear a story clearly, visitors had to place their ears directly next to an agent.

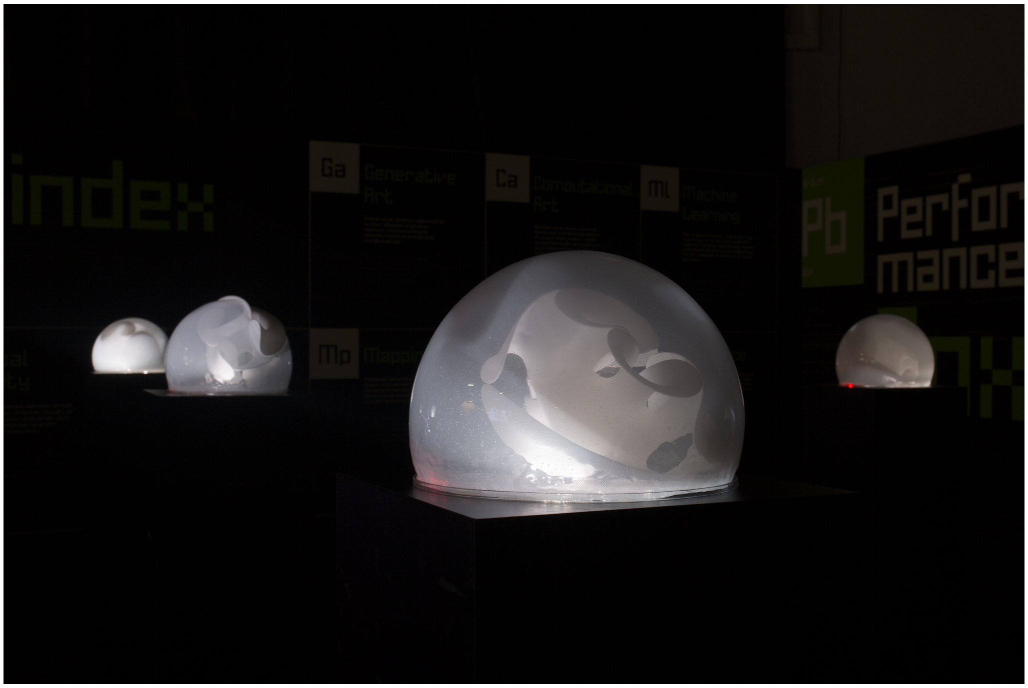


Figure 4.18: A photo of *Cacophonic Choir* from Contemporary Istanbul's Plug-in '19 exhibition. Credit: Gökhan Tugay Şeker

This created a level of intimacy between the agent and the visitor, as if it was whispering to them (Figure 4.20). As a result of this unintended interaction, we observed many of the visitors were coaxed into giving their full attention to the original testimonies, which was one of our primary goals. Furthermore, this kind of bodily closeness to the agent may help foster the much-needed empathy for listening to the emotionally difficult content of these stories.

Cacophonic Choir was also exhibited in SIGGRAPH '20, which took place virtually, due to Covid-19, and won SIGGRAPH Art Gallery's "Best in Show" award. For this exhibition, we started developing a virtual version of the work using Unity (Figure 4.21), which we then also exhibited in IEEE Visualization Conference's Art Program '20.

As of 2021, Cacophonic Choir continues to evolve in both virtual and physical platforms. The virtual version of the piece uses the unity framework. In the virtual environment the semantic and sonic coherence of the agents are modulated and spatialized

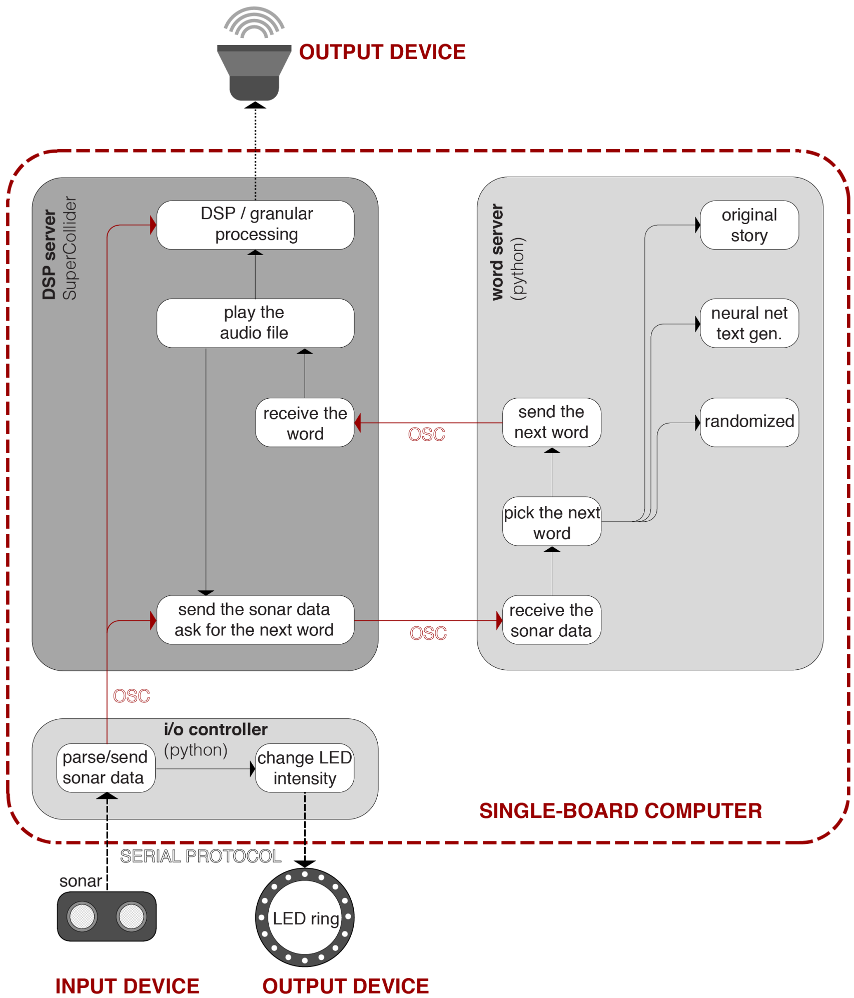


Figure 4.19: The architecture of the system.

by the distance the visitor is from them. As the visitor moves closer to an agent the membrane becomes more translucent, revealing the parametric form within. We are currently exploring different layouts and visualization techniques. The current version of the virtual environment reflects the original layout of the agents in the physical installation.

Figure 4.20: The figure shows a visitor listening closely at Contemporary Istanbul's *Plug-in '19*. (Photo credit: Gökhan Tugay Şeker)

4.5 Evaluation and discussion

This section is a discussion of this work, *Cacophonic Choir*, within the conceptual framework that I presented in Chapter 2: *Sonically Actuated Morphological Agents (SAMA)* (Figure 5.3). As a part of the evaluation, I also offer a list of the work's public dissemination at the end.

In *Cacophonic Choir*, we aimed at creating an embodied experience that gives voice to the sexual assault survivors and reflects how their stories may be distorted by digital and mass media. To do this we created nine agents, each of which represents a survivor. We used distance between the audience and the agent as a metaphor for the "distance" between the original story and its distorted renditions. We modulated the

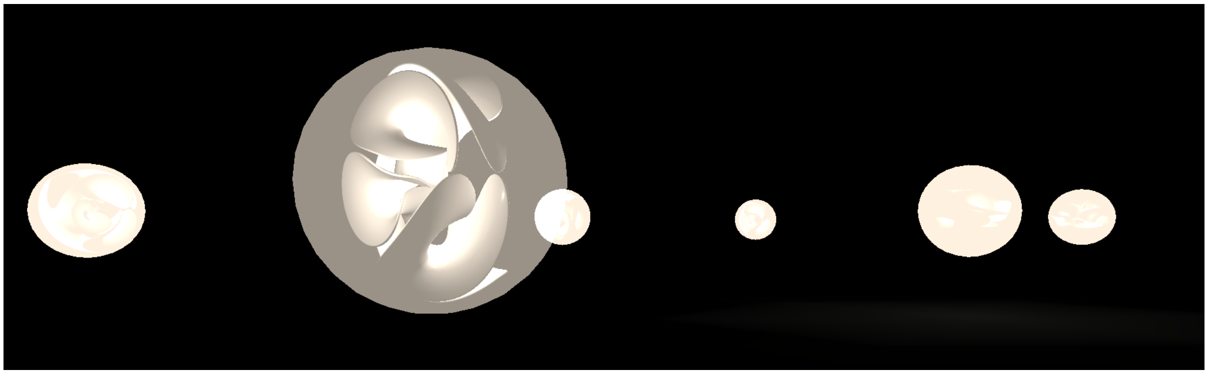


Figure 4.21: We are developing a virtual version of the work using Unity.

stories themselves, the way they sound, and the way that agents look, by the proximity of the viewers.

In this work, as in *HIVE*, both the morphology and the sonic response work in tandem in affording this attributed agency. In Chapter 2, I tied the importance of morphology to material agency and its components as architecture, body, and aesthetic object. I also discussed sonic response as a powerful way to depict agency, through three primary aspects: actuator, ecology and territory.

First, let us discuss **'body'**. Unlike *HIVE*, which is a pseudo-organism in its own right and hence has its body designed to function as a mediator of sound signals, in *Cacophonic Choir* the body is more representative. As discussed before, here we see the bodies of agents as forms, or assemblies that act as surrogate bodies, representing the survivors and embodying their voices. So, the body functions as a representation or a stand-in for the survivor. It also follows the same idea of the distance based modulation and being able to encounter the "real" version of what we see and hear, when we are close to them and paying direct attention. The piece is embodied in the sense that the meaning emerges as a result of the viewer's experience as they are moving in space and as a result of the modulation. "the modulation is the actual carrier of information —in terms of embodied interaction, the carrier of meaning". Here, even the body is static, with only the material

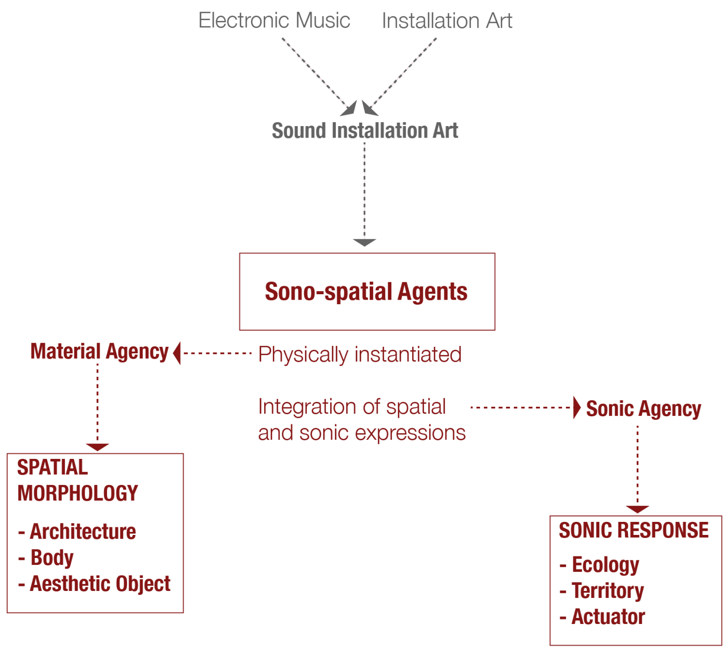


Figure 4.22: The conceptual framework of *SAMA*, as introduced in Chapter 2.

properties (transparency) of the sculptural aspects being modulated. Like *HIVE*, the body also operates as an **'aesthetic object'**; an object behind a veil—of sorts—, an object that would reveal itself in close quarters. Its **'architectural configuration'**, a grid distribution of agents in space, not only affords being walked through, but working in tandem with the interactive elements, implores one to do so, by enticing (intriguing) them through the sounds and the objects. The notion of **'ecology'** in *Cacophonic Choir* remains at a much more conceptual and meta level than in *HIVE*. That is, it is not embodied in a direct experience and is not about soundscape ecology. *Cacophonic Choir*is directly about "media ecology", which looks into "what roles media force us to play, how media structure what we are seeing or thinking, and why media make us feel and act as we do" [121]. As for **'territory'**, in addition to the cacophonous zone that the agents define altogether, individual agents also clearly mark their territory by modulating their voices based on proximity of a viewer within a spatial range. This, in fact, is arguably the most crucial aspect of the piece, since it determines the main method interaction, in which the entire meaning unfolds. Moreover, like in HIVE, the speakers and the vocal responses in *Cacophonic Choir* act as **'actuators'** for this otherwise inanimate system, not only bringing the agents to life, but also prompting the audience to walk and explore this sono-sculptural environment.

Instead of creating a complex and playful interaction, we kept the interaction design simple and to the point. This is due to not only the subject matter being a somber one, but also our desire to have the stories and voices be the primary focus; and it can take a high level of emotional energy and attention to listen to them. Overall, the audience made positive remarks, such as being captivated by the piece. Moreover, a good part of the visitors took their time to listen and engage in the work during the exhibition within *Contemporary Istanbul*.

Perhaps, one limitation of the piece was that the resolution in semantic versions of the stories were not experientially clear. In other words, without explicitly being told, it was somewhat difficult to observe and realize that there were five distinct semantic zones around each agent, and five versions of the story—gradually varying in semantic coherence— corresponded each zone. The transition from, say, the RNN level-three version of the story to the level-two, especially at the speed of one's walking is experientially almost opaque. That said, the main point went across: People were able to understand and experience that the story was much more coherent at the closest level and that it was less sensible as one was at a distance. The other point was, when the speech is also having the stuttering effect—that was also modulated by distance—that is much more immediately and clearly noticeable than the semantic changes. We took care that these two parameters not mask each other, but it was tricky.

To summarize, *Cacophonic Choir* is a group of inanimate objects embodying the voices of the survivors and reflecting the toxicity of digital and mass media environments on the survivors via sound projection modulated by a proximity based interaction. As such, it is neither robotic art—since it is static—, nor A-life art—since it does not incorporate notions of complex biological processes or evolution. It then falls into the category that we created here: *SAMA*. It relies on a combination of spatio-material and sonic agencies, as was described in the conceptual framework above (Figure 5.3), that I introduced in Chapter 2. While Chapter 2 is a discussion of the elements of *SAMA* in discrete artworks, here all the elements are synthesized and altogether embodied within the artwork.

4.5.1 Public dissemination

Below are the achievements of *Cacophonic Choir* in reverse chronological order.

- Exhibition: IEEE VISAP Art Gallery, 2020
- Publication: Leonardo Journal, "Cacophonic Choir: an interactive art installation embodying the voices of sexual assault survivors", 2020 [63]
- Publication: ACM SIGGRAPH 2020 Art Gallery Proceedings [122]
- Exhibition: ACM SIGGRAPH - Art Gallery, 2020 and won the "Best in Show" award
- Conference presentation: SOUND:: GENDER:: FEMINISM :: ACTIVISM (SGFA), Chinretsukan Gallery, Tokyo University of the Arts, Tokyo, Japan, 2019
- Exhibition: Contemporary Istanbul / Plug-in '19, "RW. [material]", Istanbul, Turkey, 2019

Below are the selected media coverage of *Cacophonic Choir*:

- Review: “Cacophonic Choir”, Neural Magazine, Issue 67, Winter 2021 (Forthcoming)

- Podcast: SIGGRAPH Spotlight: Episode 41 – Art in the Age of TikTok, 01.2021, `https://blog.siggraph.org/2021/02/siggraph-spotlight-episode-41-art-in-the-age-c` `html/`

- Article: “SIGGRAPH 2020 : Cacophonic Choir, une oeuvre artistique dans le sillage de *MeToo*”, 3DVF, by Shadows, 08.2020, `https://www.3dvf.com/siggraph-2020-cacophon`

- Article: “AI-driven Cacophonic Choir amplifies voices of sexual assault survivors”, CNET, Leslie Katz, 08.2020, `https://www.cnet.com/news/ai-driven-cacophonic-choir-amp` `#:~:text=This%20is%20Cacophonic%20Choir%2C%20an,sounds%20like%20an%20indistingui` `20jumble.`

- Interview: “’Cacophonic Choir’, the Sounds of Survivors’ Stories”, ACM SIGGRAPH Blog, 06.2020, `https://blog.siggraph.org/2020/06/cacophonic-choir-the-sounds` `html/`

Chapter 5

Conclusion and Future Work

5.1 Conclusion

5.1.1 The research problem and its context

In the *Introduction Chapter*, I discussed the significance of the notion of agency and agents in interactive media arts. The prerequisite for interaction is agency, for both sides of the interaction. Penny describes interaction as "involving two (or more) agents engaged in ongoing, dynamical exchanges" and argues that "the capacity for interactivity depends on the capacity for agent-like behavior on both sides" [3] and I proposed looking at media arts from the lens of agency. I argued that agency, in the context of interactive media arts, can be seen as a continuous spectrum—ranging from artworks that display agency via simple-reflex based responsive behavior to works that display complex behaviors that present high levels of autonomy. Following this thread, I proposed to use the notion of agency to construct a conceptual framework that can be used to contextualize, analyze, and synthesize a subset of media arts practices.

In order to do this, I looked at current *Agent-based Art* practices and their genealo-

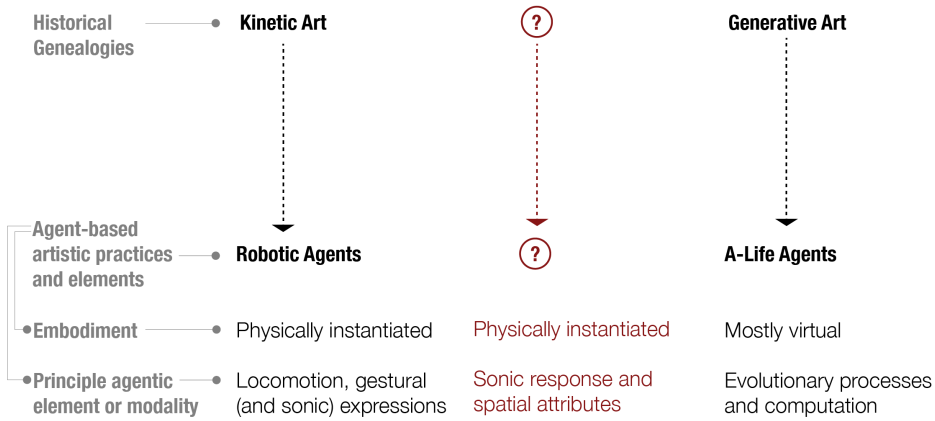


Figure 5.1: Most common agent-based art practices and their genealogies. "?" indicates the research problem.

gies. I defined *Agent-based Art* as an umbrella term for an art practice that is concerned with creating interactive artistic environments or artifacts, in which the major focus is perceived life-like qualities. I presented the most common forms of agent-based art practices as Robotic Art and A-Life Art. While both A-Life Art and Robotic Art are heavily influenced by cybernetics, their lineages as fields of practice can be tied respectively to Generative Art and Kinetic Art. Between these two, they encompass a large area of practice that comprises agents with physical bodies that can locomote—rooted in kinetic art practices—and agents with virtual bodies that are driven by overarching rules and marked by biological processes—rooted in generative art practices. This brings us to the research question: In depicting agency and designing agents, is there any space in between these two forms of art? **Can we conceive of an agent-based art practice with alternative genealogies and alternative ways of depicting agency—alternative ways that are neither robotics and motion based, nor dependent on virtual bodies that are confined to the screen or projection?** (Figure 5.1)

To reiterate, the research problem calls for an inquiry into a possible agent-based art practice which feature agents that: are life-like, are embodied and physically instantiated, that do not necessarily operate based on evolutionary processes, and that do not necessarily locomote. While such practices exist, they are scattered across a wide variety of broad contexts—such as sound art, sound sculpture, media arts or interactive art—and are not necessarily formalized, contextualized, or integrated within a firm conceptual framework. This dissertation, along with the accompanying artworks, are efforts to fill this lacuna. Here, my goal is to formalize such practices via defining their scope and lineage, as well as presenting examples and constructing a conceptual framework around them. To this end, in addressing the research question, I presented the *Sono-spatial Agent* practice, its genealogy, a conceptual framework around this practice, and the fruits of this practice itself—two artworks as case studies.

5.1.2 The definition, scope, and genealogies of *Sono-spatial Agent* practice

Sono-spatial Agents are rooted in sound installation art. They are physically instantiated artistic agents that rely on non-kinetic means to depict agency (Figure 5.2). These agents may or may not possess kinetic capabilities, and their agency is primarily rooted in their spatiality and sonority. With spatiality, the focus is on the configuration, formal, and material qualities of their morphology; with sonority the focus is on sonic expressiveness and responsiveness. *Sono-spatial Agents* integrate digitally designed and fabricated artifacts, sonic expressions, and interactive behaviors in order to create perceived life-like systems where the viewer enters and experiences the work in its totality. *Sono-spatial Agent* practice incorporates notions and tools from many design fields like architecture, parametric design, digital fabrication, speculative design, and sonic interaction design, and fuses these into a comprehensive integrated environment in order to depict agency. *Sono-spatial Agent* practice differs from both robotic agents and virtual A-Life (Artificial

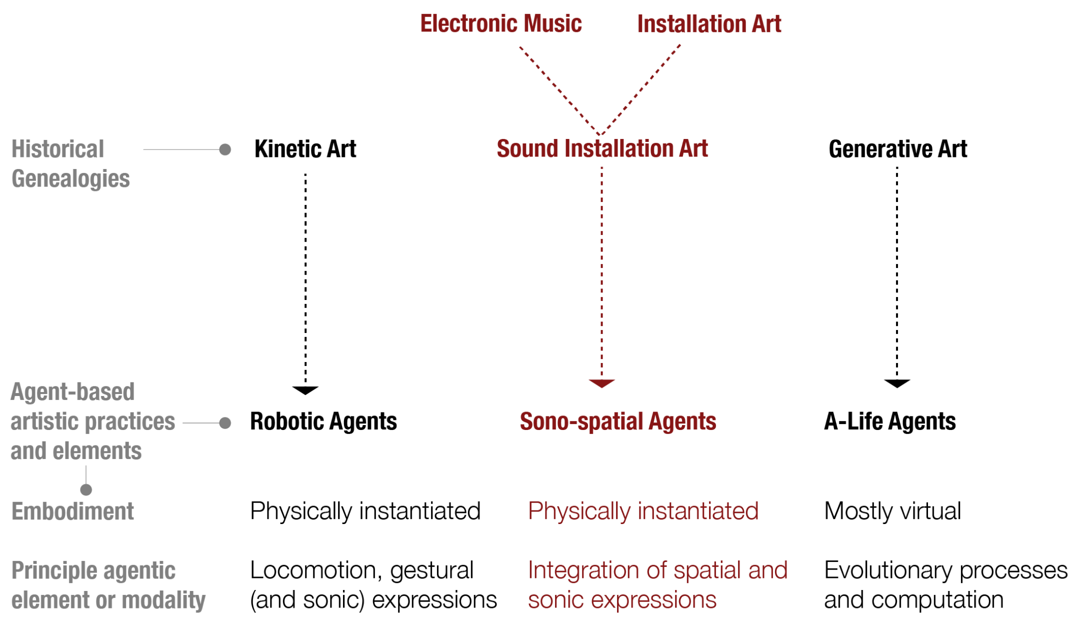


Figure 5.2: Situating *Sono-spatial Agent* practices and their genealogy.

Life) agents—the two most common agent-based practices—in that they neither rely on kineticism or locomotion to convey agency, nor are they confined to the boundaries of a screen.

5.1.3 The case studies: *HIVE* and *Cacophonic Choir*

The practice of devising and developing the interactive systems was central to this work. The case studies are the direct responses to the research questions. Both depict agency and afford complex interactions, as per our observations and as shown by their achievements in public dissemination, which are discussed at the end of the respective chapters.

The first case study, *HIVE*, was conceived of as a speculative organism that lives in a sonic *umwelt*. It has an algorithmically generated exoskeleton that houses multiple sound based sensors and speakers. By limiting its i/o to sound signals, we emphasize the importance of acoustic communication for the survival of certain organisms. Furthermore, via having the viewer activity impact on *HIVE*'s responses and the soundscape around it, we show how humans impact this soundscape.

The second case study, *Cacophonic Choir*, is an agent-based installation aimed at bringing attention to the first-hand stories of sexual assault survivors, and the ways such stories may be distorted by the media and in online discourse. The work is composed of nine embodied vocalizing agents distributed in space. Each agent tells a story. From a distance, the viewer hears an unintelligible choir of fragmented stories and distorted voices. As the viewer approaches an agent, the story becomes sonically clearer and semantically more coherent. When in the agent's immediate personal space, the viewer can hear the first-hand account of a sexual assault survivor.

I will discuss these case studies further and in the context of the conceptual framework in the upcoming sections.

5.1.4 The conceptual framework

In approaching agent-based media arts, I proposed a conceptual framework that is broadly founded upon an aesthetic fusion of sound and space, and that borrows concepts and tools from the design practices around them (Figure 5.3). The framework considers agency in two primary categories: material agency and sonic agency.

Material agency

Material agency is about formal, material, and configurational properties of objects and environments guiding and shaping our (inter)actions. It encompasses a spectrum of positions ranging from the view that (passive) artifacts have a significant role in determining the nature of agency to the view that the artifacts are agents themselves,

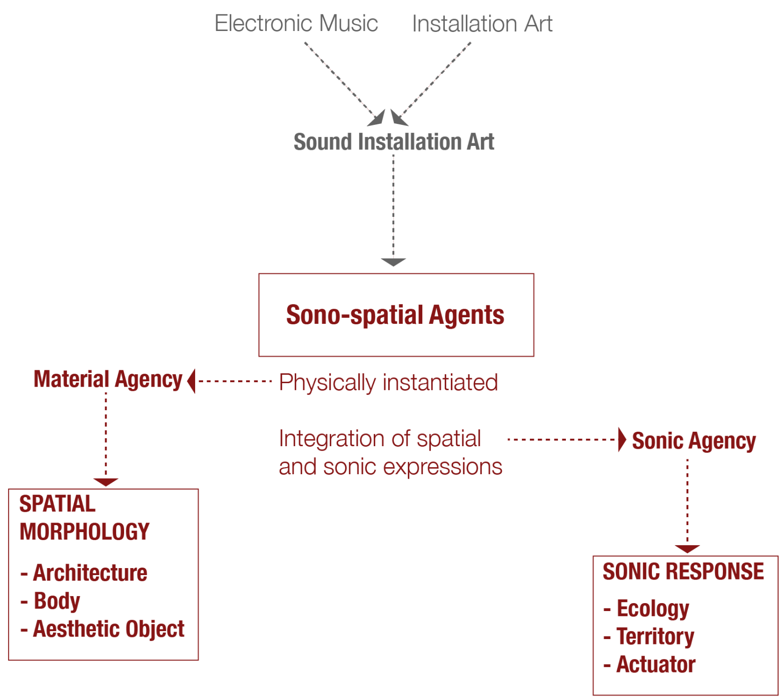


Figure 5.3: The conceptual framework

actively constructing or challenging social reality [72]. I proposed to found the material agency of *Sono-spatial Agents* on three key concepts: architecture, body, and aesthetic object.

Architecture

Through a fusion of physical and electronic elements, the spatial morphology of an agent can take on an architectural function, creating spaces, ecologies, and worlds in which the viewer and the agents cohabit. Here, the architecture—the configurations and spatial morphologies of agents and their environments—works in tandem with physical computing elements (i.e. sensors, actuators, microprocessors) in facilitating the creation of a world, a landscape, or a habitat.

Body

The morphology of an agent's body can strictly be intertwined with its hardware organization, and the software procedures in depicting agency. That is, an agent's body and its morphology can be designed to not only house its sensory-motor systems, but also can work together with the software systems to determine the control of the agent. Here, embodiment does not merely denote that the agent is equipped with a physical body, but is concerned with the ways in which that body mediates and enables its actions.

Aesthetic Object

The physical body of an agent can go beyond the electronic hardware assemblage and incorporate a sculptural materiality that acts as an aesthetic device in its own right. For example, it can reinforce the agent's quasi-biological status via biomorphic features, or its cultural status via anthropomorphic elements. An agent based artwork, can perform simultaneously as an aesthetic object and a behaving entity. Furthermore, formal aspects of agents directly impact how we attribute agency to them [81], [9]. In depicting agency, the form of the agent is equally significant as its function, or behavior.

Sonic Agency

The second primary category of the framework is sonic agency. Here, the sound medium is considered as an alternative (to physical movement) way to depict agency due its immense potential to convey space, motion, meaning, and emotion. *Sono-spatial Agents* fuse the notion of sonic agency in nature with culture to create rich interactive experiences that are primarily mediated via the sonic medium. In other words, this practice relies on an agency in which perception–action loops are mediated by acoustic signals. I proposed to found the sonic agency of *Sono-spatial Agents* on three key concepts: ecology, territory, and the actuator.

Ecology

Soundscape ecology, also defined as the set of the acoustic relationships between living organisms and their environment[91], can be a basis for aesthetics in *Sono-spatial Agents*.

Designing the sonic behavior such that it has conceptual undertones of a soundscape ecosystem can be a powerful way to depict agency and create life-like qualities in an agent-based artwork.

Territory

In addition to having spatial cues and carrying spatial information, through projection sound can be a medium for delineating space or establishing spatial relationships between the components of an installation based piece. Through modulating the spatial qualities of sound via interactive processes, we can create rich and powerful aesthetic experiences in which sound inscribes an interactive territory through its spatiality. Sound diffusion creates heterogeneities in space through waves, impulses, and rays. Although defined not through the traditional language of architecture—of walls and openings—but rather through sonic zones, intensities, and trajectories, this notion of space is very akin to that of a sculptor or an architect. Taking advantage of this kind of spatiality of sound diffusion can be carried over to *Sono-spatial Agents* creating architectures, habitats, and territories through interactive sound projection.

Actuator

Agency is broadly defined as the capacity of action and it is actuators that enable this action in the case of physically embodied agents. Typically, actuators are considered to be devices that induce motion and they are an essential part—the output—of any interactive system. In the context of art, the concept of an actuator—as it determines action and agency— need not be limited to a visible motion induction, but can be made of any modality that can help express the artistic agenda. Here, we can consider the loudspeaker as not merely a sound reproduction device, but also as an actuator, enabling response and action through expressiveness.

			Answers: Title of the Work	
Agency	**Key concept**	**Question**	**Strategy/ device**	**Affordance / agency**
Material Agency	**Architecture**	What kind of spatial configuration does this agent (do these agents) form?	(i.e. What devices or stragies are used in addressing the question?)	(i.e. What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?)
	Body	What are the ways in which the agent's body enables or mediates its actions?	...	...
	Aesthetic object	What are the ways in which the form and the appearance of the agent contribute to its agency?		
Sonic Agency	**Ecology**	What kind of sonic or behavioral relationship is created between the agent(s) and its (their) environment?		
	Territory	What kind of spaces/ territories do these agents form via sound projection/ diffusion?		
	Actuator	In what ways are the agents' bodies actuated by sound?		

Figure 5.4: Chart showing how the key concepts of the conceptual framework can be turned into questions that would help guide design efforts for future *Sono-spatial Agents*, or else help analyze the existing ones.

5.1.5 Framework applied

Here, I propose to turn these key concepts into a set of questions, the answers to which can help guide the design efforts of agent-based art projects. Figure 5.4 shows a chart where each key concept is accompanied by a related question. Two sets of answers are sought for each question. The first is about the strategy or the device that is used to address the question and the second is about how this strategy or device manifested itself in the affordances of the system and its perceived agency. I propose this as a system to guide further practice in this area—*Sono-spatial Agents*. What follows is a demonstration of how these set of questions can be answered in the context of the case studies—*HIVE* and *Cacophonic Choir* (Figures 5.5, and 5.6).

			Answers: HIVE	
Agency	**Key concept**	**Question**	**Strategy/ device**	**Affordance / agency**
Material Agency	**Architecture**	What kind of spatial configuration does this agent (do these agents) form?	Central/radial configuration	Prompts the viewer to walk around the agent and explore it from multiple viewpoints.
	Body	What are the ways in which the agent's body enables or mediates its actions?	Tightly packed horn-like inner structure creating waveguides.	Enables and shapes this creature's vocalizations. Allows for timbral and spatial transformations.
	Aesthetic object	What are the ways in which the form and the appearance of the agent contribute to its perceived agency?	Honeycomb inspired, curvilinear structure	Biomorphic features reinforce the agent's quasi-biological status
Sonic Agency	**Ecology**	What kind of sonic or behavioral relationship is created between the agent(s) and its (their) environment?	Uses the *Niche Hypothesis* as a conceptual guide.	HIVE has its own spectral, spatial, and timbral "niche", against a contrasting background soundscape.
	Territory	What kind of spaces/ territories do these agents form via sound projection/ diffusion?	16-channel audio system with a radial projection creating localized sound.	Allows the audience to recongize this as a defense mechanism; HIVE marking its territory.
	Actuator	In what ways are the agents' bodies actuated by sound?	(Localized) Sound image (point source) spirals around the agent.	Creates not only an impression of motion, but at the times pushes the audience away from HIVE's body and territory.

Figure 5.5: Chart summarizing how the questions based on the key concepts of the conceptual framework are addressed in the context of *HIVE*.

Material agency—ARCHITECTURE

Question: What kind of spatial configuration does this agent (do these agents) form? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: *HIVE* features a central/radial configuration. The agent is suspended at ear level with translucent filaments at the center of the installation. The sound projects radially, outwards from the agent.

  Affordances and agency: This configuration prompts the viewer to walk around the agent and explore it from multiple viewpoints—both visually and aurally. Ra-

			Answers: Cacophonic Choir	
Agency	**Key concept**	**Question**	**Strategy/ device**	**Affordance / agency**
Material Agency	**Architecture**	What kind of spatial configuration does this agent (do these agents) form?	Agents distributed in space with a grid configuration.	Allows for the spatial distribution of sound sources, hence the “cacophony” effect.
	Body	What are the ways in which the agent’s body enables or mediates its actions?	Translucent membrane encapsulating the rest of the body	Through light modulation, creates an effect, where the agent gradually reveals itself as one approaches.
	Aesthetic object	What are the ways in which the form and the appearance of the agent contribute to its perceived agency?	Complex curvilinear forms, reminiscent of ears or organs	The membrane and the organic form inside (or rupturing through) create biological undertones.
Sonic Agency	**Ecology**	What kind of sonic or behavioral relationship is created between the agent(s) and its (their) environment?	Modulation of sonic and semantic distortions of narratives in response to the viewer proximity.	About “media ecology”. Prompts contemplatation on how social and mass media may distort people's stories.
	Territory	What kind of spaces/ territories do these agents form via sound projection/ diffusion?	Spatial distribution of sound sources	Creates a wide sound image of a cacophonous zone of voices. Individual agents also clearly mark their territory.
	Actuator	In what ways are the agents' bodies actuated by sound?	Audio processing in response to the viewer’s proximity.	Allows agents to modulate the “stuttering effect” of their voices based on proximity of a viewer within a spatial range.

Figure 5.6: Chart summarizing how the questions based on the key concepts of the conceptual framework are addressed in the context of *Cacophonic Choir*.

dial sound projection allows the agent to create a layer of soundscape around its body—a spatial sound territory of sorts.

- ***Cacophonic Choir***

  Strategy and device: Agents are situated on ear-level pedestals distributed in space with a grid configuration.

  Affordances and agency: This spatial distribution of the agents allows for the spatial distribution of sound sources—hence the “cacophony” effect—while prompting the viewer to approach individual sources. As a spatial manifestation of the piece’s main concept, this configuration allows the viewer to experience the agents both in their entirety (as an integrated soundscape of murmuring, stuttering voices), and on the level of an individual, as one can walk through this soundscape and approach/ explore each agent individually.

Material agency—BODY

Question: What are the ways in which the agent's body enables or mediates its actions? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: The agent's body is made up of tightly packed horn-like inner structure creating multiple waveguides.

  Affordances and agency: Due to these design features, the body enables and shapes this creature's vocalizations. It creates timbral and spatial transformations. In addition, it filters and amplifies the sounds emanating from the embedded speakers, while channeling the sound waves outward creating a 360° divergent soundscape.

- ***Cacophonic Choir***

  Strategy and device: The agent's body is made up of a translucent membrane that encapsulates the hardware and the parametric form within, covering it like a veil.

  Affordances and agency: The transparency of the membrane allows for the visibility of the inside of the agent to be modulated by the proximity via using a light source inside the membrane. This creates an effect, where the agent gradually reveals itself as one approaches.

Material agency—AESTHETIC OBJECT

Question: What are the ways in which the form and the appearance of the agent contribute to its perceived agency? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: *HIVE* features a honeycomb inspired, curvilinear morphology. It is reminiscent of a shell or an exoskeleton.

  Affordances and agency: These biomorphic features reinforce the agent's quasi-biological status and its attributed agency.

- ***Cacophonic Choir***

  Strategy and device: Each agent features a complex curvilinear form, reminiscent of ears or organs. These are embedded in or rupturing through a translucent membrane.

  Affordances and agency: The membrane and the organic form inside (or, rupturing through) create biological undertones, evoking imagery of birth or growth, alluding to a womb, or a cocoon.

Sonic agency—ECOLOGY

Question: What kind of sonic or behavioral relationship is created between the agent(s) and its (their) environment? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: *HIVE* uses the *Niche Hypothesis* [88] as a conceptual guide.

Affordances and agency: *HIVE* has its own spectral, spatial, and timbral "niche" in its vocalizations, against a contrasting background soundscape, which we regard as its "environment"—as created by the external quadraphonic sound projection located at the periphery of the installation space. It is only when humans are present and their voices and activities bleed into the "environment" that HIVE starts altering its vocalizations and the system begins to "destabilize", mimicking the anthropocenic destruction of the natural soundscape ecologies. This allows the viewer to clearly hear the differences between the agent and the environment that it is a part of, and contemplate on their own actions in regards to this equilibrium.

- ***Cacophonic Choir***

  Strategy and device: The agents modulate their narratives in response to the viewer proximity creating semantic distortions.

  Affordances and agency: Here, the "environment" is taken as a broader concept, as opposed to the immediate sono-spatial context of the agent. As such, *Cacophonic Choir* is directly about "media ecology", which looks into "what roles media force us to play, how media structure what we are seeing or thinking, and why media make us feel and act as we do" [121]. The semantic and sonic distortions of the agents' narratives, in response to the proximity of the viewer, allows the viewer to contemplate on how social and mass media may cause the individual's stories to be distorted and ridiculed.

Sonic agency—TERRITORY

Question: What kind of spaces/ territories do these agents form via sound projection/ diffusion? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: The 16-channel audio system with a radial—outwards, instead of inwards—projection, sonically covers the entire surrounding area of *HIVE*, creating a spatial (localized) sound image.

  Affordances and agency: This allows the audience to recognize this as a defense mechanism; *HIVE* marking its territory, like a sonic structure, a sonic fort that it builds around itself—a mound in sound.

- ***Cacophonic Choir***

  Strategy and device: The sound sources are distributed in space.

  Affordances and agency: The spatial distribution of sound sources create a wide sound image of a cacophonous zone of voices that the agents altogether create. In addition to this, individual agents also clearly mark their territory by the modulation of digital audio parameters. This further enhances the impression of tensions between private and public spheres.

Sonic agency—ACTUATOR

Question: In what ways are the agents' bodies actuated by sound? What kind of affordances does this create? How does this directly or indirectly contribute to its perceived agency?

- ***HIVE***

  Strategy and device: *HIVE* features spatial audio with a localized sound image (point source) that can spiral around the agent, and move in and out of the agent's body.

Affordances and agency: This creates not only an impression of motion, but at the times pushes the audience away from *HIVE*'s body and territory. Sound creates motion and animation around this inanimate object, bringing it to life.

- ***Cacophonic Choir***

  Strategy and device: *Cacophonic Choir* employs a strategy, where different levels of granular processing of speech audio responds to the viewer's proximity.

  Affordances and agency: This allows agents to modulate the "stuttering effect" of the agents' voices based on proximity of a viewer within a spatial range. This is arguably the most crucial aspect of the piece, since it determines the main method of interaction, in which the entire meaning unfolds.

5.1.6 Summary: Framework

The conceptual framework is distilled from the practice itself and is aimed at formalizing it. The key concepts from the framework are translated into a set of questions, the answers to which can help guide the design efforts of agent-based art projects. The framework is deliberately broad. This is because broad notions arguably have better ability to inspire art practice. This framework is offered as a first step in this area of practice. There is room for further research to more clearly delineate these concepts and add new ones.

5.1.7 Contributions

The objective of this dissertation is to expand upon agent-based art practices in two primary ways. First is to define a neglected subset of agent-based art that is informed by recent developments in several spatial and sonic design fields such as sonic interaction design, parametric design, and digital design and fabrication. Second is to introduce a novel conceptual framework that is aimed at a deeper understanding of agent-based art practices, their lineages, and theoretical underpinnings.

These are the five ways in which I expand media arts theory and practice:

- Define an area of agent-based art practice that is neglected in the existing literature as a field of practice in its own right.
- Describe a novel conceptual framework for understanding and evaluating agent-based art practices
- Present and discuss two major artworks by the author as case studies
- Provide a set of artistic strategies, devices, expressions distilled from these case studies
- Offer an evaluation and qualitative analysis on the case studies in light of the research question and the proposed framework

In summary, the dissertation explores the ways in which media artworks depict agency and convey life-like qualities. It contextualized and situated this subset of practices within the broader histories and theories of media arts.

5.2 Future work

For SIGGRAPH 2020, which took place virtually due to Covid-19 pandemic, we started developing a virtual version of *Cacophonic Choir* (Figure 5.7) using Unity, which we then also exhibited in IEEE Visualization Conference's Art Program '20. This is still a work in progress. In this virtual version, we used similar concepts and principles for interaction: the semantic and sonic coherence of the agents are modulated and spatialized

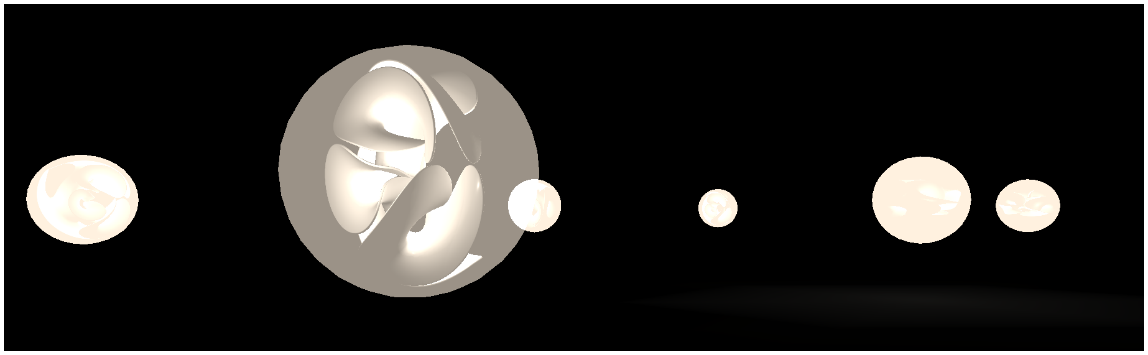


Figure 5.7: A virtual version of the work can be found at: `https://cacophonic.cs.colby.edu/`

by the distance the visitor is from them. As the visitor moves closer to an agent the membrane becomes more translucent, revealing the parametric form within.

The current version of the virtual environment reflects the original layout of the agents in the physical installation. Compared to the physical environment, a virtual environment inhibits certain affordances and also creates new ones. For example, while the virtual environment does not allow the act of walking and using our bodies, it is not bound by physical restrictions such as the scale and the number of agents. In virtual space, we can have any number of agents, and the agents can be of any size,; for instance they could be of the architectural scale, allowing the viewer to inhabit the shapes and explore the curves, the openings and the closures of this complex geometry.

While the virtual version of the work does not quite fit the description and the scope of *Sono-spatial Agent* practice, it provides a unique opportunity to observe some of the claims that I put forth in this dissertation. As an almost one-to-one translation of the work into the virtual realm, I have the opportunity to examine the ways in which agency might change between these two environments. Eliminating the physicality of the agents may give me a platform to inquire more accurately about the advantages of the physically instantiated work and material agencies.

All in all, *Cacophonic Choir* continues to evolve in both virtual and physical platforms. We will continue exhibiting this work both in the digital and physical modalities and we plan to study the differences in the way that visitors interact with the work virtually and in person.

For the overall *Sono-spatial Agent* practice, one direction could be to implement a granular aesthetic. *HIVE* is a single agent and a centralized system, whereas *Cacophonic Choir* has a distributed topology with nine agents. What could follow is thinking of each agent as a "pixel". As electronics and hardware get more powerful, cheaper, and smaller we can conceive of having thousands of these "pixels" with their own sensors, speakers, and processing units. One could conceive of these agents easily being fabricated via rapid prototyping and custom PCBs (printed circuit board) manufactured at an on-demand facility. The "pixels" could potentially self-organize (sonically), creating clusters and communities, complex sono-spatial images and ecologies. This granular aesthetic can also yield new expressions that could not otherwise be possible without such a great number of instantiations. These "pixels" can be organized and reorganized in space as a part of the user interaction, which introduces a tactile element to this type of practice that would open up new research possibilities.

Appendix A

Timeline of Achievements

2020 Exhibition: *Cacophonic Choir*, IEEE VISAP 2020 Art Gallery
(Collaboration with H.Wolfe and A.Bundy)

2020 Exhibition: *HIVE*, International Symposium on Electronic Art (ISEA) 2020 Art Gallery, Montreal, Canada
(Collaboration with H.Wolfe and A.Bundy)

2020 Award: "Best in Show" Award, by ACM SIGGRAPH, Art Gallery 2020
(Collaboration with H.Wolfe and A.Bundy)

2020 Exhibition: *Cacophonic Choir*, ACM SIGGRAPH, Art Gallery
(Collaboration with H.Wolfe and A.Bundy)

2020 Publication: S. Kiratli, H.E. Wolfe, and Alex Bundy, *Cacophonic Choir: An Interactive Art Installation Embodying the Voices of Sexual Assault Survivors*, *Leonardo* 53 (July, 2020) 446–450. Publisher: MIT Press.

2020 Publication: S. Kiratli, H.E. Wolfe, and Alex Bundy, *Cacophonic Choir* in *Proceedings ACM SIGGRAPH 2020 Art Gallery*, (pp. 457-457).

2019 Conference presentation: S. Kiratli, H.E. Wolfe, and Alex Bundy, *Cacophonic Choir*, conference presentation, *SOUND:: GENDER:: FEMINISM :: ACTIVISM (SGFA)*, (Tokyo, Japan), Tokyo University of the Arts, Oct., 2019.

2019 Exhibition: *Cacophonic Choir*, Contemporary Istanbul / Plug-in '19, Istanbul, Turkey
(Collaboration with H.Wolfe and A.Bundy)

2018 Exhibition: *HIVE* (interactive installation), CURRENTS New Media, El Museo Cultural, Santa Fe, New Mexico, USA
(Collaboration with A. Cadambi and ReTouch Lab)

2017 Exhibition: *HIVE*, ACM SIGGRAPH Asia - Art Gallery, Bangkok, Thailand (Collaboration with A. Cadambi and ReTouch Lab)

2017 Conference presentation: S. Kiratli and A. Cadambi, *HIVE: Explorations in Sonic Intelligence* in *SIGGRAPH Asia 2017 Art Gallery*, SA '17, (Bangkok, Thailand), Nov., 2017.

2017 Publication: S. Kiratli and A. Cadambi, *HIVE*, in proceedings *SIGGRAPH Asia 2017 Art Gallery*, SA '17 (Bangkok, Thailand), p.1, Association for Computing Machinery, Nov., 2017.

2017 Publication: S. Kiratli, A. Cadambi, and Y. Visell Y, *HIVE: An Interactive Sculpture for Musical Expression* in *Proceedings of New Interfaces for Musical Expression (NIME)*, (Copenhagen, Denmark), pp 267-270, Aaolborg University Copenhagen, 2017.

2017 Exhibition: *HIVE*, Santa Barbara Center for Art, Science, Technology (SBCAST), group show, "First Thursday", Santa Barbara, California, USA (Collaboration with A. Cadambi and ReTouch Lab)

2016 Exhibition: *HIVE*, Media Arts and Technology End of the Year Show, "White Noise", University of California, Santa Barbara, USA (Collaboration with A. Cadambi and ReTouch Lab)

2012 Award: Visual, Performing, and Media Arts Awards, Interdisciplinary Humanities Center, University of California Humanities Network

2012 Publication: A. Burbano A., D. Bazo, S. (Kiratli) DiCicco A. Forbes, *The New Dunites*, in proceedings *20th ACM international conference on Multimedia*, (Nara, Japan), pp.1501-1502, 2012.

2012 Exhibition: *The New Dunites* (interactive installation), ACM Multimedia - Art Gallery, "Eternal/Moment", Todaiji Art and Cultural Center, Nara, Japan (Collaboration with A. Burbano and D. Bazo)

2012 Exhibition: *The New Dunites: An Immersive Experience* (interactive immersive media), Allosphere New Media Research Facility, University of California, Santa Barbara, USA (Collaboration with A. Burbano and D. Bazo)

2010 Award: Artistic Production Incentives Grant, Vida 13.0, Fundación Telefónica, Spain

2010 Award: California-Centric Embedded Arts Research Grant in Social Ecologies, UCIRA (University of California Institute for Research in the Arts)

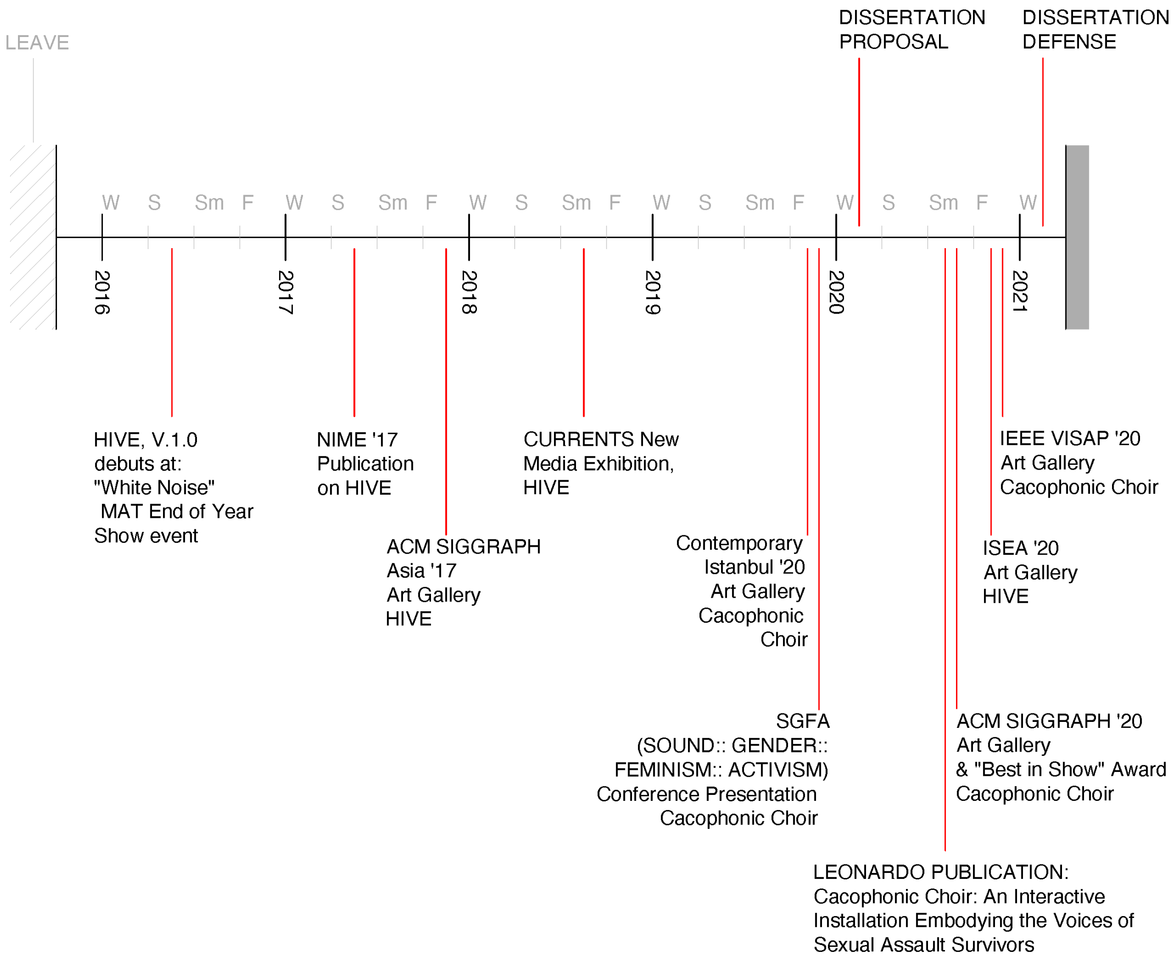


Figure A.1: The figure shows the PhD related achievements (2016-2021) in chronological order. It displays a quarterly break up. W: Winter, S: Spring, Sm: Summer, F: Fall

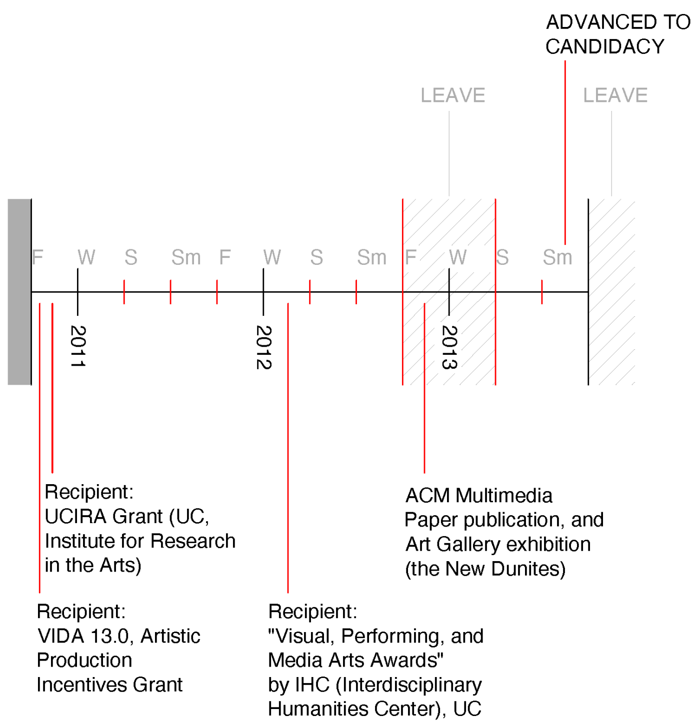


Figure A.2: The figure shows the PhD related achievements (2011-2013) in chronological order. It displays a quarterly break up. W: Winter, S: Spring, Sm: Summer, F: Fall

Bibliography

[1] R. Ascott, *Behaviourist art and the cybernetic vision*, *Multimedia: From Wagner to Virtual Reality* (1967) 95–103.

[2] S. Penny, *Agents as Artworks and Agent Design as Artistic Practice*, in *Human Cognition and Social Agent Technology* (K. Dauthenhahn, ed.), pp. 395–414. Amsterdam: John Benjamins, 2000.

[3] S. Penny, *Making sense: cognition, computing, art, and embodiment*. Leonardo book series. The MIT Press, Cambridge, Massachusetts, 2017.

[4] M. Schlosser, *Agency*, in *The Stanford Encyclopedia of Philosophy* (E. N. Zalta, ed.). Metaphysics Research Lab, Stanford University, winter 2019 ed., 2019.

[5] S. J. S. J. Russell, *Artificial intelligence : a modern approach*. Prentice Hall series in artificial intelligence. Prentice Hall, Englewood Cliffs, N.J., 1995.

[6] M. Mateas, *Expressive AI: A Hybrid Art and Science Practice*, *Leonardo* **34** (Apr., 2001) 147–153.

[7] M. Mateas, *Expressive ai: A semiotic analysis of machinic affordances*, in *3rd Conference on Computational Semiotics for Games and New Media*, p. 58, 2003.

[8] H. Limerick, D. Coyle, and J. W. Moore, *The experience of agency in human-computer interactions: a review*, *Frontiers in Human Neuroscience* **8** (2014).

[9] J. E. McEneaney, *Agency Effects in Human-Computer Interaction*, *International Journal of Human-Computer Interaction* **29** (Dec., 2013) 798–813.

[10] R. A. Wilson and L. Foglia, *Embodied Cognition*, in *The Stanford Encyclopedia of Philosophy* (E. N. Zalta, ed.). Metaphysics Research Lab, Stanford University, spring 2017 ed., 2017.

[11] R. A. Brooks, *Intelligence without representation*, *Artificial Intelligence* **47** (Jan., 1991) 139–159.

[12] P. Dourish, *Where the Action is: The Foundations of Embodied Interaction.* MIT Press, 2004.

[13] S. Penny, *Robotics and Art, Computationalism and Embodiment*, in *Robots and Art: Exploring an Unlikely Symbiosis* (D. Herath, C. Kroos, and Stelarc, eds.), Cognitive Science and Technology, pp. 47–65. Springer, Singapore, 2016.

[14] R. A. Brooks, *Intelligence Without Reason*, *Artificial intelligence: critical concepts* **3** (1991) 107–63.

[15] R. A. Brooks, *Elephants don't play chess*, *Robotics and Autonomous Systems* **6** (June, 1990) 3–15.

[16] R. Pfeifer, *How the body shapes the way we think: a new view of intelligence.* Bradford book. MIT Press, Cambridge, Mass., 2007.

[17] P. Dourish, *Embodied Interaction: Exploring the Foundations of a New Approach to HCI*, . 1999, unpublished, http://www.douri.sh/embodied/embodied99.pdf accessed: 2.27.2021.

[18] M. Costello, *Situatedness*, in *Encyclopedia of Critical Psychology* (T. Teo, ed.), pp. 1757–1762. Springer, New York, NY, 2014.

[19] H. Ishii, *Tangible bits: beyond pixels*, in *Proceedings of the 2nd international conference on Tangible and embedded interaction*, TEI '08, (Bonn, Germany), pp. xv–xxv, Association for Computing Machinery, Feb., 2008.

[20] S. Jordà, G. Geiger, M. Alonso, and M. Kaltenbrunner, *The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces*, in *Proceedings of the 1st international conference on Tangible and embedded interaction*, TEI '07, (Baton Rouge, Louisiana), pp. 139–146, Association for Computing Machinery, Feb., 2007.

[21] J. H. Kim and U. Seifert, *Embodiment and Agency: Towards an Aesthetics of Interactive Performativity*, in *Proceedings of the 4th Sound and Music Computing Conference*, pp. 230–237, 2007.

[22] S. Penny, *Embodied Cultural Agents at the Intersection of Robotics, Cognitive Science and Interactive Art*, in *AAAI Socially Intelligent Agents Symposium*, 1997.

[23] C. Sommerer and L. Mignonneau, *A-volve: a real-time interactive environment*, in *ACM SIGGRAPH visual proceedings*, pp. 172–173, 1994.

[24] H. Wolfe, *Embodied Technology: Human Machine Communication from the Media Arts Perspective.* PhD thesis, University, 2020.

[25] S. Audry, *Aesthetics of Adaptive Behaviors in Agent-based Art*, in *Proceedings of the 22nd International Symposium on Electronic Art*, ISEA '16, (Hong Kong), pp. 2–9, 2016.

[26] J.-S. Senécal, *Machines That Learn: Aesthetics of Adaptive Behaviors in Agent-based Art.* PhD thesis, Concordia University, 2016.

[27] M. A. Boden, *Artificial Life*, in *The MIT Encyclopedia of the Cognitive Sciences*, p. 37. MIT Press, Cambridge, Mass., 1999.

[28] *Art and Artificial Life—a Primer*, . unpublished, 2009, url: https://escholarship.org/uc/item/1z07j77x accessed: 06.10.2020.

[29] M. A. Boden and E. A. Edmonds, *What is generative art?*, *Digital Creativity* **20** (June, 2009) 21–46.

[30] G. Wakefield and H. Ji, *Artificial Nature: Immersive World Making*, in *Applications of Evolutionary Computing*, vol. 5484, pp. 597–602. Springer Berlin Heidelberg, Berlin, Heidelberg, 2009. Series Title: Lecture Notes in Computer Science.

[31] S. Penny, *Twenty years of artificial life art*, *Digital Creativity* **21** (Sept., 2010) 197–204. Publisher: Routledge _eprint: https://doi.org/10.1080/14626261003654640.

[32] C. Chau, *Movement, Time, Technology, and Art.* Springer Series on Cultural Computing. Springer Singapore, Singapore, 2017.

[33] F. Popper, "Kinetic art." `https://www.oxfordartonline.com/groveart/view/10.1093/gao/9781884446054.001.0001/oao-9781884446054-e-7000046632`, 2003. Accessed: 2020-06-17.

[34] J. Burnham, *Beyond modern sculpture: the effects of science and technology on the sculpture of this century.* G. Braziller, June, 1968.

[35] F. Popper, *Art: action and participation.* New York University Press, New York, 1975.

[36] E. Kac, *The Origin and Development of Robotic Art*, *Convergence* **7** (Mar., 2001) 76–86. Publisher: SAGE Publications Ltd.

[37] L. Pagliarini and H. Hautop Lund, *The development of robot art*, *Artificial Life and Robotics* **13** (Mar., 2009) 401–405.

[38] T. M. Pullen, *Whimsical Bodies and Performative Machines: Aesthetics and Affects of Robotic Art*, *Open Cultural Studies* **1** (Jan., 2018) 514–521. Publisher: De Gruyter Section: Open Cultural Studies.

[39] E. A. Shanken, ed., *Art and electronic media*. Themes and movements. Phaidon Press, London ; New York, 2009.

[40] R. P. D, PH, R. Packer, and K. Jordan, *"outlines of the Artwork of the Future, "The Artwork of the Future (1849)*, in *Multimedia: From Wagner to Virtual Reality*, pp. 3–9. W. W. Norton & Company, 2001.

[41] I. Macmillan, *Gesamtkunstwerk*, 2003. ISBN: 9781884446054 Library Catalog: www.oxfordartonline.com.

[42] R. Packer and K. Jordan, *Overture*, in *Multimedia: From Wagner to Virtual Reality*, p. xviii. W. W. Norton & Company, New York, 2001.

[43] E. Suderburg, *Space, Site, Intervention: Situating Installation Art*. U of Minnesota Press, 2000.

[44] M. M. Tinti, "Installation art in America." ISBN: 9781884446054 Library Catalog: www.oxfordartonline.com.

[45] J. Pallasmaa, *The eyes of the skin : architecture and the senses*. Polemics. Academy Editions ; Distributed to the trade in the USA by National Book Network, London : Lanham, MD, 1996.

[46] D. Reinhardt and J. Jakovich, *Trivet Fields: The Materiality of Interaction in Architectural Space*, *Leonardo* **42** (June, 2009) 216–224.

[47] J. Burnham, *Systems esthetics*, *Artforum* **7** (1968), no. 1 30–35.

[48] J. H. Frazer, *Parametric Computation: History and Future*, *Architectural Design* **86** (2016), no. 2 18–23.

[49] W. Jabi, *Parametric design for architecture*. Laurence King Publishing, 2013.

[50] A. Dunne and F. Raby, *Speculative everything: design, fiction, and social dreaming*. MIT press, 2013.

[51] M. Malpass, *Between Wit and Reason: Defining Associative, Speculative, and Critical Design in Practice*, *Design and Culture* **5** (Nov., 2013) 333–356. Publisher: Routledge _eprint: https://doi.org/10.2752/175470813X13705953612200.

[52] D. Rocchesso and S. Serafin, *Sonic Interaction Design*, *International Journal of Human-Computer Studies* **67** (Nov., 2009) 905–906.

[53] D. Rocchesso, S. Serafin, F. Behrendt, N. Bernardini, R. Bresin, G. Eckel, K. Franinovic, T. Hermann, S. Pauletto, P. Susini, and Y. Visell, *Sonic interaction design: sound, information and experience*, in *CHI '08 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '08, (Florence, Italy), pp. 3969–3972, Association for Computing Machinery, Apr., 2008.

[54] D. Rocchesso, *Explorations in sonic interaction design*. Logos Berlin, 2011.

[55] K. Rinaldo, *Trans-Species Interfaces: A Manifesto for Symbiogenisis*, in *Robots and Art: Exploring an Unlikely Symbiosis* (D. Herath, C. Kroos, and Stelarc, eds.), Cognitive Science and Technology, pp. 113–147. Springer, Singapore, 2016.

[56] M. Biggs, *The Routledge Companion to Research in the Arts*. Routledge, 1 ed., Oct., 2010.

[57] D. Lesage, *Who's Afraid of Artistic Research? On measuring artistic research output*, . *Spring* **2** (2009), no. 2 10.

[58] L. Candy and E. Edmonds, *Practice-Based Research in the Creative Arts: Foundations and Futures from the Front Line*, *Leonardo* **51** (June, 2017) 63–69.

[59] B. Krause, *Anatomy of the Soundscape: Evolving Perspectives*, *Journal of the Audio Engineering Society* **56** (Jan., 2008) 73–80.

[60] J. v. Uexküll, *A foray into the worlds of animals and humans : with A theory of meaning*. Posthumanities ; 12. University of Minnesota Press, Minneapolis, 1st university of minnesota press ed., 2010.

[61] S. Kiratli, A. Cadambi, and Y. Visell, *Hive: An interactive sculpture for musical expression*, in *Proceedings of the International Conference on New Interfaces for Musical Expression*, (Copenhagen, Denmark), pp. 267–270, Aalborg University Copenhagen, 2017.

[62] S. Kiratli and A. Cadambi, *HIVE*, in *SIGGRAPH Asia 2017 Art Gallery*, SA '17, (Bangkok, Thailand), p. 1, Association for Computing Machinery, Nov., 2017.

[63] S. Kiratli, H. E. Wolfe, and A. Bundy, *Cacophonic Choir: An Interactive Art Installation Embodying the Voices of Sexual Assault Survivors*, *Leonardo* **53** (July, 2020) 446–450. Publisher: MIT Press.

[64] S. Kiratli, H. Wolfe, and A. Bundy, *Cacophonic choir*, in *ACM SIGGRAPH 2020 Art Gallery*, SIGGRAPH '20, (New York, NY, USA), Association for Computing Machinery, 2020.

[65] C. Kelly, "Sound and art." `https://www.oxfordartonline.com/groveart/view/10.1093/gao/9781884446054.001.0001/oao-9781884446054-e-7000079882`. 2003, Accessed: 2020-08-11, ISBN: 9781884446054.

[66] A. H. Neset, *Expressway to yr, Cochlea*, in *Soundings : a contemporary score* (B. London, ed.). Museum of Modern Art, New York, New York, 2013.

[67] E. Varèse and C. Wen-chung, *The Liberation of Sound*, *Perspectives of New Music* **5** (1966), no. 1 11–19. Publisher: Perspectives of New Music.

[68] J. Chadabe, *Electric sound : the past and promise of electronic music.* Prentice Hall, Upper Saddle River, N.J., 1997.

[69] C. Bishop, *Installation art: a critical history.* Routledge, New York, 2005.

[70] B. LaBelle, *Background noise : perspectives on sound art.* Continuum International, New York, 2006.

[71] M. Joseph, "MoMA | MoMA Collects: David Tudor's Rainforest V (Variation 1)." `https://www.moma.org/explore/inside_out/2016/06/01/moma-collects-david-tudors-rainforest-v-variation-1/`, 2016. Accessed: 2020-08-12.

[72] C. Knappett and L. Malafouris, eds., *Material Agency.* Springer US, Boston, MA, 2008.

[73] M. Elshahed, *Tahrir Square: Social Media, Public Space*, *Places Journal* (Feb., 2011).

[74] J. Bentham and M. Božovič, *The panopticon writings.* Verso Trade, 1995.

[75] B. Latour, *A collective of humans and nonhumans: Following daedalus?s labyrinth*, *Readings in the Philosophy of Technology* **11** (2009).

[76] P. Beesley, "Hylozoic Ground, Canadian Pavilion Venice Biennale 2010." 2016 Exhibition catalogue, Electronic monograph, ISBN 978-1-926724-99-7, Library and Archives Canada Cataloguing in Publication.

[77] R. Gorbet and P. Beesley, *Arduino at work: the hylozoic soil control system the Hylozoic Soil control sytem*, in *Mobile Nation*, pp. 235–240. Riverside Architectural Press, Toronto, 2008.

[78] P. Beesley, "PORTFOLIO PHILIP BEESLEY." `https://docplayer.net/79026747-Portfolio-philip-beesley.html`. Online artist portfolio, Accessed: 7.15.2020.

[79] K. Rinaldo, *Trans-Species Interfaces: A Manifesto for Symbiogenisis*, in *Robots and Art: Exploring an Unlikely Symbiosis* (D. Herath, C. Kroos, and Stelarc, eds.), Cognitive Science and Technology, pp. 113–147. Springer, Singapore, 2016.

[80] J. Y. Lettvin, H. R. Maturana, W. S. McCulloch, and W. H. Pitts, *What the Frog's Eye Tells the Frog's Brain*, *Proceedings of the IRE* **47** (Nov., 1959) 1940–1951. Conference Name: Proceedings of the IRE.

[81] T. Komatsu and S. Yamada, *How Does the Agents' Appearance Affect Users' Interpretation of the Agents' Attitudes: Experimental Investigation on Expressing the Same Artificial Sounds From Agents With Different Appearances*, *International Journal of Human–Computer Interaction* **27** (Feb., 2011) 260–279.

[82] R. Morris, *Anti Form*, *Artforum International* **6** (1968), no. 8 31–36.

[83] L. R. Lippard, *Six years: The Dematerialization of the Art Object from 1966 to 1972.* Studio Vista, London, 1973.

[84] R. Gorbet, M. Memarian, M. Chan, D. Kulic, and P. Beesley, *Evolving Systems within Immersive Architectural Environments: New Research by the Living Architecture Systems Group*, .

[85] P. Beesley, *Hylozoic Ground, Liminal Responsive Architecture.* Riverside Architectural Press, Toronto, 2010.

[86] E. Stephens and T. Heffernan, *We Have Always Been Robots: The History of Robots and Art*, in *Robots and Art: Exploring an Unlikely Symbiosis* (D. Herath, C. Kroos, and Stelarc, eds.), Cognitive Science and Technology, pp. 29–45. Springer, Singapore, 2016.

[87] A. Farina, *Soundscape Ecology.* Springer Netherlands, Dordrecht, 2014.

[88] B. Krause, *Anatomy of the Soundscape: Evolving Perspectives*, *Journal of the Audio Engineering Society* **56** (Jan., 2008) 73–80.

[89] R. M. Schafer, *The tuning of the world /.* New York :, 1st ed. ed., 1977.

[90] B. Krause, *The great animal orchestra : finding the origins of music in the world's wild places.* Little, Brown, New York, 1st ed.. ed., 2012.

[91] B. C. Pijanowski, A. Farina, S. H. Gage, S. L. Dumyahn, and B. L. Krause, *What is soundscape ecology? An introduction and overview of an emerging new science*, *Landscape Ecology* **26** (Nov., 2011) 1213–1232. Company: Springer Distributor: Springer Institution: Springer Label: Springer Number: 9 Publisher: Springer Netherlands.

[92] J. R. Hugunin, *in::FORMATION: The Aesthetic Use of Machinic Beings*, *Leonardo* **33** (2000), no. 4 249–261. Publisher: [Leonardo, MIT Press].

[93] S. Penny, *Emergence, Agency, and Interaction–Notes from the Field*, *Artificial Life* **21** (2015), no. 3 271–284.

[94] T. Davis and P. Rebelo, *Environments for Sonic Ecologies*, in *Applications of Evolutionary Computing* (M. Giacobini, ed.), Lecture Notes in Computer Science, (Berlin, Heidelberg), pp. 508–516, Springer, 2007.

[95] U. Haque, *Evolving Sonic Environment*, in *Site of Sound: Of Architecture and the Ear Vol.2*, pp. 135–145. Errant Bodies Press, Berlin, 2011.

[96] C. Roads, *Composing electronic music : a new aesthetic*. Oxford University Press, New York, 2015.

[97] B. Leitner and U. Havemann, *.P.U.L.S.E.: Räume der Zeit / Spaces in Time*. Hatje Cantz, Ostfildern, Germany, 2008.

[98] B. Vorn, *I Want to Believe—Empathy and Catharsis in Robotic Art*, in *Robots and Art: Exploring an Unlikely Symbiosis* (D. Herath, C. Kroos, and Stelarc, eds.), Cognitive Science and Technology, pp. 365–377. Springer, Singapore, 2016.

[99] A. M. Turing, *On computable numbers, with an application to the entscheidungsproblem*, *J. of Math* **58** (1936), no. 345-363 5.

[100] M. Böhlen and J. T. Rinker, *Experiments with Whistling Machines*, *Leonardo Music Journal* **15** (2005) 45–52. Publisher: The MIT Press.

[101] P. Yoldas, *Speculative Biologies: New Directions in Art in the Age of the Anthropocene*. PhD dissertation, Duke University, 2016.

[102] P. Yoldas, "Ecosystem of excess, 2014." `https://pinaryoldas.info/Ecosystem-of-Excess-2014`. Online artist portfolio, Accessed: 09.23.2020.

[103] E. A. Abbott, *Flatland*. Perseus Publishing, Cambridge, Massachusetts, [1884] 2001.

[104] H. Bennet-Clark, *The mechanism and efficiency of sound production in mole crickets*, *Journal of Experimental Biology* **52** (1970), no. 3 619–652.

[105] L. Russolo, *The art of noise*. Something else press, 1913.

[106] "Grasshopper, a graphical algorithm editor for rhinoceros." `http://www.grasshopper3d.com/`. Accessed: 2021-01-14.

[107] R. M. . Associates, "Rhinoceros." `https://www.rhino3d.com/`. Accessed: 2021-01-14.

[108] E. W. Weisstein, "Circle Packing." `https://mathworld.wolfram.com/CirclePacking.html`. Publisher: Wolfram Research, Inc., Accessed: 02.14.2021.

[109] T. C. Hales, *The honeycomb conjecture*, *Discrete & Computational Geometry* **25** (2001), no. 1 1–22.

[110] G. Piacentino, "Weaverbird: A topological mesh editor (plug-in for grasshopper)." `http://www.giuliopiacentino.com/weaverbird/`. Accessed: 2021-01-14.

[111] J. Dinsdale, *Horn loudspeaker design*, *Reprinted from Wireless World* (1974).

[112] Autodesk, "Netfabb." `https://www.netfabb.com`.

[113] A. Cadambi, "Lithe: An object-based audio graph framework for spatial composition and sound design." `https://www.mat.ucsb.edu/Masters/Akshay_Cadambi_Masters_Thesis.pdf`, 2017.

[114] "The when you're ready project." `https://whenyoureready.org`. Accessed: 05.05.2020.

[115] M. Stubbs-Richardson, N. E. Rader, and A. G. Cosby, *Tweeting rape culture: Examining portrayals of victim blaming in discussions of sexual assault cases on Twitter*, *Feminism & Psychology* **28** (Feb., 2018) 90–108.

[116] S. O'Hara, *Monsters, playboys, virgins and whores: Rape myths in the news media's coverage of sexual violence*, *Language and literature* **21** (2012), no. 3 247–259.

[117] E. K. Carll, *News portrayal of violence and women: Implications for public policy*, *American Behavioral Scientist* **46** (2003), no. 12 1601–1610.

[118] S. N. Krivoshapko and V. N. Ivanov, *Minimal Surfaces*, in *Encyclopedia of Analytical Surfaces* (S. Krivoshapko and V. Ivanov, eds.), pp. 427–457. Springer International Publishing, Cham, 2015.

[119] J. Plateau, *Statique expérimentale et théorique des liquides soumis aux seules forces moléculaires*, vol. 2. Gauthier-Villars, 1873.

[120] S. Fujimori, S. Kobayashi, and W. Rossman, *Loop Group Methods for Constant Mean Curvature Surfaces*, *arXiv:math/0602570* (Dec., 2009). arXiv: math/0602570.

[121] C. A. Scolari, *Media Ecology: Exploring the Metaphor to Expand the Theory*, *Communication Theory* **22** (May, 2012) 204–225.

[122] D. C. Llach, J. L. Liu, Y.-C. Lee, H. E. Wolfe, K. Solen, A. Bundy, S. Brueckner, N. Mendoza, Pazera, D. Franusich, T. Klein, E. Polyak, Y. Katsumoto, J. Kuchera-Morin, A. Cabrera, K. H. Kim, G. Rincon, T. Wood, L. Demarest, S. Hong, H. Kim, S. Kim, B. Lee, and M. Breeze, *Mediating Public Space: Art and Technology That Goes Beyond the Frame Art Gallery*, *Leonardo* **53** (July, 2020) 455–473. Publisher: MIT Press.