The Sounds of Jean Tinguely:

Acoustic imaging as a tool for kinetic art conservation

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Evaluating Acoustic Imaging in Kinetic Art Conservation

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Abstract

Swiss artist Jean Tinguely created many moving art pieces, known as kinetic sculptures. These sculptures create unique soundscapes as they scrape against themselves, but this causes continual wear to the pieces. This IQP, sponsored by Empa and Haute-École Arc and in collaboration with the Museum Tinguely, aimed to evaluate the use of an acoustic camera, a device that can find the source of specific sounds. By using this camera to discern any new or altered sounds the sculptures create, we could suggest sites of wear to be investigated by conservators. This technique could be applied to kinetic art conservation as a whole, preserving these pieces for generations to come. We also created an exhibit for museum patrons that explains the potential role of acoustic imaging in art conservation.

Executive Summary

Jean Tinguely's art holds meaning and feelings from his life and environment. It conveys the situation in the world and in his life at the time that they were created and carry that forward into the present and the future. Conservators agree that these artworks should be preserved as they were when they were created so that future generations can remember Tinguely and have a window into his mind and world through enjoying his works. However, all works of art in the world tend to degrade over time. This simple fact has given rise to the extensive field of art conservation, which has developed into a science as much as an art. This project aims to add an element of science to the conservation of works by Jean Tinguely (1925-1991), a Swiss artist who created moving sculptures powered by electricity. These 'kinetic' artworks move and spin, each having their own unique structure, motion, and sound. One of the largest, *Grosse Méta-Maxi-Maxi-Utopia* (1987), can be seen in Figure ES1.

> "Every Tinguely [piece] who is laid to rest and they don't let them work anymore, it's another [part] of Tinguely who dies"
> **- Jean-Marc Gaillard**
> **Conservator, Museum Tinguely**

Figure ES1

Jean Tinguely's Grosse Méta-Maxi-Maxi-Utopia*, one of the largest pieces at the museum.*

The visual and auditory aspects of the pieces work together to create an atmosphere and instill meaning in the viewer. However, they also tend to change over time as the artwork degrades. As the pieces slide against each other or hit each other, they wear themselves down, until eventually the piece stops moving or the sound changes entirely. Conservators agree that these artworks should be preserved as they were when they were created so that future generations can enjoy the work of Tinguely.

The largest collection of Tinguely's works is in the Museum Tinguely in Basel, Switzerland. Conservators at the museum are specialized in the unique requirements of conserving Tinguely's art. Every day, conservators walk through the museum and listen to the artworks, keeping track of any piece that has a new sound. Jean-Marc Gaillard, conservator at the museum and former assistant to Tinguely, says that he most often hears a change in an artwork before he sees it. This experience-based subjective approach can be augmented with a technology known as acoustic imaging.

Acoustic imaging uses a special device called an acoustic camera to "see" sound. This camera can display a heatmap of where sounds originate from. We can point the camera at a sculpture and record high-fidelity data showing the location and intensity of any sound produced at a frequency between 0 and 20 kHz - roughly the range of human hearing. It does this by overlaying data gathered by an array of microphones onto the output of a video camera. In addition, we can utilize a program written in MATLAB to generate spectrograms from the recordings that give a clear visual representation of the frequencies that each sculpture is generating.

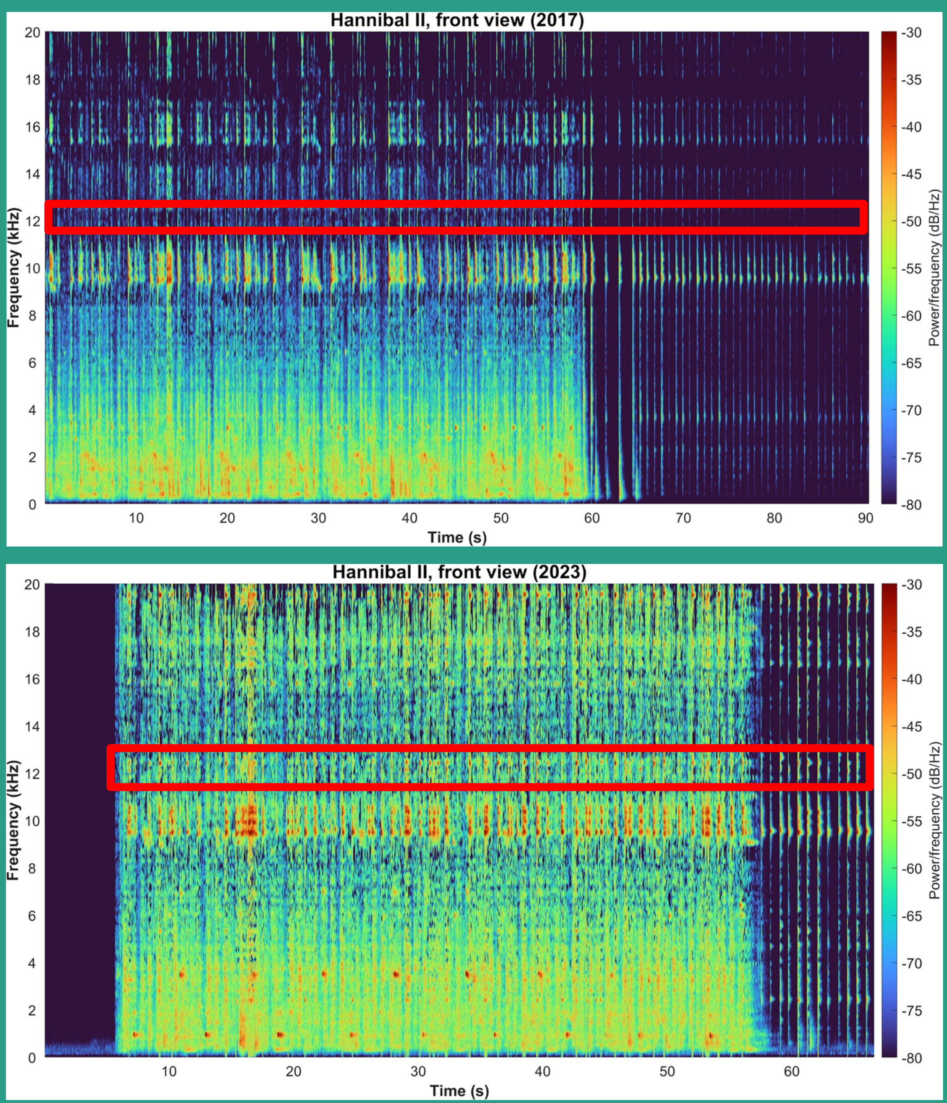
The goal of our project, which was sponsored by Rowena Crockett at the Swiss Federal Laboratories for Material Science and Technology (Empa) and Laura Brambilla at Haute-École Arc (HE-Arc), was to evaluate the applicability of acoustic imaging to the conservation of kinetic sculptures, and to create an exhibit that explains acoustic imaging technology and its use in conservation to the public. To accomplish our goal, we were provided with data of four sculptures taken by a 2017 WPI IQP. We compared the spectrograms of both sets of data, searching for any new or altered frequencies. When we found a change, we isolated that frequency in the BeamformX software to find out the source location of that frequency. This informed us that the piece had likely changed and would inform a conservator that they should investigate further and potentially take restorative action.

While recording and analyzing data, we also conducted key informant interviews with experts in the field. The goal of these interviews was to better understand the conservation of kinetic sculptures, and where the acoustic camera can fit in. We found these experts mainly through their relationship with the museum, and all were open to interviews. These interviews were conducted in a semi-standardized format to allow us to follow up on any points the interviewees brought up.

Through these procedures, we found multiple sites of altered frequencies. One was located in the sculpture *Hannibal II* (1969). The spectrograms in Figure ES2 show the audio profile of the sculpture as it runs. Highlighted in the red boxes is the 12.5 kHz frequency, showing the discrepancy between the 2017 and 2023 data. This difference means that the sculpture has likely changed in some way.

Figure ES2

Comparison of spectrograms created from 2017 and 2023 recordings of Hannibal II*. The 12.5 kHz frequency is shown with a box. See Appendix A for a guide on reading spectrograms.*



Isolating the 12.5 KHz frequency in the BeamformX software provides the image shown in Figure ES3. The two "hot spots" of sound are the chains on the left and the wheel and wooden "sword" on the right. The chains are very loud and are visible in most frequency bands. The wheel is an iron cylinder that rotates freely while the wooden sword slides along the top of it. This is meant to represent a soldier advancing across the Alps and then retreating. As can be seen in Figure ES4, this site is one where the sculpture has been wearing down. There is a significant groove present in the wheel.

Figure ES3

Acoustic camera recording of Hannibal II, *showing the sources of 12.5 kHz sounds. The wooden "sword" can be seen on the right above the heatmap overlay.*

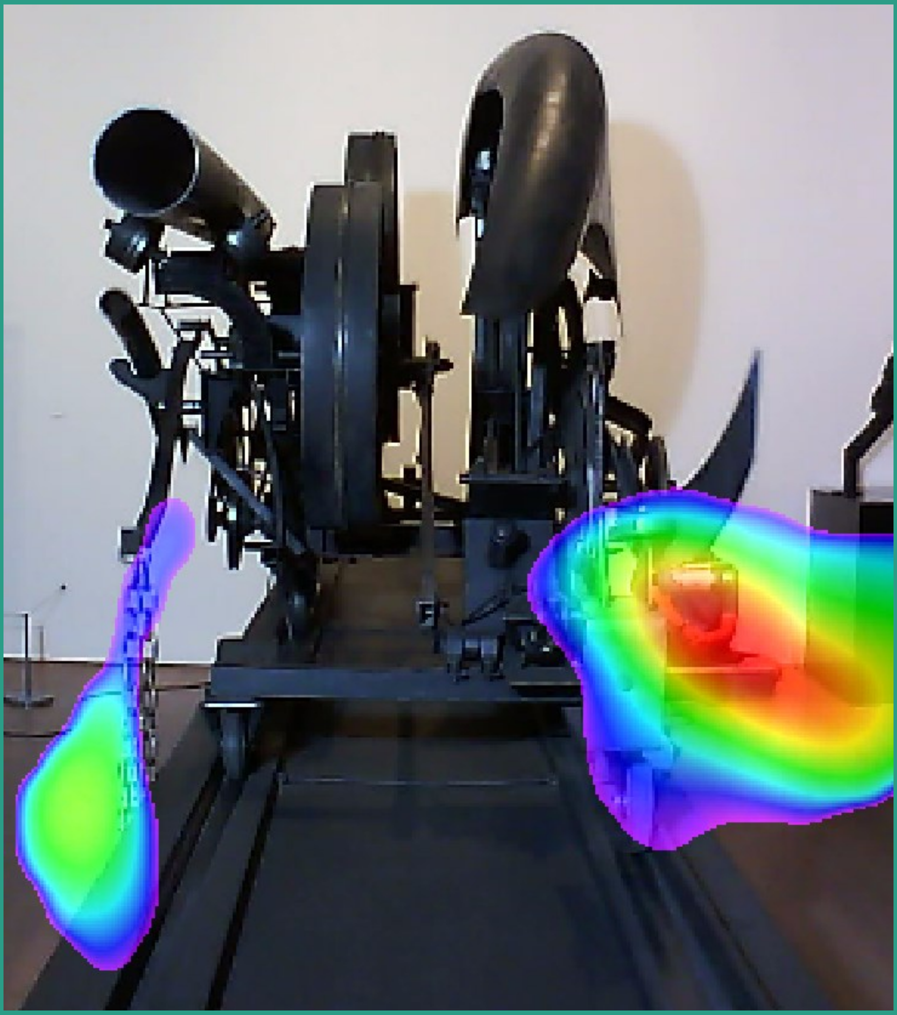
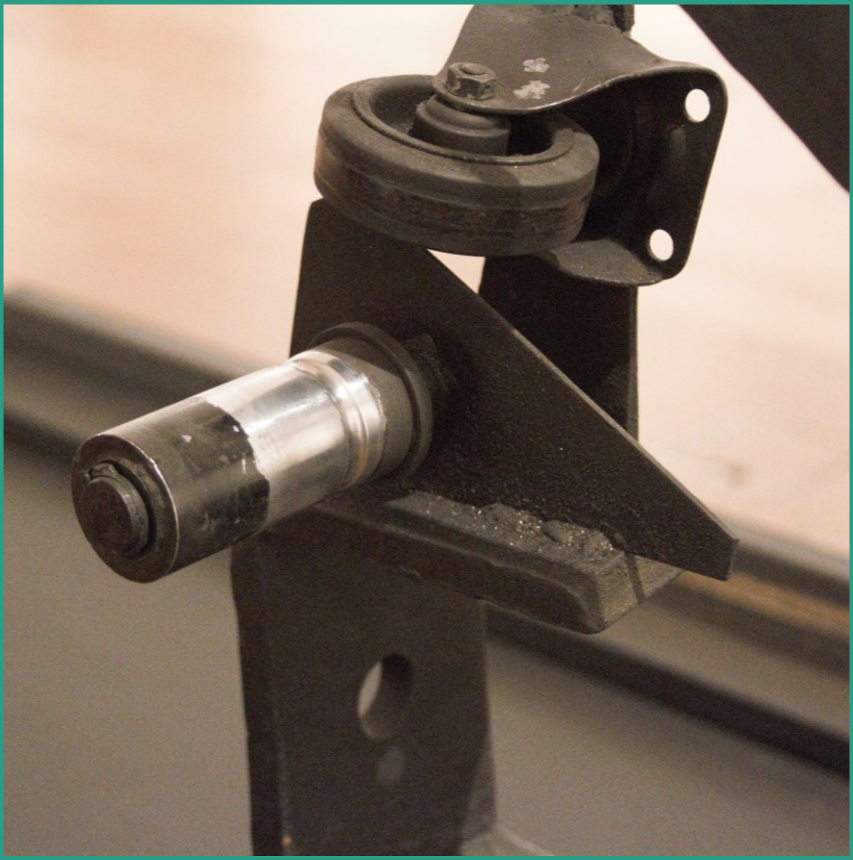


Figure ES4

Detail view of worn-down metal rolling cylinder in Hannibal II. *This cylinder makes contact with a wooden "sword" that slides across it.*



These findings show the potential of the acoustic camera to suggest sites of wear for conservators to investigate further. However, there are limitations to keep in mind. The acoustic camera being placed at a distance to the machine brings forward a few of these limitations. One is that it is susceptible to background noise in the room as well as sound reflecting off of walls or the floor. A large amount of background noise can mask important frequencies in the spectrogram and in the acoustic camera output, making it difficult to discern if there are any substantive changes. Additionally, the distance to the sculpture was not recorded for the 2017 data. This poses a potential problem as sound intensity decreases as it travels, reducing by about 6 dB for every doubling of distance traveled. However, we were able to match the view of our camera with that of the 2017 group in order to keep the distance as similar as possible. We are confident that we were not close to double the distance. A possible technique to mitigate these drawbacks is called acoustic emission, which involves placing sensors directly on the sculpture, but this technique was rejected due to strict limitations on physical contact with the art.

Museum conservators agree that the camera presents a novel way to document sculptures for the future, but there are several important steps that would need to be taken to fully evolve the acoustic camera as a conservation tool. These are:

1. Establish a standardized procedure for making acoustic recordings and spectrograms,
2. Devise a long-term plan for regularly taking acoustic recordings and storing them in an accessible way,
3. Replace or upgrade BeamformX with a more stable acoustic analysis software,
4. Research more objective means of determining the rate of wear of parts, and
5. Acknowledge the strengths conservators bring by being able to listen to and watch sculptures for detecting potential problems.

With these recommendations in mind, the acoustic camera is poised to be a useful new tool in the field of kinetic art conservation. The tool can be used to keep detailed records far into the future, as well as to assist in detecting wear. In order to show these benefits to the public, we created a video to be presented in the Museum Tinguely. This video showcases the operation of the acoustic camera, with the goal of educating the public on the need for conservation and how this tool can fit in. The video can be viewed here: https://youtu.be/wy-il4GCx_8. The video also served as a proposal to the museum on how they could use the acoustic camera to help better conserve the artworks. Given that some of the museum's conservators are due to retire soon, it is imperative that new processes be considered to aid new conservators in their efforts. If the Museum Tinguely decides to adopt acoustic imaging to supplement the expertise of conservators and develops a protocol for data collection from the sculptures, it would be a powerful tool for them to document the sculptures' current state and identify signs of deterioration as time goes by.

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Authorship

Note: All sections were edited by the full team through group meetings and comments. This work is original to the project authors and study participants and was not generated or assisted using ChatGPT or any other AI tools.

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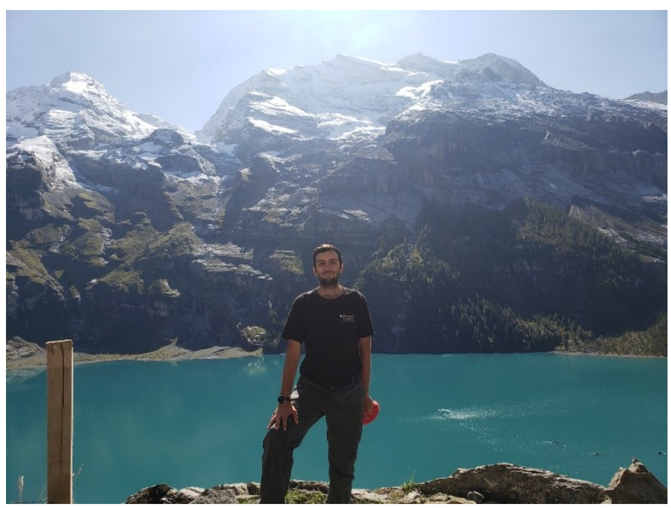


Grüezi! My name is Mark Caleca and I am originally from Queens in New York City. As a Junior at WPI, I study Robotics Engineering. Throughout the school year, I participate in the Robotics Engineering Honor Society Rho Beta Epsilon, the Alpha Chi Rho Fraternity, and the Information Technology Service Desk as a Lead Specialist, in addition to other extracurriculars. I took my adventurous spirit with me to Switzerland and hiked several of the country's panoramic mountains and the Alps. While completing IQP, I learned new perspectives in a variety of interviews with experts and professionals, gained hands-on experience working with and analyzing the efficacy of acoustic cameras, and collaborated with my team on this report. I gained many important skills during IQP from working with teams to meeting goals with sponsors that I will take with me in the future.

Emma Pollak

Hallo! My name is Emma Pollak. I'm studying Robotics Engineering and Computer Science and I'm originally from Concord, New Hampshire. Throughout this project, I enjoyed getting the opportunity to interview experts in the field. Their experiences and knowledge are deep and fascinating. This project has helped me greatly to build my communication skills through working with the team and in talking to interviewees.

Nicolás Mejía Muñoz

Hallo alles, I'm Nico, an Electrical Engineering student originally from Bogotá, Colombia. This project was really interesting to me because of its combination of data analysis and signals processing with art conservation, which are fields I'm very interested in. I very much enjoyed being able to work with art museum staff as well as the artworks themselves. Visiting Switzerland was also an excellent time, and being able to take a train to anywhere in the country was perfect for weekends. I really enjoyed also being able to practice my German. The IQP allowed me to hone in my teamwork skills and communicate with people in really interesting fields; I could definitely see myself looking deeper into art conservation as a graduate study field. I'm also part of the executive board for the Photography Club back on campus, so photographing scenes in and around Switzerland was a great experience.

Aquil·lí Rodríguez Plassa

Hello! My name is Aquil·lí Rodríguez Plassa. I'm a junior at WPI from Valls, Spain and I study aerospace engineering with a focus on astronautics along with a minor in astrophysics. The project I have been working on gave me a new perspective on the world of art. We have been researching restoration and conservation methods, something I didn't have previous knowledge about. It was interesting to argue with my teammates how far a restored artwork can be considered original and the thoughts of the experts on how conservation and restoration should be handled. One of our deliverables was to create a video explaining how an acoustic camera works and how it could help in the future of conservation. This allowed me to use some of the beginner skills I had with video editing as well as improve them. Additionally, I also learned valuable knowledge on how to plan and produce a professional video. Staying in Switzerland has been a wonderful experience, I have been using my free time to hike around the beautiful sceneries of the Swiss mountains as much as I could and explore remote villages and famous Swiss cities.

Acknowledgements

We would first like to thank Dr. Rowena Crockett at Empa and Dr. Laura Brambilla at Haute-École Arc. They both provided support and assistance throughout the project, giving helpful suggestions and constructive criticism. Dr. Crockett provided us with the acoustic camera so we could collect the data necessary for our project, as well as her knowledge of and connections with the Museum Tinguely. Dr. Brambilla assisted us by sharing her experience with kinetic art conservation and gave us some relevant papers to look into.

We greatly appreciate all the help provided by the Museum Tinguely in letting us analyze and record the sculptures. We would especially like to thank Jean-Marc Gaillard, conservator at the Museum Tinguely. Gaillard was a very gracious host to us at the museum, helping us with anything we needed and giving us access to him, his knowledge, and the museum. He assisted us by doing everything from turning on machines for us to allowing us to borrow studio lighting from the museum. Gaillard, along with all of our interviewees, provided a look into the world of kinetic art conservation that was vital for us, not only as a source for our paper, but to better understand what we are writing about.

We would like to express our utmost thanks to Heidelberg Instruments Nano AG for providing us a comfortable and accessible workspace for us to be able to work on our project. Special thanks to Emine Cagin, WPI alumna from 2003, for reaching out to us with this proposal and introducing us to the rest of the Heidelberg Instruments team to create a comfortable environment.

Finally, we would like to thank the WPI faculty that assisted us in this project. Our advisors, Professor Leonard Polizzotto and Professor Uma Kumar, were vital to keeping us on track and within the scope of our project. They also provided helpful and accurate revisions to drafts of this paper. We would also like to extend our gratitude to Professor Nancy Burnham, the director of the Zurich Project Center, for connecting us with our sponsors, as well as Dr. Curt J. Davis for his excellent guidance in the creation of our proposal during ID2050

Chapter 1. Introduction

Art is an invaluable element of culture around the world. It connects people through time, bringing the artist's feelings and wishes forward while transporting viewers back. To do that, however, it must stay the same. This is a challenge for any artwork, as every object degrades over time; paints can fade and parts can wear out. Conservators must decide when to intervene in a work's life and the best course of action for the art. Our project looks specifically at the conservation efforts undertaken to preserve art by Jean Tinguely, a Swiss sculptor, and how acoustic imaging technology can be a tool for conservators to use.

In 1944, Tinguely began to experiment with and produce a variety of dynamic, or kinetic, sculptures. These art pieces had complex mechanical workings and many moving parts. Tinguely produced a vast amount of these moving sculptures, using his art to comment on themes of overproduction and art in the modern era. The Museum Tinguely displays and preserves many of these works. However, after decades of exhibition, many of these sculptures show signs of wear or have stopped working. Museum conservators are constantly working to preserve the sculptures as best they can while keeping the experience of viewing the sculptures the same. This entails daily walk-throughs of the exhibits to take stock of the state of the sculptures and meetings between museum staff to determine the best method of conserving worn out pieces. To conserve the artworks, the conservators must be able to monitor wear in a non-destructive manner. Conservators use a variety of techniques to identify this wear; most commonly they use sound. According to Jean-Marc Gaillard, conservator at the Museum Tinguely, it is easier to hear the pieces wearing down than to find signs of deterioration visually (J.-M. Gaillard, personal communication, 2023). This opens the door to a potential technological tool in the form of acoustic imaging.

Acoustic imaging technology allows us to see the sounds that Tinguely's art makes and compare them objectively over time. This area is relatively unexplored in literature relating to art conservation, as Tinguely's sculptures are somewhat unique in art and techniques for conservation of them are still progressing. Art conservation has previously been united with science through materials science and other disciplines for the purpose of preserving paintings, and this technology provides another avenue for that (Muller, 2000).

Our project evaluated the condition of selected works of Jean Tinguely using acoustic imaging and created a cohesive exhibit using our research that explained to visitors how the sculptures changed over time. To accomplish this goal, our objectives were to:

1. assess current conservation and restoration methods available, particularly concerning kinetic sculptures, in order to better understand the possible application of acoustic imaging;
2. evaluate the acoustic dynamics of the current condition of a selection of Jean Tinguely's work and compare with past data to identify possible sources of wear; and
3. create a video explaining acoustic imaging functionality and its use to guide the preservation of the sculptures.

In this report, we will first provide an understanding of relevant information contained in literature through the background chapter. This chapter contains information on conservation, acoustic imaging, and exhibit creation. Then, in the methodology chapter, we show how we used that information and what research we conducted while in Switzerland. Finally, we conclude with the result of our project, and recommendations for how to continue our work and implement it in museums.

Chapter 2. Background

Jean Tinguely's art presents a unique problem for art conservators. The nature of the work as kinetic sculptures leads to their eventual degradation and wear, even more than traditional static art. This problem of how to conserve his art requires careful study of Jean Tinguely and his intentions, as well as conservation techniques and the philosophical dilemma of restoring or conserving an artwork. This information will be used to better evaluate the potential use of acoustic imaging as a tool for conservators. Additionally, this information can be valuable for the general public, so it must be understood how it can be best communicated. In the following chapter, we will discuss each of these considerations as well as introduce our project sponsors and stakeholders.

2.1. Jean Tinguely: "static with movement"

Before learning about art conservation and how we might contribute to it, it is important to understand the art itself and how it changes over time. This section details the life and history of Swiss artist Jean Tinguely (1925-1991), covering his artwork and style as it evolved. We then cover the potential issues with artwork, especially those created by Tinguely, in order to show the reasons why our work is needed.

Throughout most of his working life, Tinguely was known for his expansive kinetic (i.e., moving) sculptures, often commenting on themes like overproduction, industrial society, and art in the modern era (Tomkins, 1985). Although he was often grouped into the European Dada movement, eminent Dadaist Marcel Duchamp—as well as Tinguely himself—would refute this nomenclature. Tinguely would instead continue to operate without an attached label and draw the attention of the art world at large. For example, the 1961 exhibition "Art in Motion" at the Stedelijk Museum in Amsterdam, at which twenty-seven of Tinguely's machines were the main attraction, drew in record-breaking crowds at the Dutch art venue.

Born in Fribourg in 1925, Tinguely was trained as a window-dresser and graphic artist, but otherwise had no formal art training (Bek, 2004). While living in Paris in the mid-1950s, he began creating sculptures; his first kinetic pieces consisted of cogs built out of wire soldered together, and in 1954 he began experimenting with "reliefs": wall-mounted pieces mainly consisting of a solid-color background with moving parts cut from steel serving as the foreground (Isgro, 2020). Motors mounted on the back of the piece would move these parts. Sometimes, his art served as homages to past artists, such as Russian painters Kazimir Malevich and Vasily Kandinsky, as evidenced by his pieces *Méta-Malevich* (1954) and *Méta-Kandinsky* (1956), respectively. He built upon this usage of movement with his 1959 manifesto *Für Statik* (lit. "For Statics"), in which he states "everything moves, there is no standstill…. be in time, be static, be static with the movement…. stop building cathedrals and pyramids that crumble like candy" (Tinguely, 1959, para. 1).

Beginning in the 1960s, Tinguely moved away from these reliefs to machine installations intended to sit on a base and produce quicker movements than earlier wall-mounted pieces. These were first made only from scrap, but he later refined these pieces and often painted them black to underscore the importance of movement and sound over static form. Tinguely's work from this period makes a variety of noises, "... mak[ing] creaking noises as they wave their arms about, or they turn their large, brightly-colored wheels in silence, creating a kind of music that matches their rhythm and character" (Bek, 2004).

Figure 1

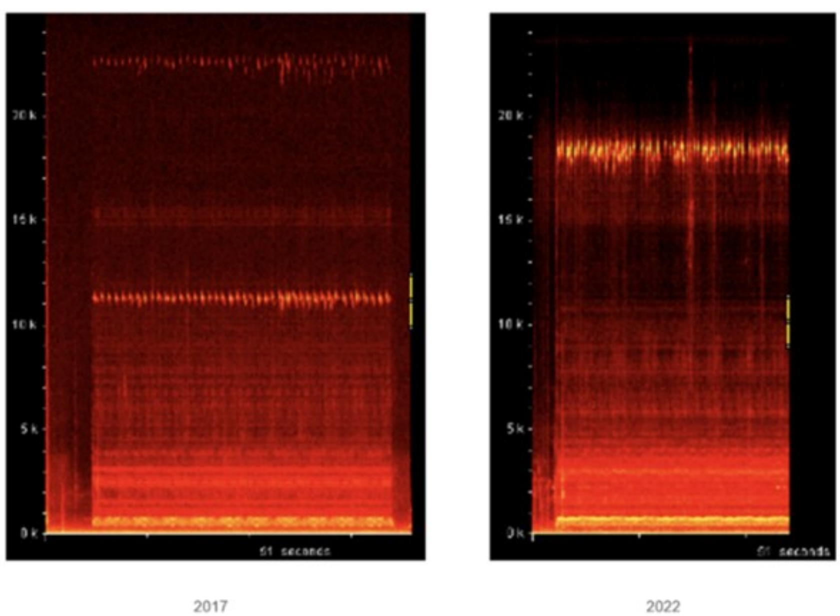
Jean Tinguely's Santana *(1966)*

Note: From WikiArt, 2013 (https://www.wikiart.org/en/jean-tinguely/santana-1966).

In 2022, a team of students from WPI working with the Museum Tinguely recorded a sonogram of *Méta-Kandinsky I* and found that the frequencies emitted by the machine's motion had significantly changed when compared to a sonogram taken five years earlier, as seen in Figure 2 (Bolshakov et al., 2022). The spectrograms are depictions of the volume across all of the frequencies over time. The brighter red sections correspond to frequencies (the y-axis) that are louder than the darker red areas. The figure shows that the loudest frequencies shifted between 2017 and 2023. The change in these frequencies is attributed to the emergence of the stick-slip phenomenon between two or more elements within the piece. This phenomenon occurs when two objects rub against each other due to friction and a force is applied to one of the objects. At first, the two objects are stationary relative to each other (the "stick" in "stick-slip"), but eventually the force overcomes the friction in the system, causing one of the objects to slide across the other (the "slip") (Casado, 2017). This phenomenon often causes a vibration that produces sound. A violin, for example, produces sound via the bow sticking and slipping across the strings when the instrument is played.

Figure 2

Spectrograms of frequencies emitted by Méta-Kandinsky I (1956) taken in 2017 (left) and 2022 (right)



Note: From *Developing a Relational Database of Approaches to Conservation of Functional Artifacts*, by Bolshakov et al., 2022 (https://digital.wpi.edu/concern/student_works/sq87bz219).

Researchers from the Swiss Federal Laboratories for Materials Science and Technology (Empa), as well as the Haute-École Arc (HE-Arc) in Neuchâtel, are interested in using acoustic cameras to further investigate this phenomenon. In particular, they want to compare past and present acoustic data as a method of detecting changes and potential wear in Tinguely's artworks. They would also like to increase public awareness of using acoustic imaging as a tool for assisting in art conservation. To achieve these goals, they have sponsored us to work with the Museum Tinguely on this project.

2.2. Empa, HE-Arc, and their involvement with the Museum Tinguely

The Museum Tinguely was founded in 1996 in the city of Basel, Switzerland, where Tinguely studied before moving to Paris (Museum Tinguely, n.d.a). Tinguely's widow, fellow artist Niki de Saint-Phalle, donated fifty of his works to begin the museum's collection. It possesses the largest collection of his works in the world and has a conservation department tasked with maintaining and restoring the movement in Tinguely's sculptures. It is financed by Roche, a Swiss healthcare multinational, and is housed in a building designed by renowned architect Mario Botta.

The Swiss Federal Laboratories for Materials Science and Technology (Empa) is a Swiss research institute in Dübendorf, Switzerland. The institute mainly focuses on materials science research and has in the past worked with the Museum Tinguely on research into anti-wear coatings for selected pieces at the museum (R. Crockett, personal communication, 2023). Dr. Rowena Crockett, who worked with the museum in the past, is a researcher at Empa who specializes in tribology, the study of friction and wear.

Haute-École Arc (HE-Arc) is a Swiss university with several campuses. Dr. Laura Brambilla, a professor and researcher at HE-Arc in Neuchâtel, Switzerland, currently specializes in studying wear and conservation techniques for cultural items, such as old automobiles or art pieces.

2.3. Key parties potentially benefiting from conservation research

This project's key stakeholders are the Museum Tinguely's visitors and conservation staff, as well as external figures like Empa and HE-Arc. Visitors and staff to the museum can learn about acoustic imaging and its use in the museum from the exhibit, and Empa can use it to advance their research related to Tinguely's pieces. Moreover, the museum can use our research to adjust and better define its approach to conserving Tinguely's work, as well as to use nondestructive evaluation (NDE) practices in order to better ascertain whenever restoration is needed. HE-Arc, as well as Empa, stand to gain from this project as some of their research lies in NDE and the project would serve as a practical application of such methods.

2.4. Current conservation and restoration strategies at the Tinguely Museum

Now that the interested parties have been established, we can expand on the problem of deterioration and the ways it can be mitigated. Art conservation is an established field with many experts that can be drawn from. There is a space in conservation for the application of acoustic imaging as a technology that allows art conservators to further their work and visualize otherwise unseen aspects of an artwork.

In the world of paintings, museums began to study and develop art conservation techniques in the early 20th century (Muller, 2000). However, there was little documentation of changes made to artwork and conservators largely learned from experience and were self-taught. Due to the need for art protection and conservation during World War II, conservators and restorers met in conferences to determine best practices for storing, protecting, and transporting works of art. This precursor to modern conservation was similar to the basics taught to modern art conservation students and led to increased interest in conservation after the war (Muller, 2000).

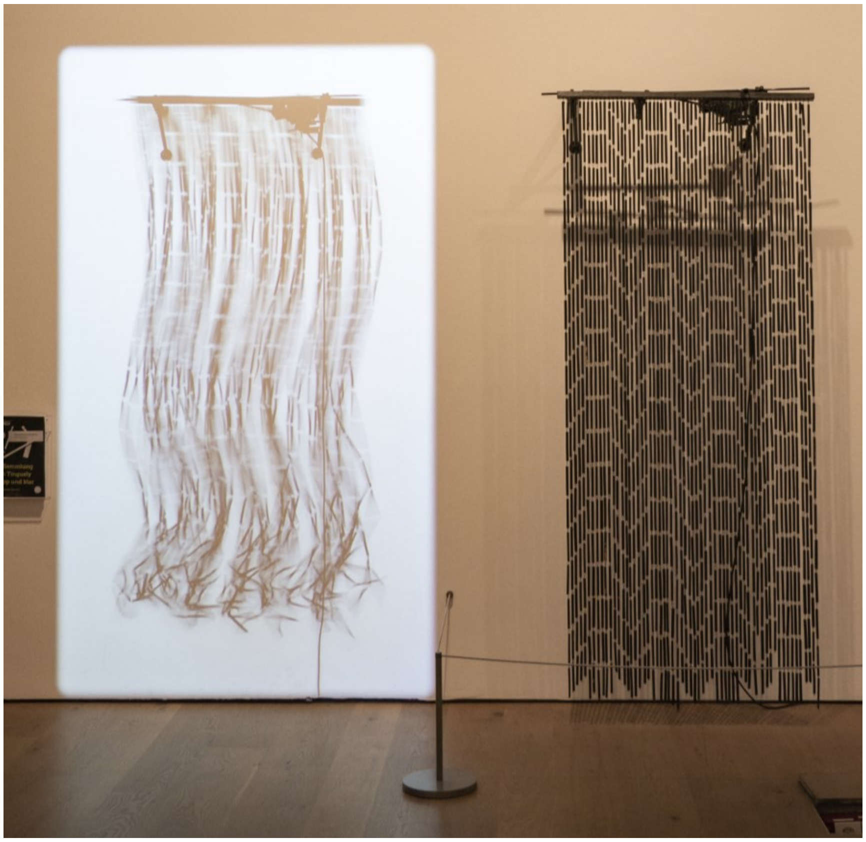
However, conservation and restoration are not clear-cut topics, as conserving or restoring an art piece requires subjective decision-making. Restorer David A. Scott (2017) says that restoration has been in humanity for thousands of years. However, the intent of restoration or conservation is mutable. For some, it is to keep the artwork exactly as it was when it entered the conservator's care. For others, it is to display the artwork as the artist intended. Yet others believe that art should be allowed to change over time. The Museum Tinguely (n.d.a.) purports that conservation is a balance of these three motivations.

The Museum Tinguely is uniquely positioned to benefit from conservation knowledge. Jean-Marc Gaillard, who currently works at the museum as a conservator, worked as Jean Tinguely's assistant prior to his passing (Museum Tinguely, n.d.a). Gaillard's approach to conservation had to shift when Tinguely died. Before Tinguely's death, they would work together to maintain the sculpture, replacing parts as they wore out or changing the design to make it function. In this style, they viewed the art as machines whose purpose was to function. The machine moving was more important than the composition of the piece remaining fixed. However, once Tinguely died, the museum shifted to a policy of attempting to freeze the art in time. They have preserved the works as they were when he died (Museum Tinguely, n.d.a). This process of preserving Tinguely's works is easier said than done, though. Reinhard Bek, who worked as a conservator for the Museum Tinguely, writes that "wear and tear is built into the works" (Bek, 2004, p. 46). This consideration must be taken when we build the final exhibit.

The Tinguely Museum employs several strategies to minimize strain on the aging sculptures. Most of the sculptures are operated with "mushrooms" (seen in red at the bottom right corner of Figure 1), which are large foot-activated buttons a visitor to the museum can press if they wish to see a specific piece move. These buttons close a circuit wired to each piece for a short amount of time, anywhere from 15 seconds to a minute. After this time has passed, a cooldown is built into the circuit where the visitor must wait around ten minutes to activate the piece again. This is indicated via an LED array on the button that goes from red to green. When the LED is green, the piece is ready to be activated. Moreover, bigger pieces like *Grosse Méta-Maxi-Maxi-Utopia* (1987) are turned on at specific times of the day, with a placard next to the piece informing visitors when it will next be functioning, usually every hour or two hours. Moreover, some pieces that have fully stopped working will have video representations of their movement projected next to them, as seen in Figure 3. These methods further illustrate the constant need for restoration efforts, as degradation has already caused pieces in the museum to stop functioning beyond repair.

Figure 3

Sculpture La Jalousie I *(1960) with video projection of its ordinary movement (left).*



The conservators at the museum must listen and observe very carefully to notice any aberrations in the operation. This requires experience to notice when a machine's auditory signature has shifted, and to know what fix to apply to prevent damage or further changes. It is also a highly subjective process, relying on conservators' opinions to decide if a piece sounds wrong. However, as time passes, it will become increasingly difficult for the museum to remember what the original sound of the machines was as conservators who were familiar with the pieces at the time of Tinguely's death, such as Gaillard, eventually retire from work at the museum. Additionally, the Museum Tinguely is highly specialized towards Tinguely's artworks. Through interviews with Gaillard and museum director Roland Wetzel, we have learned that other museums in possession of works by Tinguely come to the Museum Tinguely for assistance. Conservators in these other museums might have less time and experience to dedicate to works by Tinguely. The acoustic camera provides a way of creating an objective history of the artwork that can be used into the future for comparisons and thus for conservation.

2.5. Principles and use cases of acoustic imaging technology

It is important to understand the functionality of the acoustic camera in order to realize the limitations and opportunities it brings. In this section, we will discuss the basic operation, benefits, and drawbacks of the acoustic camera.

In principle, imaging is simply gathering and processing different types of waves to visualize an environment (Maev, 2013). Waves are emitted from objects and provide a way of transferring energy. For imaging, two useful forms of waves are electromagnetic and mechanical waves. Mechanical waves, including sound waves, are caused by a vibration or change in matter and require a medium through which to travel. In contrast, electromagnetic waves, including optical or visible light, can travel through a vacuum and are composed of perpendicular electric and magnetic fields emitted from a source. All waves have several similar properties, including wavelength (the distance between corresponding points on the wave), frequency (the number of cycles the wave completes in a given time frame), energy (the amount of work the wave can do), and ways that waves interact with other objects (reflection, refraction, and diffraction) (National Aeronautics and Space Administration, n.d.). Acoustic imaging allows the user to see the source of these sound waves overlayed on a regular video.

There are several types of acoustic imaging with a variety of purposes, such as ultrasonography and phased array imaging. One of the more well-known forms of acoustic imaging, ultrasonography, works by transmitting a sound wave at an ultrasonic frequency through a medium and recording the returned sound to create a sonogram - a visual image showing the different sound wave energies and frequencies (Maev, 2013). In contrast, phased array imaging uses multiple microphones to generate an image. The difference between using one microphone and using multiple means the acoustic camera can collect not only the level of noise generated, but also pinpoint the location of the sound. A sound propagation model can use the geometric shape of the microphone array to determine the originating location and magnitude of the sound (Merino-Martínez et al., 2019).

The first well-documented use of beamforming—the use of microphone arrays—was in World War I. To aid in the war effort, a hexagonal arrangement of inverted horns was implemented to detect the presence and direction of oncoming aircraft. Phased arrays were further developed and implemented with radar antennas in World War II. This technology later evolved into SONAR for locating submarines and even as “passive” sensors onboard submarines (Michel, 2006). Acoustic imaging further improved as hardware could support more microphones, a faster sampling frequency rate, a greater dynamic range of sound wave analysis, geometric optimization, and more computational power (Michel, 2006).

Unlike some sensors, acoustic imaging allows for less intrusive measurements that are typically more cost effective. Acoustic cameras have a variety of applications as a result, such as for engines and wind turbines. Importantly, they can be used to localize sound on both stationary and moving objects (Michel, 2006). One important aspect of acoustic camera functionality is the ability to specify the displayed frequencies. By inputting a frequency or frequency range, an acoustic camera can display only that range instead of the full frequency range of sound it picks up. This functionality is very useful for noninvasive monitoring. Asea Brown Boveri (ABB), a Swiss electrical and robotics equipment company, employs acoustic imaging and frequency seeking techniques to monitor the condition of their electric motors. By specifying which frequencies were often emitted by a malfunctioning electric motor as opposed to a healthy one, researchers at ABB were able to find which motors were malfunctioning by simply pointing the microphone array at a group of motors (Orman & Pinto, 2013). Similarly, acoustic cameras could be used to study the audio output of Tinguely’s machines to detect potential problems.

When using acoustic cameras, sound reflection and interference must be considered and accounted for. To gather useful data, the object in question or its surrounding environment may need to be “acoustically treated” (i.e. soundproofed) to reduce the amount of reflected sound (Merino-Martínez et al., 2019, p. 200). Otherwise, the resulting reflections could result in “phase and amplitude errors” that can render the data more difficult or impossible to work with (Merino-Martínez et al., 2019, p. 203). Design considerations also need to be made for signal-to-noise ratio, sampling frequency (typically twice the desired input frequency), microphone directionality, frequency range, and the sensitivity and dynamic range of the microphones (Merino-Martínez et al., 2019). A possible method to mitigate these factors is through a process known as acoustic emission testing, which involves placing microphones directly on the sculpture. This removes the problem of reflections in the room but comes with significant drawbacks. For one, it requires making physical contact with the sculptures, which is impossible for us to do. Another issue is that it requires significantly more time to set up and to collect data, which would be highly difficult in the short time that our group is able to visit the museum. For those reasons, the acoustic camera is the best choice for this application. However, Dr. Brambilla, one of the project's sponsors, is looking into utilizing acoustic emission technology with the museum in the near future. In addition, to effectively communicate these findings to the visitors of the museum, it is important to understand how to effectively share this information. This technical explanation is good for a research paper but would not work for the general public.

2.6. Science communication through museum exhibits

One of the anticipated outcomes of our project was to create a video explaining the role of acoustic imaging in detecting and analyzing how the sculpture is decaying. Therefore, it is essential to know more about museum exhibits and how to properly communicate the science of acoustic imaging in a way that is easy to understand for every museum visitor.

2.6.1. How does the human mind understand science?

To understand better how to communicate science, we find it important to analyze how the human mind understands new science concepts. When we are trying to understand a scientific concept for the first time, two phenomena occur: intuitions and psychological essentialism. Psychological essentialism is the process where we can create an idea of how something might function with little information (Blancke et al., 2018).

When learning about a scientific topic like acoustic imaging, people usually create some general intuitions of how or why acoustic imaging might function; most of these ideas are created mainly by past experiences. These intuitions serve as a crucial starting point for grasping the concept, as building upon correct intuitions can significantly aid in understanding. However, having an incorrect intuition about a concept could create difficulties in changing this initial idea. As intuitions are created with the small amounts of information a person has gathered, they are easier to learn and challenging to contrast without evidence (Blancke et al., 2018; Palomba, 2017). This information helped us understand how to better communicate science by understanding the complications of learning a complex science topic for the first time.

2.6.2. Types of visitors in a museum

There are many types of visitors to a museum, which can be categorized into three main groups. The first of which is the visitors who have something in mind that they want to see and therefore have a particular interest in seeing specific artwork. The second group would be the visitors who go to the museum without a clear idea of what to see. They might roam through the museum stopping only to admire the artworks that catch their eye. Lastly, we could define a third group of visitors, the “companions.” Companions are usually less interested in comprehending the artwork, and just like the second group, they will most likely roam through the museum. However, in this case, they will probably go over the artwork faster and wait in a quiet space for their family or friends to finish exploring the museum (Blancke et al., 2018; Borun, 1992; Palomba, 2017).

From this classification of visitors, only those with a motivation to see a specific artwork will want to read in detail any supplementary information accompanying the artwork. Therefore, in order for the information to reach the maximum number of visitors, it must be eye-catching, exciting, and brief (Palomba, 2017).

2.6.3. Communicating science to the public

A visit to the museum can be categorized as a type of informal learning (Borun, 1992). In 1992, Minda Borun, director of science education at the Franklin Institute Science Museum, conducted a study about a class of students going to the museum as a method of learning rather than taking a science class. It showed that instead of learning more material as they would probably do if attending class, the students had a clearer and better understanding of the scientific phenomenon taking place. The museum exhibit also positively affected the students’ motivation to learn more about what was shown (Borun, 1992).

Science in a museum is a form of education and entertainment. As a result, visitors to the museum, even the ones that want to study the artwork, want to learn more about it by putting in the least effort possible. To convey information effortlessly to visitors, the representation of additional information must be structured so that any visitor can easily absorb it. This additional information would likely be read by the visitors with more interest in the artwork and ignored by the most casual visitors. Therefore, this supplementary information should be clearly differentiated from the essential basic information. Doing this makes the basic information easier to read and allows all visitors to obtain a general and simplified idea about the artwork. In the case of showcasing the idea through text, one method to achieve this could be making the basic information stand out with a bigger font, color, or style and placed at the beginning of every paragraph (Borun, 1992). For a video, a good strategy would be to have an introductory part of the video about the general information but have interactive sections where the visitor can select to know more about the artwork.

Recall that everyone has their individual intuitions and assumptions about science, and the same is true for communicators explaining a phenomenon. Science communicators must be cautious in how they express their ideas. Using specific words that could mean more than one thing depending on perspective could cause the audience to be misguided. One clear example of this can be traced back to Darwin's theory of evolution. He used artificial selection as an analogy to explain his theory on natural selection to illustrate human evolution. However, the use of "natural selection" as a metaphor (precisely the word "selection") to explain his theory had a negative effect on some of the audience as they understood natural selection as a process in which nature chooses the best individuals; the same way as how artificial selection works (Blancke et al., 2018).

2.7. Case studies

To create the best project, it is also important to learn from past work. To accomplish this, we look at three previous publications that deal with relevant topics. In doing so, we also discuss their experience so that we may learn from their outcomes and shortfalls.

2.7.1. Case study 1: Scaffolding informal learning in science museums

Scaffolding is the material that supports the content that the students are meant to learn. A group of graduate students from the University of Pennsylvania conducted research in 2013 to study different scaffold methods that could be used to aid learning in science museums in conjunction with a previous study that utilized augmented reality devices that could enhance learning in a science museum.

To perform the research, they selected 307 students from middle school to learn about electric conductivity. They made the students complete an interactive activity related to electric conductivity followed by five different scaffolds.

The study concluded that the posted questions and collaborative groups were the best learning scaffold for young visitors. It is also mentioned that digital augmentations are helpful to visitors for conceptual learning, and a visual representation with augmented reality can help visitors understand the concepts of science in a museum and boost their interest (Yoon et al., 2013).

2.7.2. Case study 2: Metropolis II

Figure 4

An operator inside Metropolis II

Note: Adapted from Keep It Moving: Conserving Kinetic Art (chapter 3), by R. Bek and R. Rivenc, 2018, Getty Publications (https://muse.jhu.edu/book/74912). CC BY 4.0.

Metropolis II is a large dynamic sculpture created by Chris Burden in 2011. It features an expanse of buildings and tracks with cars and trains driving about. The maintenance of this sculpture is a laborious and involved task. There are 1,200 cars in motion at any given time, along with trolleys running between them (Bek & Rivenc, 2018). These must all be cleaned and checked for damage regularly. In addition to the cars, the tracks wear out over time. The conservators working on the piece regularly check for grooves in the track and analyze how they affect the cars. To plan for possible issues, they take precise measurements of track sections so that they can manufacture new parts to seamlessly replace worn out components (Bek & Rivenc, 2018).

The conservators found that preventative maintenance was highly important to maintaining a piece of moving artwork. This requirement for in-depth analysis and constant work requires a significant amount of effort from conservators. Bek and Rivenc (2018) write that museums often underestimate this need and fall short of properly conserving kinetic art. However, they also find it important to consider the intent of the artist when considering any maintenance actions.

2.7.3. Case study 3: Science exhibit on science stereotypes

The book *Turn on the Light on Science* written by Rosella Palomba (2017) narrates how to undo stereotypes about science and scientists by using their exhibits as an example. Their exhibit was composed of interactive activities for the visitors, meet and greets with scientists, and some video exhibitions explaining scientific processes. Their exhibit positively affected visitors in understanding science from a more casual point of view. Visitors' interaction with science-related activities helped them to break down some of the stereotypes they had about science and the figure of the scientist.

Furthermore, in the book, Palomba explains their methods to complete an exhibit appealing to all visitors. They mention that the exhibit should be placed where it is easy to access and catches the visitors' attention. One of the ways they achieved that was by having some of the videos on the screens roll and not pause until the visitor interacts with them. As a result, they managed to attract around 20,000 visitors in a limited number of hours. They learned that choosing the correct spot for setting up the exhibit was key for visitors to be attracted.

Additionally, they specifically mention that it is important when communicating science to state how and why a scientific phenomenon takes place (Palomba, 2017).

2.7.4. Case study 4: Acoustic imaging and machinery maintenance

A 2015 study, developed by gfai tech GmbH as well as Volkswagen AG, explores the potential use of acoustic imaging in an automotive production line with the end goal of facilitating machinery maintenance. Their team pointed an acoustic camera looking down on a specific machine in a section of the assembly line. The plant functioned as it normally would while these measurements were collected. Researchers found that after the machine finished pressing, a spectrogram of the data collected showed several irregular peaks that should not be visible under normal functionality of the press. When the frequencies responsible for said peaks were isolated in the acoustic camera's video output, the software showed that two specific areas generated this sound. Manual inspection of the highlighted areas revealed a faulty gear. After the gear was replaced, further acoustic imaging of the press no longer showed any irregular peaks. The researchers estimate that this acoustic imaging investigation, as opposed to shutting the plant down and performing inspection by hand, amounted to savings of around 250,000 euro. They also stress the practicality of the device's setup, saying:

> [The acoustic camera] is an easy to use system that can be set up quickly and is operable within a few minutes. It is not necessary (or even desired) to stop machinery or the whole production process. Down-times are avoided and the plant is fully operational at all times (Böck et al., 2015).

2.7.5. Case study takeaways

We took a few points away from these case studies. From the science museum exhibit, we learned an example of how we would structure our information to best communicate our topics. The article presented many ways that we could present our findings and background and gave useful comments on their effectiveness. Additionally, the example of *Metropolis II* presented additional context for conservation and restoration of kinetic art. They took a very involved role in maintaining the artwork, replacing parts frequently. However, the Museum Tinguely may not wish this for their art. This case study will prove useful to compare and contrast with our findings. From the third case study we learned that we would have to make sure to locate our exhibit in a place that is not close to a corner or that can be easily overlooked. From the final case study, we learned about techniques and applicability of the acoustic camera to industry. This shows that the acoustic camera is a proven technology that we can use for conservation.

2.8. Summary

The Museum Tinguely has a difficult challenge in conserving Tinguely's unique artworks. Their moving nature inherently leads to wear, which can at best alter the sound or visuals of the machine, and at worst bring it to a halt completely. As such, they require techniques to spot potential problems before they become catastrophic. As of now, those techniques are learned by conservators and passed down. However, as years pass, memories of the original artwork can fade. To counter this, the use of modern methods like acoustic imaging can aid in the preservation of these invaluable artworks. This process is complex, and the museum identifies the importance of educating its visitors on the difficulties of conserving work such as Tinguely's.

Chapter 3. Methodology

Jean Tinguely created three-dimensional kinetic sculptures that move when activated. The Museum Tinguely and our sponsors feel concerned that these movements cause wear to the artworks' components, which alter or break the original works. Therefore, there is a need to determine how these works of art are changing. The goal of our project was to evaluate the applicability of acoustic camera imaging to kinetic sculpture conservation and share the results of that evaluation with the museum-going public. To accomplish this goal, our objectives were to:

1. assess current conservation and restoration methods available, particularly concerning kinetic sculptures, in order to better understand the possible application of acoustic imaging;
2. evaluate the acoustic dynamics of the current condition of a selection of Jean Tinguely's work and compare with past data to identify possible sources of wear; and
3. create a video explaining acoustic imaging functionality and its use to guide the preservation of the sculptures.

This chapter details how we completed each of these objectives during our time in Switzerland.

3.1. Assess conservation and restoration methods

In order to better understand how to apply the acoustic camera, we needed to understand current conservation and restoration methods available, particularly concerning kinetic sculptures. As suggested by Bogner et al. (2018), we conducted key informant interviews with experts in the field, including three kinetic art conservators as well as the director of the Museum Tinguely, to get specific advice and knowledge, rather than the aggregate and general outcome of the literature review. We identified these experts through our sponsors and talking to staff at the museum. They have experience working with conserving art in general, as well as specifically with Tinguely's work, and were able to provide us with insight into the process and considerations. We gained entrée with them through direct email and through requests from our sponsors.

We conducted the interviews in a semi-standardized format and began with a set of questions tailored to the expertise of each interviewee (see Appendix F for interview guide), which enabled us to ask each informant to elaborate on their responses and thus ensured that we got a diversity of information and perspectives (Berg & Lune, 2012). This flexibility was key in discovering new areas of inquiry and uncovering topics that we did not think to ask about. Before the interviews, we reviewed the consent process, as required by the Institutional Review Board at WPI, and informed the interviewees of how we would use their responses and what we would share with whom (see Appendix G for the consent script). If they consented, we recorded the interview so that we could include parts of it in the exhibit, as well as to transcribe and reference it more easily. We securely stored the recording in a Google Drive folder that only our four group members had access to. Participants were informed that they could request to stop recording at any time and delete the video anytime during or after the interview.

We analyzed the information shared with us through the coding process. Coding allowed us to symbolize an idea and look for repetition of it across interviews (Saldana, 2016). This approach allowed us to compare and contrast techniques from various conservators and scientists and gave us the ability to build a complete picture of the current methods of art conservation. We also looked for unique viewpoints, opinions, and techniques as possible entry points for us to build on through research or follow-up interviews. At the conclusion of the project, we reached out to interviewees to share with them our results in our final IQP report. This allowed them to see what they contributed and how we used their knowledge.

3.2. Acoustic camera evaluation

In addition to conducting interviews with experts and a thorough literature review of existing kinetic sculpture conservation methods, we also evaluated the current condition of some of Tinguely's pieces through noninvasive acoustic imaging. The acoustic camera we used was the Signal Interface Group (SIG)'s ACAM 120, which was provided to us by Empa. This camera is equipped with OptiNav BeamformX software (R. Crockett, personal communication, 2023).

Dr. Crockett provided us with past data containing acoustic imaging of three of Tinguely's pieces through the ACAM 120 device taken in 2017 by a previous WPI IQP at different angles and distances. This data was sent in five files compatible with the BeamformX software so that we could visualize it on our computers. We used this past data as a baseline so that when we took our own measurements, we could compare and contrast changes in emitted frequencies over six years.

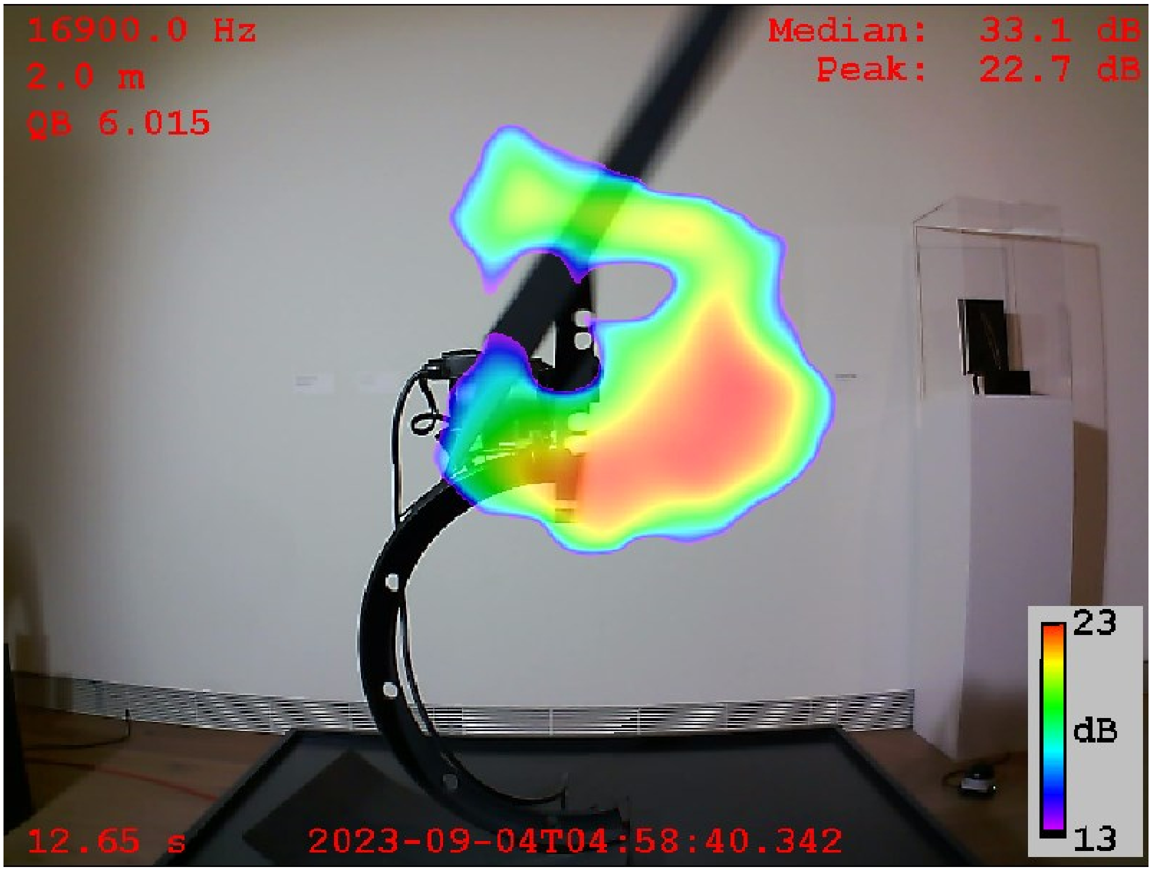
We felt it was important to learn what modifications, repairs, or attempts at restoration, if any, were made to the sculptures between 2017 and 2023. Changes to the sculptures may have affected their patterns of wear, so we needed to consider this when taking the data at the museum.

The ACAM 120, as with other acoustic cameras, is a passive device and thus does not emit any sound waves (or any other radiation, for that matter) and records at a distance. Appendix C contains an image and technical details of the camera. After analyzing past acoustic data provided to us, we identified patterns in the acoustic "heatmap" output we could compare with new data, such as the sound emitted by a specific component of a sculpture. We then pointed the camera at the selected sculpture and observed which segments were worn down and which were functioning properly by comparing our data with that of the museum. The museum granted us access to its premises on Mondays, when it is closed to the public, so that there was no interference from other visitors in our measurements and recordings.

We created recordings of the sculptures *Matrac* (1966), *Char MK* (1967), *Santana* (1966), and *Hannibal II* (1970) (see Figure 5). We ensured that the lighting of the acoustic imaging videos allowed the viewer to see specific components within the sculptures, as some files in the 2017 dataset are very dim and difficult to make out. The museum provided a studio light to assist with this, as well as a camera tripod to record regular video on a digital camera in addition to the acoustic imaging output. The regular video allowed us to stitch different takes together between visual and sound output so a museumgoer could understand what the acoustic camera is doing, as well as how measurements were taken.

Figure 5

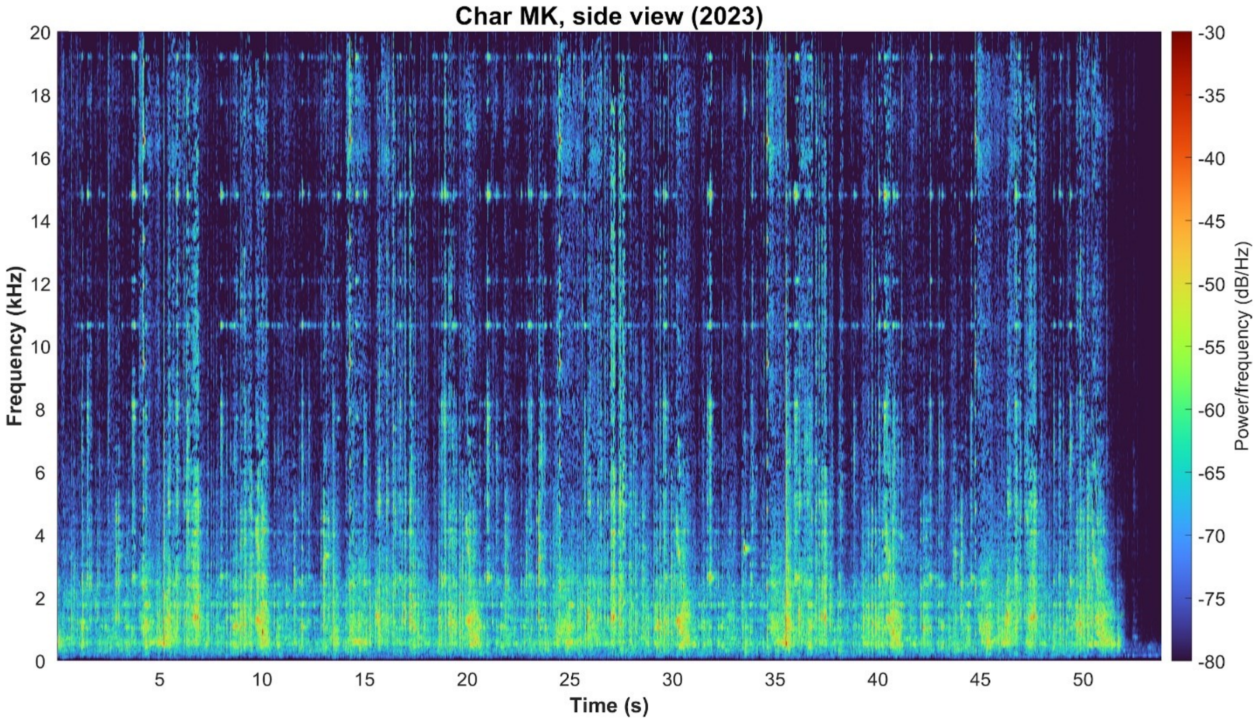
An example of the acoustic heatmap of the sculpture Matrac (1966) *generated by BeamformX as part of the gathered data.*



Videos taken with the acoustic camera are stored by the software as binary files, which the BeamformX software can read from and write to. In addition to the acoustic camera output, we also generated spectrograms of each of the recordings. To generate spectrograms from the acoustic imaging videos, the binary files were converted to MP4 video files using BeamformX. We were then able to isolate the audio tracks and generate spectrograms for each run using a script written by the team in the MATLAB programming language. An example spectrogram is shown in Figure 6. The purpose of these spectrograms is to give an overview of the sound produced by the sculpture as it runs. We compared the 2023 spectrograms to ones we produced from 2017 data to more quickly identify changes in frequencies that would be difficult to discern using the video alone. We isolated frequencies of interest in the BeamformX software to identify which element or elements of the sculpture were producing them.

Figure 6

An example of a spectrogram of the sculpture Char MK *(1967), generated with MATLAB. The figure relates the frequencies in kHz recorded by the camera vs time in seconds. The color shows the sound intensity at each frequency, per the color bar.*



Although acoustic imaging provides a noninvasive way to identify signs of deterioration in Tinguely's sculptures, acoustic cameras have several limitations due to their reliance on sound. Museum researchers alerted us that some sculptures may be difficult to study with the acoustic camera due to sound reflections off the wall (Brambilla & Crockett, personal communication, 2023). Due to the possibility of this becoming a significant problem for creating reliable, useful, presentable, and repeatable acoustic images and data, we looked into methods to reduce reflections and background noise and studied the feasibility of implementing these methods during our project. However, Dr. Crockett informed us that moving pieces into and out of a workshop would not be possible and that we would not be able to dampen the exhibition room. Sound reflections can also be easily visualized and ignored using the BeamformX software's Region of Interest (ROI) function. Ultimately, we concluded that it would be more beneficial to keep the environment as similar as possible between the 2017 data and our newly recorded data, and as such we decided not to use sound dampening.

The possibility of analyzing the sculptures with acoustic emission technology was also considered. Acoustic emission involves placing a sensor on the surface of the object and detecting how stress travels through it (Ohtsu, 2008). This is similar to a medical ultrasound, insofar as it serves as an imaging method that uses sound waves to generate an image. However, this is limited to monitoring structural faults in the sculpture such as physical cracks or fractures in its components, but this does not take into account general wear, such as gears being ground down. The use of acoustic emission was subsequently dismissed as a potential idea due to limitations around physical contact with the artwork, as very few people are cleared by the museum to directly touch the sculptures, much less attach monitoring equipment to them.

3.3. Creation of the video

The final goal of our work was to propose to the public and the museum an alternative in analyzing Jean Tinguely's artworks as well as showcasing the difficulties of conservation and restoration of kinetic sculptures. We created an exhibit with a goal of explaining the problem of degradation, the basics of acoustic cameras and how acoustic imaging can be used to identify this problem, along with the complexities of conservation and restoration of kinetic sculptures. To accomplish this, we decided that the video would showcase information about acoustic imaging and a demonstration of the use of the acoustic camera, followed by a conclusion on how acoustic imaging can help in the long term conservation of the sculptures.

We structured the video to include basic information about acoustic imaging and the use of the acoustic camera as a tool to evaluate the sculptures. We also showed the data we gathered as well as our method as an example to illustrate how acoustic imaging functions. Basic information about the acoustic camera and acoustic imaging was provided from our background chapter as well as our experience in using the acoustic camera.

Furthermore, our group was determined to create a professional video of high quality. Therefore, we performed a literature review by accessing sources we had gathered to learn how to produce a compelling video for a museum. These sources helped us learn tips and tricks on how to record a pedagogic video intended to explain the functionality of the acoustic camera as well as our experience of how we analyzed specific sculptures. Sources such as "The Exhibit," a website that publishes exhibitions online and offers advice for projects like ours provided us with information on how to produce a video for a museum. The literature review also included sources to help us learn how to edit a video. The video was edited with Final Cut Pro, a software with a license owned by one of the group members.

In the video, we needed to explain somewhat complex information. Because our objective is for the information to reach as many types of visitors as possible, we learned how to illustrate the data and explain complex information in a way that can be comprehensible for every visitor. To do so, we relied on our background chapter and used different sources we had gathered that clearly illustrated how to effectively communicate data and complex information simply.

Creating the exhibit was the last thing we worked on as all the information displayed came from beforehand expert interviews, data collection, and a literature review. Therefore, we considered the video itself a result of that work; further explanation on the procedure can be found in the result chapter. The exhibit can be considered the deliverable of all our work assessing the sculptures with the acoustic camera and our study of conservation and restoration methods and difficulties through expert interviews.

Chapter 4. Results and Discussion

The results of our work included key expert interviews, findings from our acoustic analysis comparing our data with that from 2017, and the creation of the video for the museum.

4.1. Expert interviews on kinetic art restoration and acoustic imaging

We conducted four interviews with experts and professionals in the field of kinetic art. These interviews helped us understand the difference between conservation and restoration as well as gave us insight into how kinetic sculptures are usually treated. In total, we conducted four interviews:

1. Jean-Marc Gaillard, lead conservator at the Museum Tinguely,
2. Roland Wetzel, director at the Museum Tinguely,
3. Marc Egger, professional conservator and professor at the Hochschule der Künste Bern, and
4. Reinhard Bek, former conservator at the Museum Tinguely and current partner at Bek & Frohnert LLC, a contemporary art conservation firm based in New York City.

The interview with Jean-Marc provided us with an introduction to the world of restoration and conservation of kinetic sculptures as well as the importance of conservation and the original message of the artist. Additionally, he gave us insight into how conservation should be done and why. He explicitly mentions that the artworks should resemble as much as possible the original made by the artist and that the restoration methods have to be done the same way to obtain the same result.

Marc Egger provided us clarification on the differences between conservation and restoration as well as a detailed explanation on what is his procedure when conserving or restoring kinetic sculptures. His procedure when working with sculptures is to first complete documentation before working with them. He values working with specialists. Additionally, he mentions that working on kinetic art is complex and sometimes long-term. He mentions that sculptures by Tinguely, for example, which are not constructed in the manner of an engineer, can be tricky in terms of replacing individual consumable parts: If a worn part is replaced, it will probably no longer fit on another part that was previously still functioning. Furthermore, he cleared for us the difference between active conservation and passive conservation methods. He pointed out that passive conservation methods would include factors like the temperature of the room, whereas active preservation includes, for example, renewal of lubrication in a gearbox.

Roland Wetzel gave us valuable input on how the visitors usually behave in the museum. From the interview we also obtained another perspective on how the sculptures should be treated and the philosophical question that is if the artworks should perform or should be immobile.

Reinhard Bek provided us with other formats of documentation for kinetic sculptures. He mentioned that aside from recording the video and sound of every artwork he often also used a stereoscopic camera to capture the movement of the artwork in 3D. As he said, the 3D models of the artworks are often too abstract to analyze. Bek also explained to us the methods he had for data collection. Along with the video recordings and 3D recordings the audio was a key datapoint for him. He used different types of microphones with different settings. Lastly, the interview with Bek helped us see a possible future for the acoustic camera in conservation procedures of kinetic sculptures like Jean Tinguely's. Bek mentioned that for a conservator's daily use, the camera could have its limitations since the 3D nature of the sculptures makes it difficult to locate what is in the background.

All four interviewees agree that sound is an important aspect when analyzing the state of kinetic artworks. The three conservators also brought up that sound is one of the most difficult things to document since it depends on different factors such as the acoustics of the room the artworks are placed in. They agree that the use of the acoustic camera can be integrated in the future as a helpful tool for conservation efforts but right now there is no clear way to use it. However, they can see a future when this tool can be used for long-term analysis and documentation because of its ability to compare past data with present data. This information and discussion based on the future of the acoustic camera gave us the point of view of the professionals in the field which helped us shape our recommendations considering how they could use this technology in the future.

4.2. Key findings from acoustic imaging of selected sculptures

We have identified multiple places where the sound produced by Jean Tinguely's kinetic sculptures has shifted in the six years between the 2017 and 2023 data. These changes in frequencies show that an acoustic camera can be used to identify possible sites of wear. The emission of specific frequencies by a sculpture does not necessarily suggest wear, rather the change in emitted frequencies between the two data sets does. As we have shown in the background chapter, it is important for conservators to know the location of wear so that they can evaluate its severity and potentially take corrective actions to preserve the piece for the future. One such place is in *Hannibal II* (1967). As can be seen in the 2023 data in the red boxes in Figure 7, there are peaks in the sound in the area of 12.5 kHz that are not nearly as pronounced in the 2017 data, indicating that this is a frequency of interest in the acoustic recording for this sculpture.

When searching for 12.5 kHz sound in the 2023 data generated by the acoustic camera, there are two "hot spots", as can be seen in Figure 8, representing two places where sound at that frequency is being emitted. One of the sources, on the left side of the image, is two chains that hang down from the sculpture and hit into each other and the base of the machine. These chains are very loud and are visible in most frequency ranges. Their sound signature can be seen on the right side of Figure 7. This is after the machine turns off at approximately sixty seconds, leaving the chains to move and hit each other for a time afterwards while the rest of the machine is still. The other source of sound is the interaction between a wooden board and a rolling metal cylinder. This board moves forward and backward (towards and away from the camera in Figure 8) repeatedly as the machine runs. According to Gaillard, this is meant to represent a soldier wielding a sword, advancing and then retreating.

Figure 7

Comparison of spectrograms created from 2017 and 2023 recordings of Hannibal II. *The 12.5 kHz frequency is shown with a box.*

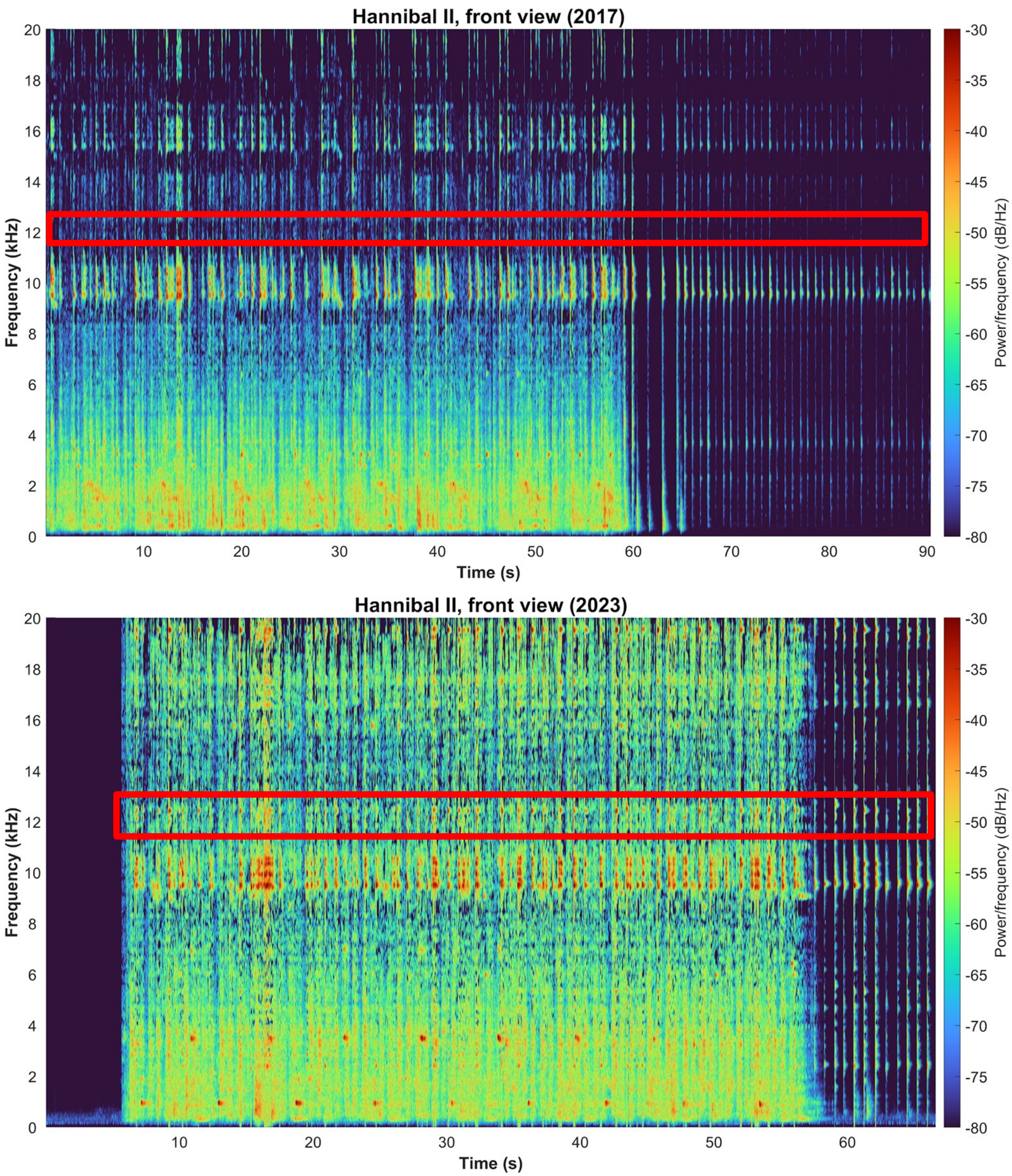
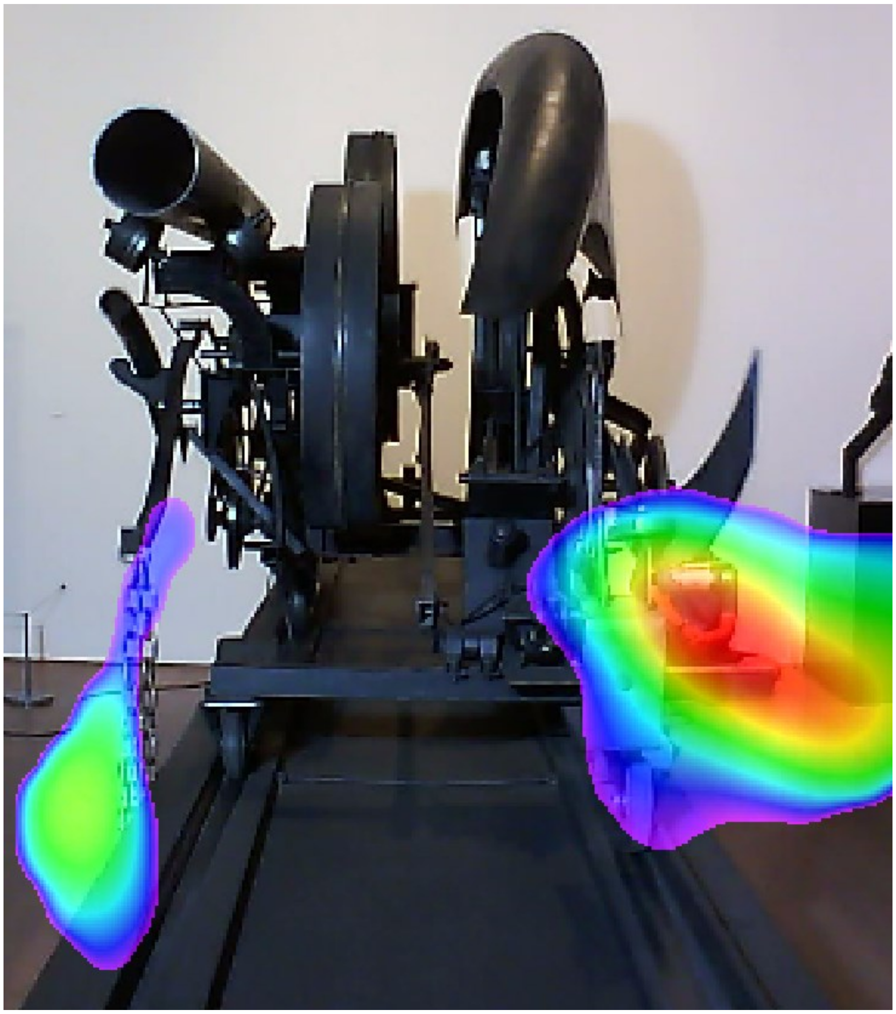


Figure 8

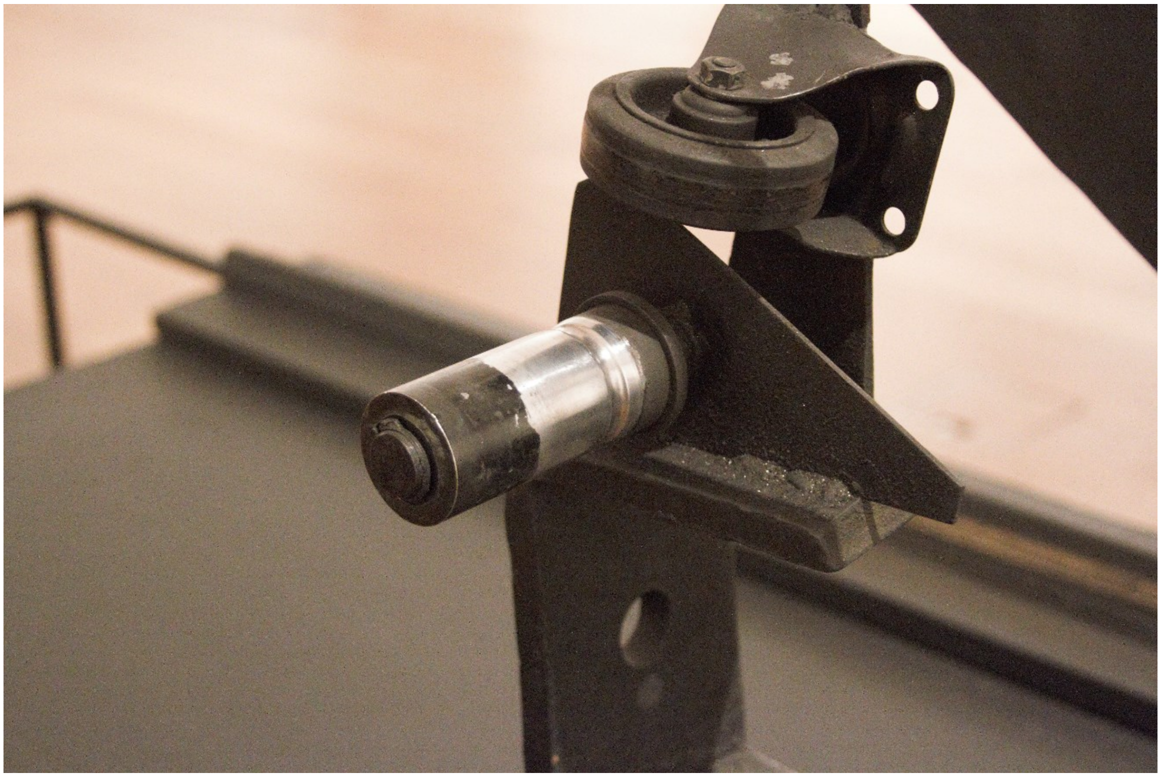
Acoustic camera recording of Hannibal II*, showing the sources of 12.5 kHz sounds. The wooden "sword" can be seen on the right above the heatmap overlay.*



As can be seen in Figure 9, this cylinder exhibits significant wear, as the board has worn a noticeable groove into the metal. It should be noted that this instance of wear was not unknown to the museum. Staff at the museum are monitoring the groove to decide when to take corrective action. However, we did not use this knowledge when we were analyzing the data. Gaillard also singled out the cylinder to us when we asked him to show us examples of signs of wear in the sculptures we were imaging, stating it had begun to wear down very recently. This shows that changes in data produced by the acoustic camera can correlate to actual wear on the objects. Additional spectrograms can be found in Appendix D and Appendix E.

Figure 9

Detail view of worn-down metal rolling cylinder in Hannibal II. *This cylinder makes contact with a wooden "sword" that slides across it.*



Of course, there are limitations to consider with this data. For one, we were not able to measure the sculptures for wear. We saw the wear shown in Figure 9, which allows us to verify that changes in sound between 2017 and 2023 may correlate to changes in the sculpture, but for other shifts, we are not able to definitively say that wear is occurring, nor are we able to discern the severity. For example, Figure 10 shows a new sound found at the 18 kHz band in the sculpture *Matrac* (1966), and shows the associated heatmap of where this frequency is generated. It is generated at the pivot point between two arms of the sculpture, shown in Figure 11.

Figure 10

Comparison of spectrograms created from 2017 and 2023 recordings of Matrac. *The 18 kHz frequency is shown within the red box.*

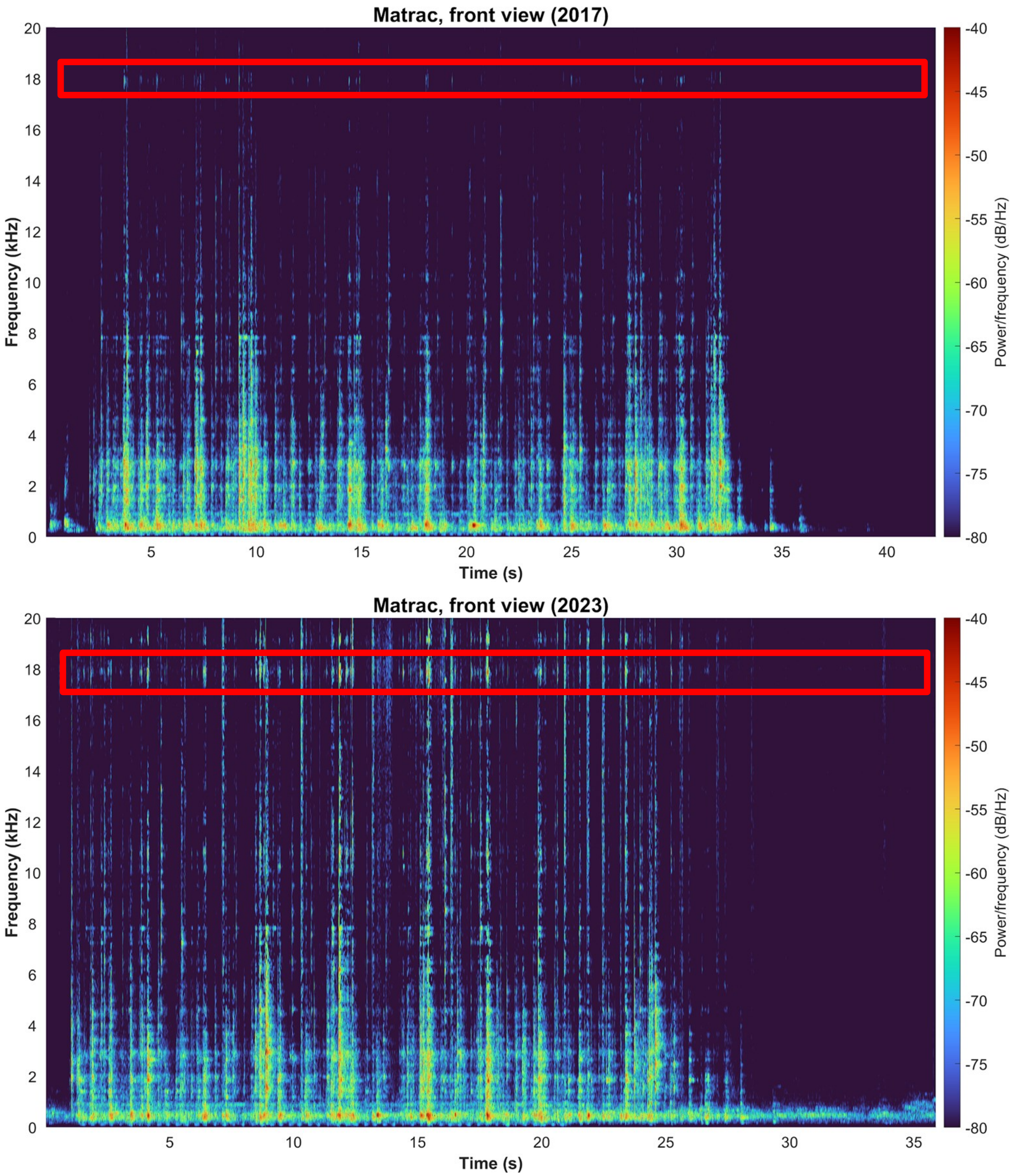
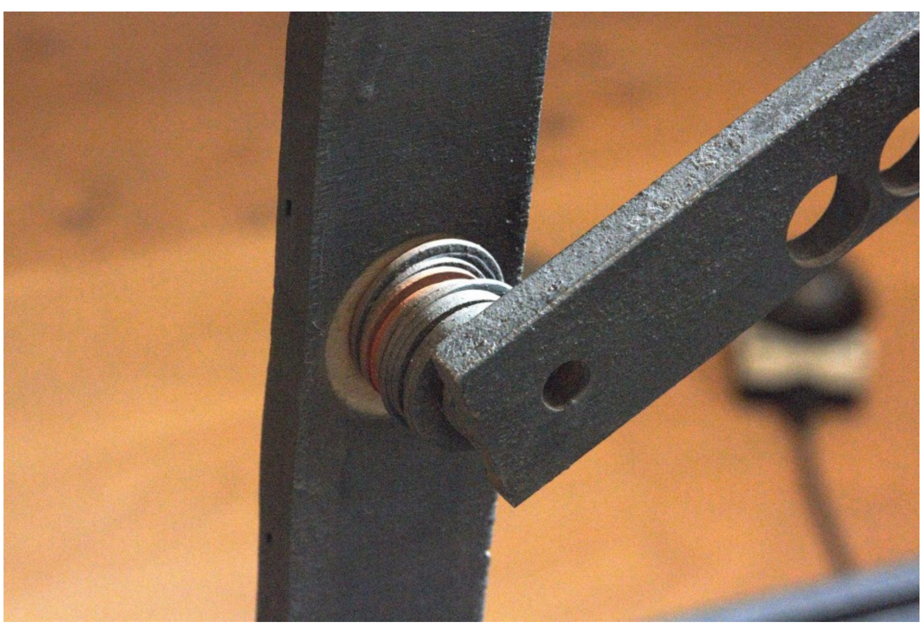


Figure 11

Acoustic camera recording of Matrac*, showing the source of 18 kHz sounds.*

Figure 12

Detail view of joint between the two arms of Matrac*. Wear can be seen between the washers, as exposed wood and rust is shown.*



Despite having this data, we are unable to determine the severity of wear. The acoustic camera can be used to point out a possible site of wear to the conservator, but it is up to their experience to verify the wear is occurring, and to assess the next steps to be taken. We did not take measurements of the severity of the wear due to a lack of previous data, so we were unable to correlate changes in frequency over time to the gravity or nature of wear that occurred, but the museum could work out a method for assessing the rate of wear upon repeated uses of the tool over time. However, this can still be useful, especially to a conservator who may not have experience with the art. Narrowing down the sites of wear to a few to keep track of can be a helpful addition to the conservator's toolbox.

4.3. Considerations and limitations of acoustic imaging

Acoustic imaging presents a potentially groundbreaking new method for helping conservators preserve kinetic sculptures. Throughout our interviews with experts and conservators, as well as our literature review and our own usage of acoustic cameras, we identified several strengths of using the technology. However, acoustic cameras have several significant limitations for setting them up as well as for analyzing their output that should be taken into account.

4.3.1. Record keeping

One approach some conservators use to detect signs of wear or potential failures in kinetic sculptures is to listen to the sound made while the sculpture is moving. For instance, Gaillard told us he routinely goes through the museum before it opens and listens by ear to the pieces for any new sounds that were not there the previous day or week or if something sounds wrong. Just by listening to a piece over time, a skilled conservator could determine if a piece on a sculpture is changing or needs to be maintained or replaced soon. Acoustic recordings and spectrograms provide a way for conservators to track changes in sound over time. The recordings could be especially useful for newer conservators so they can hear and see the sounds that a piece or motor made originally before they worked on the sculpture. As Gaillard told us, newer generations "will need [records] because they do not have the experience from the last 25 years."

Record keeping is important for keeping sculptures running as close as possible as their intent when they were originally made. Records such as pictures, films, and documentation of preservation work allow conservators to see how. Furthermore, if acoustic images and spectrograms were collected at regular intervals, then conservators would have a new tool to analyze changes over the years and see any patterns and perform preventative maintenance as necessary. Gaillard agreed that using acoustic cameras as an additional form of documentation would be useful because "the more you have, the better." Acoustic imaging and spectrograms provide an objective and preservable means of storing and visualizing sounds. As shown in Section 4.1, these spectrograms can indicate to conservators both signs of and the location where wear is occurring before parts break down.

However, record keeping can only be useful to conservators and art owners if it is done well. This includes the description of the condition of the work, the description of the causes of the damage and the implemented concept, if possible in words and (moving) pictures including sound. Egger stressed to us in an interview the importance of maintaining records of changes made by conservationists. He said he would take videos and audio recordings of pieces he received to further document their state. Gaillard identified another problem with maintaining records - storing data and finding it effectively later on was quite difficult, and sometimes data was lost. Gaillard also felt concerned about whether future conservators would have enough time to listen to all of the recordings and analyze the spectrograms. Thus, acoustic recording data can only be useful if it is stored in a manner that is easily accessible to conservators, but there also should not be so many of these recordings and figures that they get ignored due to time restraints. Each recording also requires up to about a gigabyte worth of storage for only thirty seconds to a minute of data, which could reduce the number of recordings that a museum or institution is willing to make.

Bek expressed concern that the documented data needs to be easy to understand for conservators. Based on our engineering background with data analysis, we could configure the different programs and analyze the data relatively easily since we had experience with using complex programs and reading spectrograms and heat maps. In contrast, a conservator may not have such experience, or may need additional training to use the programs and analyze the data effectively. Bek further elaborated that since conservators regularly go through museums to listen to and watch pieces for signs of wear, daily or regular acoustic recordings would present a hassle for conservators rather than a benefit and presents the potential for conservation work to become too theoretical. Conservators could spend extensive periods of time simply documenting a piece with new and exotic tools rather than working on the piece itself or using simpler, quicker methods of noticing changes, which lessens the value of documentation. He agreed that acoustic recordings could be useful for long-term comparisons and present a more scientific means for detecting wear. Since conservators subjectively observe changes with their senses, having a sensor- and software-based approach allows for a more objective method for conservation. The records also preserve historic operations that would otherwise not be preserved when the conservator leaves the museum and takes their years of experience with them.

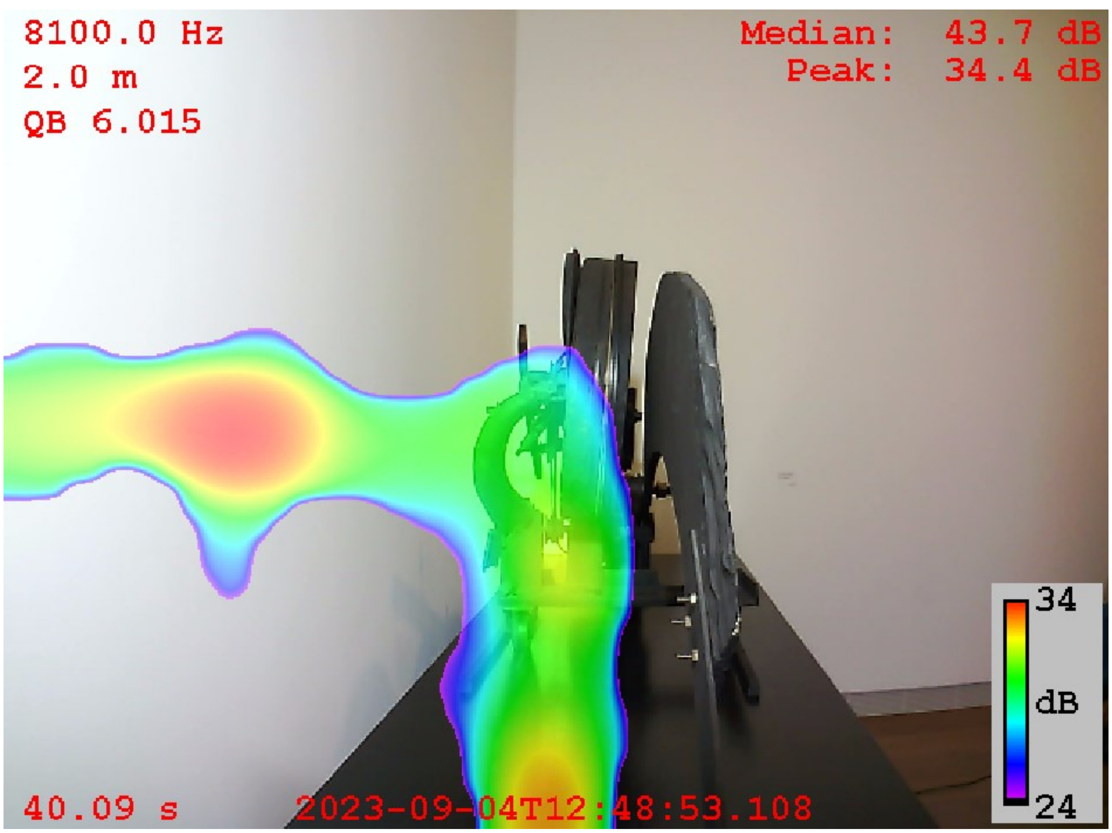
4.3.2. Quality of data and ease of acquisition

Our method of acoustic recording only requires the sculpture to operate as it would normally in front of visitors to the museum. The camera is passive, non-invasive, and non-destructive because it merely records sound waves and video without any physical contact with the sculptures. From our experiments, the camera can pinpoint the location of multiple sources of sound with up to several centimeters of accuracy. The data we collected also showed changes in the sound's location, frequency, and intensity as the sculptures moved.

However, because we recorded audio at a distance, the data became susceptible to background noise and other environmental interference that had to be accounted for in data analysis. When loud noises occur outside the visible view of the camera, the audio can be picked up and displayed at the perimeter of the recording, or as an additional frequency visible everywhere. To account for background noise, we attempted to record when there was less activity in the museum, and to screen out certain frequencies to select only certain regions of interest. Although we briefly experimented with audio filtering techniques within the MATLAB script such as moving median smoothing and a Savitzky-Golay filter, we eventually discarded audio filtering as we did not want to potentially lose too much data to it. This was also supported by Dr. Brambilla, who agreed some data could be lost in the process. Additionally, the sound waves travel in all directions, and if they reflect off objects or walls, the waves can be picked up by the camera multiple times. For example, as shown in Figure 13, the sculpture emitted the sound in the center of the camera, but sound bounced off the wall to the left and reflected back toward the camera. Since we were unable to move the sculpture or acoustically treat the wall, we had to use the software to select the data we were interested in. Moreover, according to one of our sponsors and a researcher in wear in historical pieces, Dr. Laura Brambilla, we could have eliminated these environmental factors by using acoustic emission sensors. Her studies have suggested that background noise does not affect data acquisition with these sensors. However, the sensors need to be in contact with the sculptures using gel or another coupling agent, and most museums are strongly reluctant to allow anything or anyone else to touch their pieces (L. Brambilla, personal communication, September 11, 2023). Thus, although environmental factors add noise and undesirable data to recordings when using acoustic cameras, these cameras are more museum-friendly and robust for collecting reliable data than other sound recording techniques.

Figure 13

Acoustic image of side profile view of Char MK *(1966) showing echo off a wall (left).*



Another benefit of using the acoustic camera was speed. Data collection with the camera proved to be quick - it only took us a few minutes to position the camera near a sculpture and connect it to the BeamformX software, and the program saved the data in real time. We converted this data into a spectrogram in a few seconds using a script written by us in MATLAB (see Appendix B for our code). One slowdown we encountered with our setup was with the BeamformX software. Despite our mitigation efforts and switching devices, the software routinely froze or crashed, stopped recording early, failed to adjust to our inputted configuration parameters, and lagged, among other bugs. Overall, using acoustic imaging and analysis is quite fast, but considerations must be made for software glitches or a newer software should be used.

After analyzing our data, one additional concern we had was with the distance between the sculptures and the camera. The data from 2017 did not include any information on distance, so we did not maintain a standardized procedure for measuring distance since there was nothing to correlate. We experimented by recording the same sculpture at different distances of up to half a meter in the same room under the same environmental conditions. Regardless of distance, however, we obtained similar sound patterns from the same sculpture across different runs. While we did see a change in overall volume, the prominent frequencies relevant to our analysis were still standing out from the general noise. However, if the camera were moved multiple meters back, there is a potential for the camera to not record a certain frequency or for the sound to be dispersed by the acoustical dynamics of the room. According to the inverse square law, the intensity of a sound is halved when the distance from the sound source is doubled; however, this only constitutes a decibel decrease of 6 dB (Baker, n.d.). Considering the sounds emitted by the sculptures ranged from 30 to 50 dB in volume in our recordings, this change would be noticeable, but not so much so that we could not draw any conclusions from the data recorded. Additionally, the difference in distance between the 2017 and 2023 data is much less than double. The BeamformX software has a parameter for camera distance from the target source that could be useful for future recordings.

4.3.3. Takeaways

Acoustic cameras can be used to pinpoint the location, frequency, and intensity of sound being emitted by different moving parts, which could be useful to kinetic art conservators for detecting wear and visualizing changes over time. The technology can be set up in minutes and does not require any intrusive sensors. However, the cameras are susceptible to environmental factors such as background noise that must be considered when using them. Additionally, conservators should carefully plan how often to use them for record keeping to avoid having too much data to analyze. To communicate this information to the museum and its visitors, we created a video to be displayed in the museum.

4.4. Exhibit creation

To create our video, we conducted an extensive literature review about video making for a museum. There are many steps involved in the production of a professional video, so we divided the literature review into three main parts that are linked together with our process of creating the video:

1. Video planning
2. Video Recording
3. Video editing

4.4.1 Video planning

The first stage in creating a video is the pre-production stage, where the planning of the video is created. Many sources agree that it is essential to create a planning checklist when starting up a new video project and concluding that it's the best way to start the planning stage (Cockerham, 2023; Fox, 2019; Trussel, 2022). More importantly, as Fox (2019) mentions, the quality of the planning for a video will most likely determine how proficient the video will turn out.

A planning checklist is essential because it can help prevent future issues with production like setting up the wrong tone or not including all the information in the video. Each video project has its own planning checklist, so some videos might be simpler; therefore, they will not need an extensive checklist. Nevertheless, there are some important features that every checklist must have. Some of the essential features of the planning checklist include:

1. Define the goal of the video,
2. develop your message,
3. define the target audience,
4. define the type of video you want to make, and
5. create a storyboard with script.

Following the recommendations of the sources visited, our group started the planning stage for the video. The first thing we did was to define our video's objective and the message we wanted to give the audience. The video's objective was to propose and explain to museum visitors how an acoustic camera can be useful for the conservation process of Jean Tinguely's sculptures. The next step was to consider the target audience that we were addressing. In our case, the target audience was not very specific since the visitors of a museum vary in age, culture, and knowledge. According to museum director Roland Wetzel, the Tinguely Museum draws roughly twice as many children as other museums in the area, due to the machines being interesting to anyone from child to art lover. With that in mind, the planning for our video took a turn, where the message of the video was adapted in a way that every museum visitor could understand the video. To do so, we relied on the information we gathered in the background section about the types of visitors in a museum. Furthermore, as Serrell (2002) comments in his research, visitors are tempted to move from exhibition to exhibition once their interest in the video has waned. Watching a video forces a visitor to stay in place for several minutes, which can bother some visitors. Therefore, we set the goal of creating a video that would not exceed more than five minutes.

With that in mind, we started developing the message we wanted to convey through the video. This was one of the most challenging parts. A video's message must be clear and focus on the main ideas you want to show. The more ideas you want to include, the less likely the audience will remember (Fox, 2019). Furthermore, there is a quote mentioned in Pierce (2022) from Shannon Tipton (a learning consultant) that clearly defines the importance of focusing on the message: "Throw out the learning objective and focus on what you want the learner to actually do." This was a key aspect of video planning because the goal was to make a video where, in the end, the public understood what we wanted to transmit through the video.

Therefore, it was essential to plan ahead with a storyboard and a script that were clear and did not deviate from the goal and message defined in the planning checklist. Additionally, it is mentioned by Serrell (2002) that in order to make the public hold watching the video, the story and message evolve clearly supported by visuals. Therefore, in our case, the message had to be simple enough and supported by images so that everyone could understand and enjoy how acoustic imaging worked and how it could be used to aid conservation. In his conclusions, Serrell (2002) mentions that for his research, visitors often spend less than 20 minutes on an exhibition; therefore, a video should be no longer than three or five minutes if the goal is to make the visitors watch the whole video. With the message, objectives, and target audience clear we defined the type of video we wanted to create. We thought that the best way to introduce the acoustic camera as a tool for the museum conservators was to do an explainer video. That is a video whose aim is to communicate how something works in an engaging way; these videos are typically used to demonstrate the benefits of a product. (Dowdall, 2021) Therefore, this video's objectives should be clear and concise, it was essential for us to complete a planning checklist beforehand, so we didn't include footage unrelated to the objectives and end goal of the video. A document with the planning steps we took to complete the video can be found in Appendix H.

We then started planning out the storyboard, keeping in mind the message and goal of the video. The storyboard was the last step to complete the video's planning stage, but it was also the step that included all the planning done until then. A storyboard is a roadmap containing the keyframes or ideas you want to include in your video. It's a visual guidance about how you want your video to look like. Storyboards are usually drawn and have small descriptions on the side explaining the action along with the script (Vyond Team, 2023). The importance of the storyboard is to have in mind what kind of shots you want to record and share with the rest of the team how the production of the video will look (Barking Squirrel Media, 2017). To complete our storyboard, we first made a document with ideas we wanted to include in the video. After that, we arranged them in a way that would make the video progress smoothly. For the first storyboard, we drew keyframes that would give an idea of what we wanted to record, along with some text describing the action. After several team discussions on what to include in the video and what information might be useful to include our storyboard changed a bit. The two storyboards and the differences between them along with an explanation of the changes can be found in Appendix I. To summarize, the main idea and structure of the storyboard was:

- to first introduce the sculptures and its unique nature,
- explain simply why sculptures wear over time,
- show the most significant parts that have been worn down,
- explain current conservation methods applied by the museum with Jean-Marc's thoughts,
- explain how an acoustic camera works,
- show how the acoustic camera can aid the analysis of the artworks, and
- conclude with Jean-Marc's thoughts about the possible future of using the acoustic camera.

It is important to note that the storyboard is only a guidance for the production stage. It is not always needed to follow it strictly. In our case, after completing the recordings for the video, we added a small scene that was not in the storyboard but would make the video flow better. This new scene compares previous data from 2017 with current data from 2023 of a sculpture illustrating how sound frequency in a sculpture can change over time. Once the storyboard was completed, we started developing the script for the video. Usually, the script goes along with the storyboard in the same document, but we decided it would be much cleaner if it were in a separate document. The script was a delicate part of the process because, as mentioned before, science can be a difficult theme to explain to a very broad audience since not everyone has the same knowledge background. To keep that in mind we used the information gathered in the background section as well as information from some sources to make our script and message as simple as possible for everyone to understand.

The University of Alabama at Birmingham has collected some tips about science communication, we used some of these tips to shape our script. One important tip they mention and that we used in our script was to put science in context. They mention that it is important that one doesn't assume that the public has any knowledge of the topic and therefore one should explain the context on why this topic is important and how it can help. Along the same lines, they mention that it's important to keep the communication with a fluid progression just as one would telling a story. Additionally, it is best to not include very specific science jargon since it can prove confusing for the audience. Instead, it would be best to explain a concept in the simplest way possible or using analogies (Hiden, n.d.). The script we completed was based on storyboard draft two and can be found in Appendix J.

4.4.2 Video recording

Although video planning is one of the most important aspects when making a video, the filmmaking of the video must be of quality in order to achieve the quality standards created during the planning stage. The video filmmaking stage was the stage where the ideas on the storyboard had to become reality. To properly film the video we had in mind, we researched different techniques used by professional filmmakers.

One of the most basic and essential techniques when filming a video is the use of proper lighting. The placement of the lighting is also essential in making the video look more professional. Too much light will ruin the video, and too little light will make the video unwatchable. Therefore, there must be a balance in lighting. Bedrina (2023) recommends using a technique called “lighting triangle” if you are shooting a video indoors or in a place with poor illumination. This technique, as its name mentions, consists of creating a triangle between the subject, the light, and the camera. Another critical aspect to take into account was the source of lighting. The sun is the best light source of a video, but only on footage that is recorded outside. If shooting a video inside, the most important thing is to have an extra light in case the lighting inside is not balanced. It is also important to consider the angle the light is making with the subject since overhead lighting will cast shadows on subjects’ faces or other materials (Bedrina, 2023; Thapa, 2022). In our case, we decided to use the lighting triangle technique using a studio light. This was necessary for most of our videos of the sculptures since the lighting inside the museum was too dim to film a proper video. The only case we didn’t need extra lighting was during the interview with Gaillard since the lighting at his workshop was adequately balanced, as seen in Figure 14.

Figure 14

Jean-Marc Gaillard, conservator at the Museum Tinguely, in his workshop

The background when taking videos is also an important element to consider. To shoot footage of sculptures and people, it’s best to avoid distracting backgrounds. The subject has to be the center of attention. Therefore, it’s best to use simple backgrounds or backgrounds that will not distract the audience (Bedrina, 2023). In our case, we decided to take footage of the sculptures at an angle where the background was simple enough to make the sculpture the primary source of attention. In the case of the interviews, we selected a space with simple backgrounds, but that didn’t look too dull. For example, in the case of the interview with the conservator Gaillard, we chose his workshop, and for the interview with the director, we chose the restaurant downstairs the museum.

One of the most important things when recording videos is the audio. Sometimes, the audio quality can be even more important than the images. Fuzzy or poorly balanced audio can completely destroy your video (Bedrina, 2023). In our case, we couldn’t buy a lavalier microphone in time to do some of the interviews. Instead of a microphone, we used a phone to record the interview audio. For general footage of sculptures moving, we used the camera’s microphone.

The last big thing we considered when filmmaking the video was the composition of the footage. One of the most essential principles in film is the rule of thirds, which is overlaying a three-by-three grid over the image that is being recorded (Bedrina, 2023). We took the advice of the rule of thirds into account when taking our footage. A problem that could arise when taking footage was shaky footage. Shaky footage can make viewers seasick, mainly because the camera is sensitive to movement. Therefore, it is best to use either a tripod or a camera stabilizer (Bedrina, 2023). This was something we considered from the first moment we knew we had to make a video. We considered buying a camera stabilizer to record while moving, but most of the videos in the museum (if not all) had still shots (recordings with a fixed camera); therefore, the only apparatus we used was a tripod.

The last thing we took into consideration was taking footage from different angles. When shooting a voice-over video, you want to support what you are saying with quality footage. The goal is to immerse the audience to let them find a conclusion with images as well as with the audio (Thapa, 2022). That is why we used different angles. We wanted to complement our footage with different angles to make the audience more invested in the video.

Figure 15

Assorted scenes from the video

In addition to the research, we also watched the videos posted around the museum to get a feel of how the videos were recorded. We didn’t want to make a video that was entirely different from the other videos since we thought that would create a rift in the visitor’s museum experience.

4.4.3 Video editing

The last step in the video production was to edit the video. To do this, our team studied how to use the video editing software Final Cut Pro X and completed a small literature review on what are the most important methods and features in editing a video so it looks professional.

We started our editing process by consistently balancing the video clips' length. It is common for a video to have longer clips and shorter clips. However, the clips of a video must have an appropriate length. Clips that are too long will bore the audience, and short clips will make the video's pace too fast. Having an unbalanced pace in the video makes the video completely unwatchable. Therefore, the speed of each scene should match its tone. For example, if there is a voice-over explaining how the sculptures are decaying, using different clips to show this can be helpful. However, it might be better to even out the length of these clips rather than having multiple short clips contrasting the message. In video editing, sometimes less is more (Riverside Team, 2023).

Following that, we focused on adding transitions to the clips. Transitions are an essential key feature in video editing since they smoothly bring unrelated or related clips together. To complete a good video, there is no need to use fancy transitions; instead, the most effective transitions are simple cuts, fades, or dissolves (Riverside Team, 2023; Vegas Creative Software, n.d.).

Our idea was to add some text in the video, especially in the intro scene and whenever a character for the video was introduced. When editing text in a video, it is helpful to keep the same font for the whole video. Changing the font back and forth can make the video look amateur. It is also important to select a color that has a balanced contrast with the background, making the text easy to read but not stand out too much. Adding a drop shadow to the text comes to the front and makes the text more readable (Riverside Team, 2023; Vegas Creative Software, n.d.).

We used color correction methods to fix any problems with the color balance of different clips. Color correction is a technique used to edit the contrast and brightness of a video to appear more natural. This helps make the video more pleasant to the eye and more faithful to the natural colors. The best way to adjust the colors is to look at the color curves to even out the colors (Riverside Team, 2023; Vegas Creative Software, n.d.).

The audio level is one of the most basic features that must be edited in a video. This should be done once every visual in the video is in place. It is important to balance the audio in a video; the sound of dialogue or speech should be the same and consistent. To achieve this, it is vital to use sound meters that show the decibels of the sound. Usual dialogue and speech decibel range are from -20 dB to -12 dB. It is also important to make the subject's dialogue or speech the primary audio source. To do so, background noises or music should be in a lower decibel range than the dialogue so this audio source can stand out and the public can follow it more easily. Every audio source, like music or sound effects, should have a consistent audio balance; it should not have spikes or dips (Riverside Team, 2023; Vegas Creative Software, n.d.). The final step was to add subtitles to the video. Since Switzerland is a multilingual country, we decided to add subtitles in German, French, Italian and English, with translation help from our sponsors. Overall, this video serves as a way for us to convey the use of the acoustic camera and to present the scope of our work.

Chapter 5. Conclusions and Recommendations

Our background research, experiments and results, and interviews with experts has repeatedly indicated the efficacy of using acoustic cameras to record kinetic sculptures. Specifically, by comparing our acoustic imaging data with past data, we identified potential signs of wear in Jean Tinguely's sculptures. A confirmation of this technique came from our analysis of *Hannibal II*. We were able to find a distinct change in the sound level at 12.5 kHz, which when viewed with the acoustic camera showed the change occurring at a metal wheel. This wheel has a clear groove in it, created by a wooden "sword" that slides across it while the machine runs. Furthermore, we were able to identify the 18 kHz frequency as having increased in volume in the sculpture *Matrac*. This sound is predominantly produced at the joint between two arms of the sculpture, which is a likely site of wear given that the joint is simply a bolt in a wooden hole.

This conclusion shows that the acoustic camera is able to be used to identify changes in frequencies, and that those changes may correspond to wear on the artwork. Conservators and the Museum Tinguely's director agreed that the technology could be useful for maintaining a robust record of changes in the sculptures over time. However, there are several important limitations that should be considered with the cameras. Therefore, we recommend the following changes be established for future groups that would like to use acoustic imaging cameras to study kinetic sculptures:

1. Establish a standardized procedure for making acoustic recordings and spectrograms,
2. Devise a long-term plan for regularly taking acoustic recordings and storing them in an accessible way,
3. Replace or upgrade BeamformX with a more stable acoustic analysis software,
4. Research more objective means of determining the rate of wear of parts, and
5. Acknowledge the strengths conservators bring by being able to listen to and watch sculptures for detecting potential problems.

5.1. Developing a standardized acoustic imaging procedure

When we took our recordings, we placed the camera at various distances to the sculptures or at specific parts and angles of the sculptures. We documented the side or part that we were analyzing, but we did not take specific distance or angle measurements because the data from 2017 did not have any specific measurements for us to compare to. Since the sound intensity can vary with distance, we recommend to the museum and any future researchers to note the camera's distance to specific parts, as well as the angle of the camera relative to those parts. The BeamformX software has a field for inserting distance measurements, which may improve the resolution of results.

Furthermore, since we could not move the sculptures nor touch them, we often recorded undesirable background noise and sound reflections off walls. We attempted to select frequencies and regions of interest to mitigate these environmental factors; however, we recommend attempting to move the sculptures or acoustically treat the room before recording. Although acoustic emission technology (which involves physical contact with the sculptures) may provide a similar effect of removing background noise, the technology requires more setup and permissions than acoustic cameras, and thus the sensors should not be used as a replacement to the camera. Acoustic emission is an invasive technique, meaning that the sculpture would have to be handled, whereas acoustic imaging is a noninvasive technique that does not require contact with the artwork. The acoustic camera provided sufficient data needed to localize frequencies to certain spots while only requiring a few minutes of setup time, making it a practical, useful, and robust tool to supplement conservators' subjective analysis.

5.2. Long-term usage of acoustic imaging recordings

On their own, the spectrograms and acoustic recordings that we took in 2023 only show so much about the state of the sculptures. By comparing the data to 2017, we were able to spot new sounds and louder frequencies that indicated signs of wear. Conservators with years of experience working with kinetic sculptures can listen to sculptures regularly and determine short-term changes that indicate possible deterioration. Acoustic recordings, in contrast, do a much better job of preserving frequencies from the past. Thus, we recommend that any researchers or conservators using this technique use the camera to record sculptures of interest annually or every few years. Recording it more frequently would create too much data to effectively analyze and store and would be a hassle to repeat, while a more long-term approach allows for showing changes.

These recordings must be stored in a secure and easily accessible manner. Several of the conservators we interviewed expressed concern with losing records or not being able to easily locate them. The spectrograms and acoustic recordings should be saved online in a well-known location with additional data that confirms the procedure used to take the recordings. Conservators have repeatedly told us how they find original recordings useful as a reference point in their work, so it is imperative that older acoustic recordings be kept in perpetuity in addition to more recent ones.

5.3. Current issues with BeamformX

The BeamformX software provided us a way to interact with the acoustic camera. We appreciated being able to filter by frequency and intensity in real time. However, the software has several important limitations that may hinder future projects. The program repeatedly stopped responding or recording, ignored our parameters, and was quite sluggish. These bugs occurred on all of our devices despite being updated and following the manual. We were also disappointed that the software did not provide more direct control over certain parameters, such as resolution. For a conservator, the software may not be easily usable since multiple different windows open and not all of the configuration parameters are intuitive. Therefore, we recommend to the museum to upgrade or replace the program for reliability and usability.

5.4. Objective analysis of acoustic imaging’s relation to wear

With only two data sets of acoustic recordings for each sculpture in 2017 and 2023, we lacked sufficient information to objectively determine the rate of wear of certain parts. Furthermore, although we could see changes in frequency on spectrograms and in BeamformX emitted by certain parts, we had to assume that these changes implied that some form of wear occurred. We lacked a method for correlating each frequency to a type or level of deterioration.

We recommend further research by the museum, our sponsors, or a future IQP into determining an objective way of correlating changes in frequency with specific, measurable changes in the parts. A possible strategy is to measure or photograph parts similar each time an acoustic recording is made to determine a relationship, similar to our methodology.

5.5. Future of conservation at the Museum Tinguely

Conservators at the Museum Tinguely bring years of experience to analyzing Tinguely's sculptures for potential signs of wear and parts that need to be better preserved, repaired, or replaced. Just by routinely listening to a piece, Jean-Marc Gaillard could identify any problems and act accordingly. For experienced conservators, the technology may be another useful tool for analyzing wear over time. However, future generations of conservators without as much experience may gain more out of acoustic recordings, as the pieces sound different over time. Newer conservators may lack the knowledge and art of listening to notice problematic changes in sound; thus, acoustic imaging may prove useful for them as a record of the pieces.

5.6. Final thoughts

The acoustic camera presents a novel tool for art conservators. We have shown that this technology can be used to identify wear in Tinguely's artworks, and how it may be useful to conservators. However, acoustic camera technology does not apply solely to the Museum Tinguely. Tinguely's artworks are spread across the world in many collections and exhibitions, and each of those must be conserved for future generations. Gaillard said that "every Tinguely [piece] who is laid to rest and they don't let them work anymore, it's another [bit] of Tinguely who dies … there's a lot of Tinguely's life in there and in these machines and in the movements that they do." We hope that this project can lay the groundwork for the implementation of a new tool to help conservators to keep Tinguely's spirit alive well into the future.

References

Baker, R. (n.d.). *Inverse Square Law*. Manchester: Basic Acoustics. Retrieved September 18, 2023, from https://personalpages.manchester.ac.uk/staff/richard.baker/BasicAcoustics/4_inverse_square_law.html

Bedrina, O. (2020, September 16). 12 Simple Tips for Making Your Videos Look More Professional. *Wave.Video Blog*. https://wave.video/blog/12-simple-tips-for-making-your-videos-look-more-professional/

Bek, R. (2004). Conserving junk and movement: Machines by Jean Tinguely. *Studies in Conservation*, *49*(sup2), 44–48. https://doi.org/10.1179/sic.2004.49.s2.010

Bek, R., & Rivenc, R. (2018). *Keep it moving? Conserving kinetic art*. Getty Publications. https://muse.jhu.edu/book/74912

Berg, B. L., & Lune, H. (2012). *Qualitative research methods for the social sciences* (8th ed.). Pearson.

Blancke, S., Tanghe, K. B., & Braeckman, J. (2018). Intuitions in science education and the public understanding of science. In K. Rutten, S. Blancke, & R. Soetaert (Eds.), *Perspectives on Science and Culture* (pp. 223–242). Purdue University Press. https://doi.org/10.2307/j.ctt2204rxr

Böck, M., Vonrhein, B., Mehlhaff, M., & Ulrich, M. (2015). The Acoustic Camera as a tool for machinery maintenance. *Inter.Noise 2015*, 8.

Bogner, A., Littig, B., & Menz, W. (2018). Generating qualitative data with experts and elites. In U. Flick (Ed.), *The SAGE handbook of qualitative data collection* (pp. 652–665). SAGE Publications Ltd. https://doi.org/10.4135/9781526416070

Bolshakov, R., Kasischke, E., Galbiati, F., & Hess, L. (2022). *Developing a Relational Database of Approaches to Conservation of Functional Artifacts*. Worcester Polytechnic Institute.

Borun, M. (1992). The Exhibit as Educator: Assessing the Impact. *The Journal of Museum Education*, *17*(3), 13–14.

Casado, S. (2017). Studying friction while playing the violin: Exploring the stick–slip phenomenon. *Beilstein Journal of Nanotechnology*, *8*, 159–166. https://doi.org/10.3762/bjnano.8.16

Cockerham, L. (2015, June 21). *5 Things You Must do for Successful Video Content Planning*. Skeleton Productions. https://www.skeletonproductions.com/insights/5-things-for-successful-video-content-planning

Dowdall, E. (2021, May 10). *Explainer Videos: What are They and Why are They Great?* Kartoffel Films. https://kartoffelfilms.com/blog/explainer-videos-what-are-they-and-why-are-they/

Fox, J. (2019, December 16). *Video Planning Checklist—12 Keys to Success*. One Market Media. https://onemarketmedia.com/2019/12/16/video-planning-checklist-12-keys-to-success/

Hiden, K. (n.d.). *10 Tips to Successful Science Communication*. Retrieved October 2, 2023, from https://www.uab.edu/ccts/news-events/10-tips-to-successful-science-communication

How to edit videos like a professional: 9 editing tips you need to master. (n.d.). Vegas Creative Software. Retrieved October 2, 2023, from https://www.vegascreativesoftware.com/us/video-editing/tips-to-edit-videos-like-professional/

Isgro, M. (2020). Modernism in motion: Jean Tinguely's meta-mechanical reliefs, 1954–59. *Art Journal*, *79*(2), 6–23. https://doi.org/10.1080/00043249.2020.1765550

Maev, R. Gr. (Ed.). (2013). *Advances in Acoustic Microscopy and High Resolution Imaging: From Principles to Applications*. Wiley-VCH Verlag GmbH & Co. KGaA. https://doi.org/10.1002/9783527655304

Matti Haapoja (Director). (2018, May 7). *How To PLAN The BEST Video*. https://www.youtube.com/watch?v=eP5QZcxQ6g0

Merino-Martínez, R., Sijtsma, P., Snellen, M., Ahlefeldt, T., Antoni, J., Bahr, C. J., Blacodon, D., Ernst, D., Finez, A., Funke, S., Geyer, T. F., Haxter, S., Herold, G., Huang, X., Humphreys, W. M., Leclère, Q., Malgoezar, A., Michel, U., Padois, T., … Spehr, C. (2019). A review of acoustic imaging methods using phased microphone arrays: Part of the "Aircraft Noise Generation and Assessment" Special Issue. *CEAS Aeronautical Journal*, *10*(1), 197–230. https://doi.org/10.1007/s13272-019-00383-4

Michel, U. (2006). History of acoustic beamforming. *Berlin Beamforming Conference*, *1*. https://www.bebec.eu/fileadmin/bebec/downloads/bebec-2006/papers/BeBeC-2006-01_Michel.pdf

Muller, N. (2000). Slowing the Clock: Art Conservation at the Art Museum. *Record of the Art Museum, Princeton University*, *59*(1/2), 3–15. JSTOR. https://doi.org/10.2307/3774798

Museum Tinguely. (n.d.). *Conservation Strategy*. Museum Tinguely. Retrieved April 1, 2023, from https://www.tinguely.ch/en/tinguely-collection-coservation/restaurierung/restaurierung_haltung.html

National Aeronautics and Space Administration, S. M. D. (n.d.). *Tour of the Electromagnetic Spectrum: Anatomy of an Electromagnetic Wave*. NASA Science. Retrieved April 10, 2023, from https://science.nasa.gov/ems/02_anatomy

Ohtsu, M. (2008). Sensor and Instrument. In C. Grosse & M. Ohtsu (Eds.), *Acoustic Emission Testing* (pp. 19–40). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-69972-9_3

Orman, M., & Pinto, C. T. (2013). Usage of acoustic camera for condition monitoring of electric motors. *2013 IEEE International Conference of IEEE Region 10 (TENCON 2013)*, 1–4. https://doi.org/10.1109/TENCON.2013.6718909

Palomba, R., & Tintori, A. (2017). How to undo stereotypes about scientists and science. In *Turn on the light on science: A research-based guide to break down popular stereotypes about science and scientists* (pp. 19–50). Ubiquity Press. http://www.jstor.org/stable/j.ctv3t5r1s.6

Pierce, M. (2018, April 4). *Video Plan: The Beginner's Guide to Successful Video Pre Production*. The TechSmith Blog. https://www.techsmith.com/blog/video-pre-production/

Riverside Team. (2023, August 10). *10 Effective Video Editing Tips for Beginners to Improve Easily*. Riverside. https://riverside.fm/blog/video-editing-tips-for-beginners

Saldana, J. (2016). *The coding manual for qualitative researchers* (3rd ed.). SAGE Publications. https://www.sfu.ca/~palys/Saldana-CodingManualForQualResearch-IntroToCodes&Coding.pdf

Scott, D. A. (2017). Art Restoration and Its Contextualization. *Journal of Aesthetic Education*, *51*(2), 82–104. https://doi.org/10.5406/jaesteduc.51.2.0082

Serrell, B. (2002). Are They Watching? Visitors and Videos in Exhibitions. *Curator: The Museum Journal*, *45*(1), 50–64. https://doi.org/10.1111/j.2151-6952.2002.tb00049.x

Thapa, M. (2022, June 2). 19 Videography Tips for More Professional-Looking Videos. *42 West*. https://www.adorama.com/alc/13-videography-tips-for-more-professional-looking-videos/

Tinguely, J. (1959). *Für Statik*. https://www.tinguely.ch/.imaging/large_jpg/dam/Biografie/Wendepunkt/Doc-000014.jpg.jpg

Tomkins, C. (1985). Jean Tinguely. In *The bride and the bachelors: 5 masters of the Avant-Garde* (Repr., expanded ed, pp. 112–143). Penguin Books.

Trussell, J. (2022, May 24). *Video Production Planning Checklist: 15 Keys to Success*. QuickFrame. https://quickframe.com/blog/video-production-planning-checklist/

Vyond Team. (2023, January 11). *What Is A Storyboard & How Do You Create One?* Vyond. https://www.vyond.com/resources/what-is-a-storyboard-and-why-do-you-need-one/

Why Using Storyboards Are Important. (2022, March 17). Barking Squirrel Media. https://barkingsquirrelmedia.com/video-production-blog/what-to-know-about-why-using-storyboards-are-so-important/

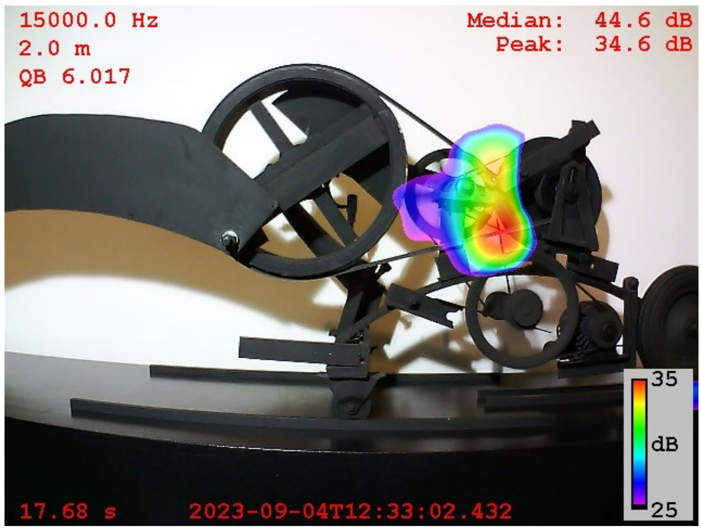
Yoon, S. A., Elinich, K., Wang, J., Van Schooneveld, J. B., & Anderson, E. (2013). Scaffolding informal learning in science museums: How much is too much? *Science Education*, *97*(6), 848–877. https://doi.org/10.1002/sce.21079

Appendices

Appendix A: Interpreting spectrograms and acoustic camera readings

Figure A1

Screenshot of acoustic camera visualization of Char MK *in BeamformX.*

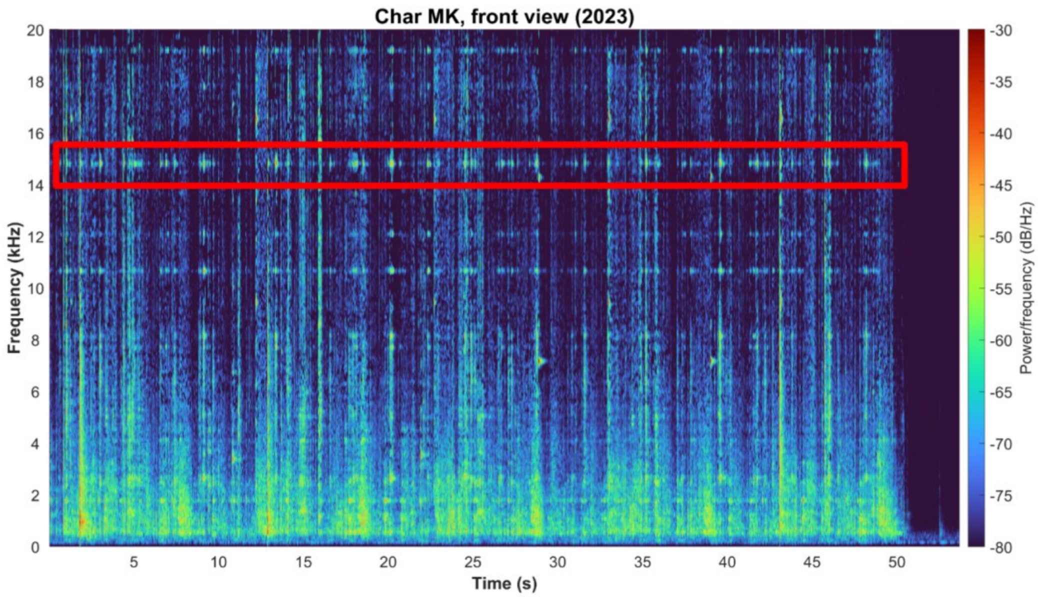


Understanding how to interpret acoustic camera outputs as well as sonogram diagrams is crucial to this paper. As seen in Figure A1, the computer software allows us to see which areas of the sculpture produce specific frequencies; for instance, when the 15 kHz frequency is selected (seen printed on the top left corner of the screenshot), a heatmap is generated telling us the sound is emitted mainly by the connection between the two wheels at the top right of the sculpture. The software also generates a colorbar indicating the relative strength of the audio signal (i.e., the volume of this sound as experienced by the acoustic camera), seen at the bottom right. For instance, in this output, a deep purple corresponds to a relatively quiet sound of 25 dB, whereas the bright red area seen between these two wheels indicates a louder sound of 35 dB.

It is important to note the two-dimensionality of these readings. The camera's output is not spatially aware; that is, it cannot differentiate different depths in emitted sound. Sometimes, emitted sounds are perceived by the camera as louder than they actually are if they echo off a wall. Furthermore, from the perspective recorded in Figure A1, the camera cannot distinguish between sounds emitted by two different parts if they are in front of each other. These side effects can be remedied by collecting several takes at different angles, allowing us to see if there are any reflections and how to factor that into our interpretation of the collected data.

Figure A2

Example spectrogram taken from a recording of Char MK *(1966).*



We also generated spectrograms from the collected audio, with an example seen in Figure A2 from the same dataset as the output in Figure A1. The generated spectrograms allow us to see a relationship between frequencies emitted by the sculptures, their relative intensity, and time. An important consideration is that these are not sonograms, as that term is related more to imaging generated through acoustic imaging technology, for example an ultrasound image of a baby in a womb. Spectrograms instead are a representation of emitted frequencies over time. On the left, a scale indicates which parts of the graph correspond to which frequency; from bottom to top, sounds are higher in frequency and thus higher in pitch. The horizontal scale indicates time; this specific recording was around 55 seconds long. Finally, the colorbar at right allows us to see the relative intensity of the emitted frequencies (i.e., their "loudness"), represented in these diagrams as dB/Hz (decibels per hertz). A darker blue means a sound is not very loud, while a red color indicates a louder sound. This spectrogram, for instance, lets us see the most representative frequencies emitted by *Char MK* are around the 0-2 kHz, 8 kHz, 11 kHz, 15 kHz, and 19 kHz ranges, as evidenced by the horizontal green lines in the graph (for example, the 15 kHz frequency, also highlighted in Figure A1, is shown here inside the red box).

Appendix B: MATLAB spectrogram generation script

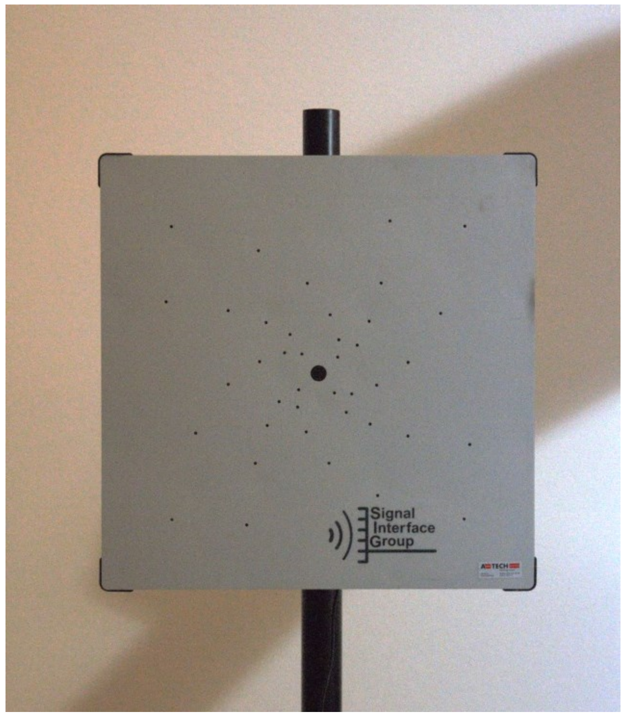
The following MATLAB script was written by the team with the goal of generating spectrograms from acoustic camera recordings, exported from BeamformX as MP4 files.

```
raw = audioread('myFile.mp4'); % read audio from bfx-generated video
fs = 44100; % set sample rate and time limits
dt = 1/fs;
t = (0:dt:5-dt);
window = hamming(512);
N_overlap = 256;
N_fft = 1024;
[S,F,T,P] = spectrogram(raw,window,N_overlap,N_fft,fs,'yaxis'); % generate
spectrogram
figure
surf(T,F,10*log10(P),'EdgeColor','none');
axis tight; view(0,90); colormap(turbo); %set view range and color map
set(gca,'clim',[-80,-40]); % determines decibel range, varies by sculpture
ylim([0 20000]); % minimum - maximum hz range for spectro. should be usually
kept at 0-20khz
yt = get(gca, 'YTick')
set(gca, 'YTick',yt, 'YTickLabel',yt/1E+3) % fix frequency bar to display kHz
instead of Hz
xlabel('Time (s)','FontSize',15,'FontWeight','bold');ylabel('Frequency
(kHz)','FontSize',15,'FontWeight','bold');
title('Figure Title','FontSize',20); % main title, change for each
sculpture/angle
ax = gca;
ax.XAxis.FontSize = 15;
ax.YAxis.FontSize = 15;
a = colorbar; % gen. colorbar w/ label
a.Label.String = "Power/frequency (dB/Hz)";
a.FontSize = 15;
set(gcf, 'Units', 'Pixels', 'Position', [0, 1000, 1570, 820]);
filename = fullfile('C:\Users\user\myFilePath',"mySpectrogram.png");
exportgraphics(ax,filename,'Resolution',300);
```

Appendix C: ACAM120 acoustic camera

Figure C1

Photograph of the SIG ACAM 120's beamformer head. The full device is mounted on a tripod.



The SIG ACAM 120 consists of an array of 40 digital microphones mounted on a plate (Signal Interface Group, n.d.), as seen in Figure 4. According to SIG's spec sheet, the microphone array has a useful frequency response from 50Hz to 20KHz, with useful data being output at up to 24KHz. In the middle of the plate is a 5-megapixel optic camera. These provided video output of Tinguely's sculptures as well as an overlay showing where sound is being emitted by the sculptures.

The microphones are placed in a logarithmic spiral formation, which helps them determine directionality and improves their angular resolution during beamforming. Due to this logarithmic geometry, there are no parallel lines or repeated distances between microphones which allows the camera to detect a wider range of frequencies (Aldeman, 2020). The spiral nature also inherently reduces the detected maximum sidelobe level, or undesired noise. However, a recent beamforming study comparing a spiral microphone array with a separable rectangular microphone array (wherein the microphones are arranged in a linear as opposed to spiral pattern with irregular distances relative to each other), as shown in Figure 1 in their paper, suggested that the two may have similar performance for moving sound sources if deconvolution methods are used on the separable array (Meng & Vorlaender, 216).

Appendix D: 2023 spectrograms

The following is a collection of all spectrograms generated from our data collection. To see the spectrograms generated from the data collected by the 2017 IQP team, refer to Appendix E.

Figure D1

Spectrogram of Char MK*, front view.*

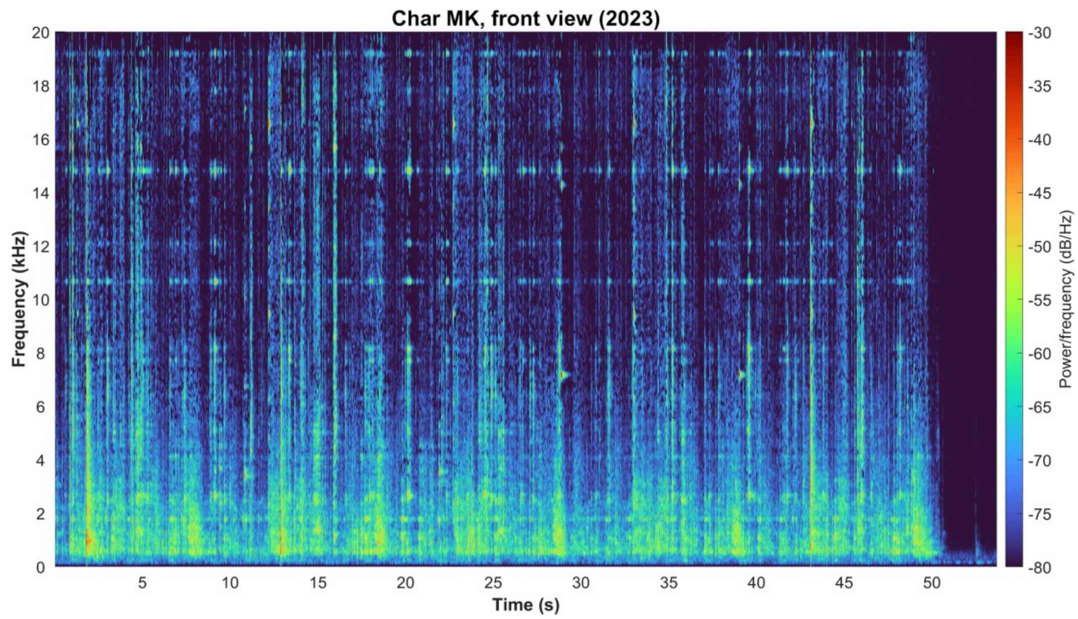


Figure D2

Spectrogram of Char MK*, side view.*

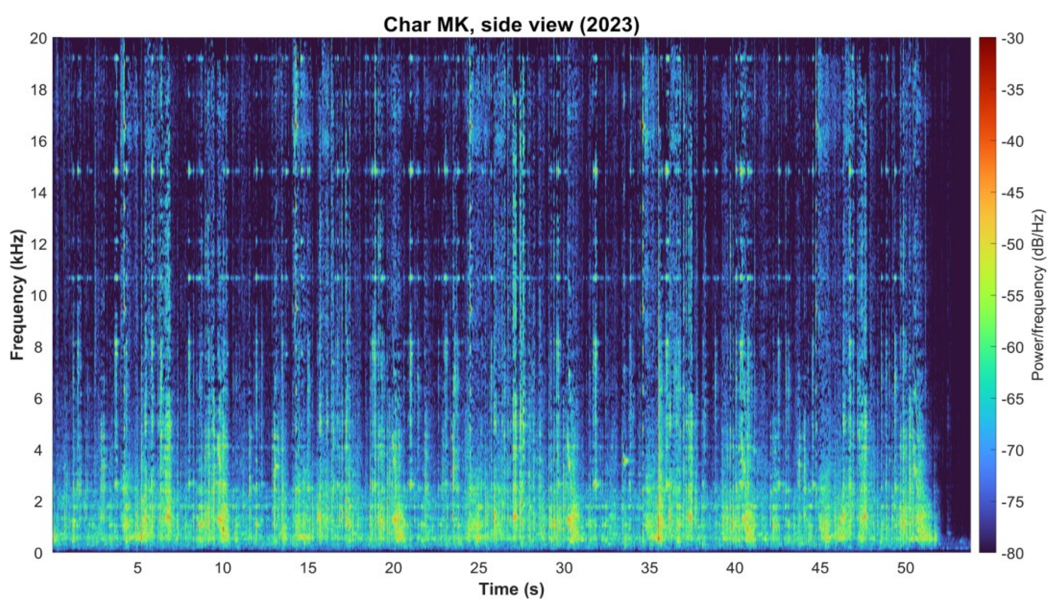


Figure D3

Spectrogram of Hannibal II*, front view.*

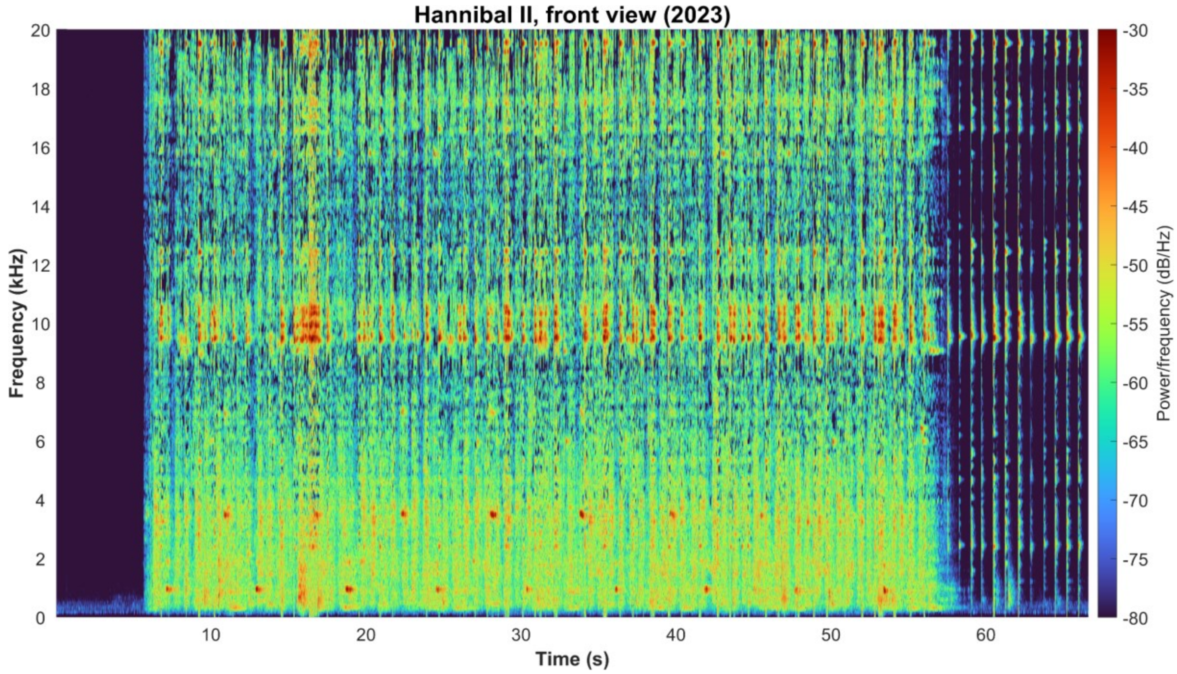


Figure D4

Spectrogram of Hannibal II*, side view.*

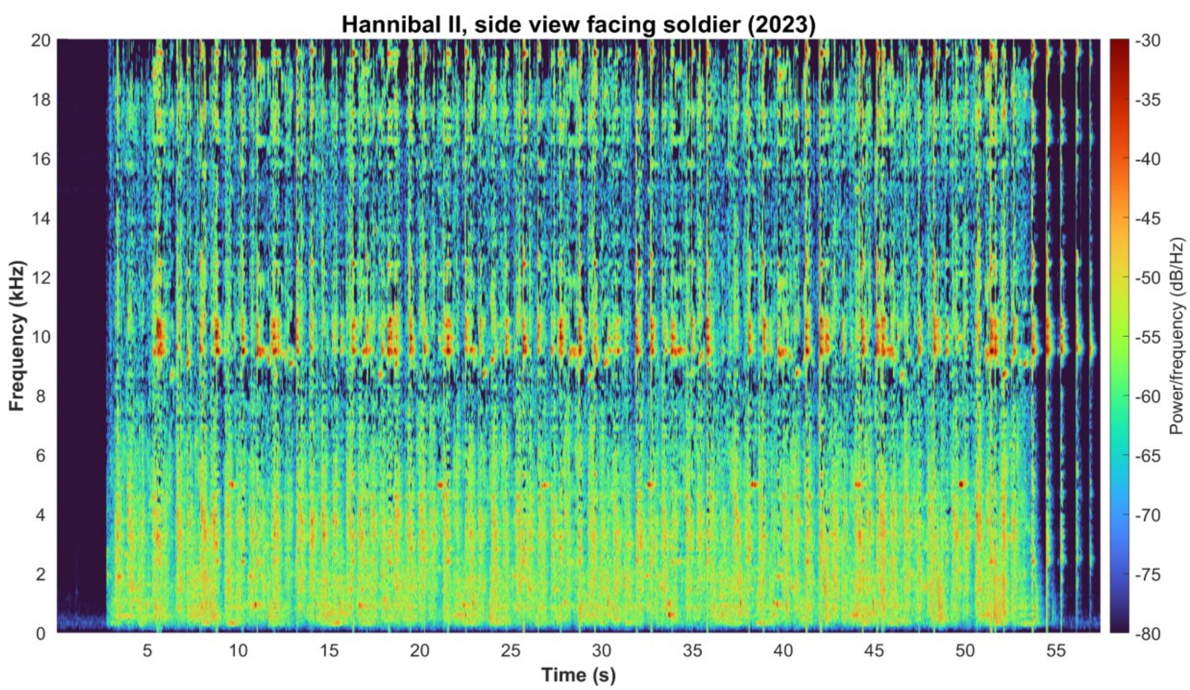


Figure D5

Spectrogram of Hannibal II*, with the acoustic camera focused on the "elephant" (i.e., the larger section of the sculpture as opposed to the smaller "soldier").*

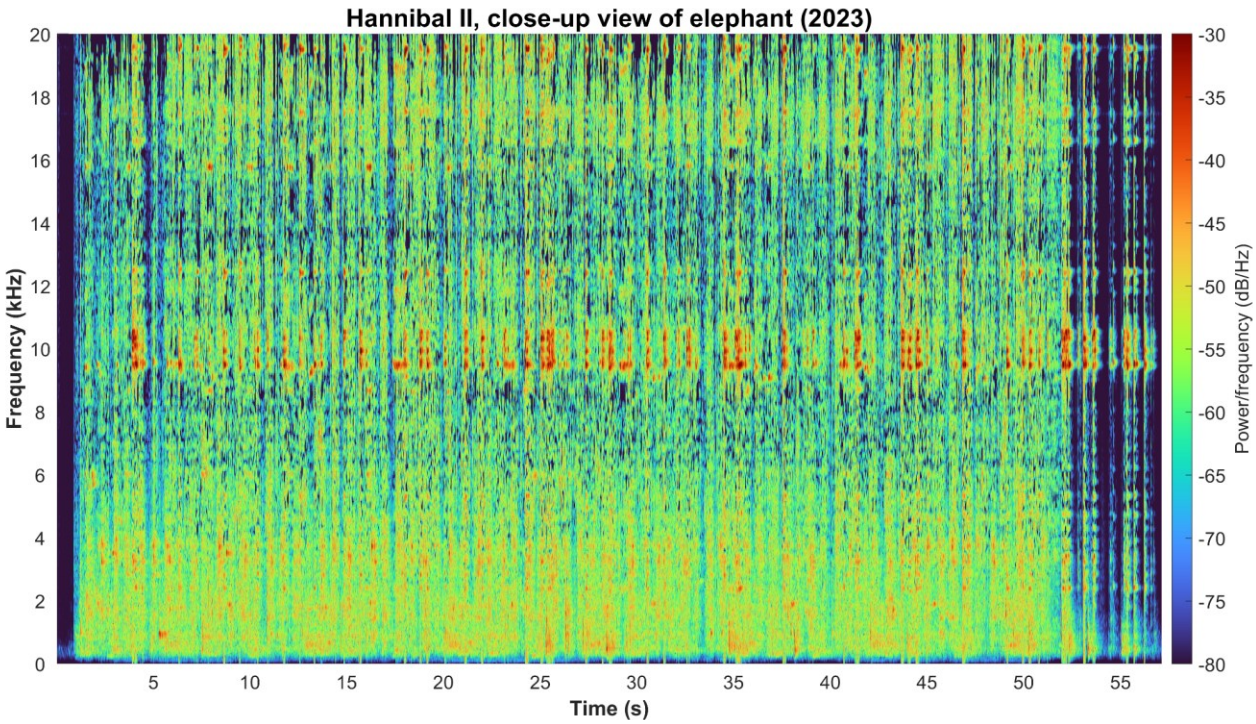


Figure D6

Spectrogram of Hannibal II*, back view.*

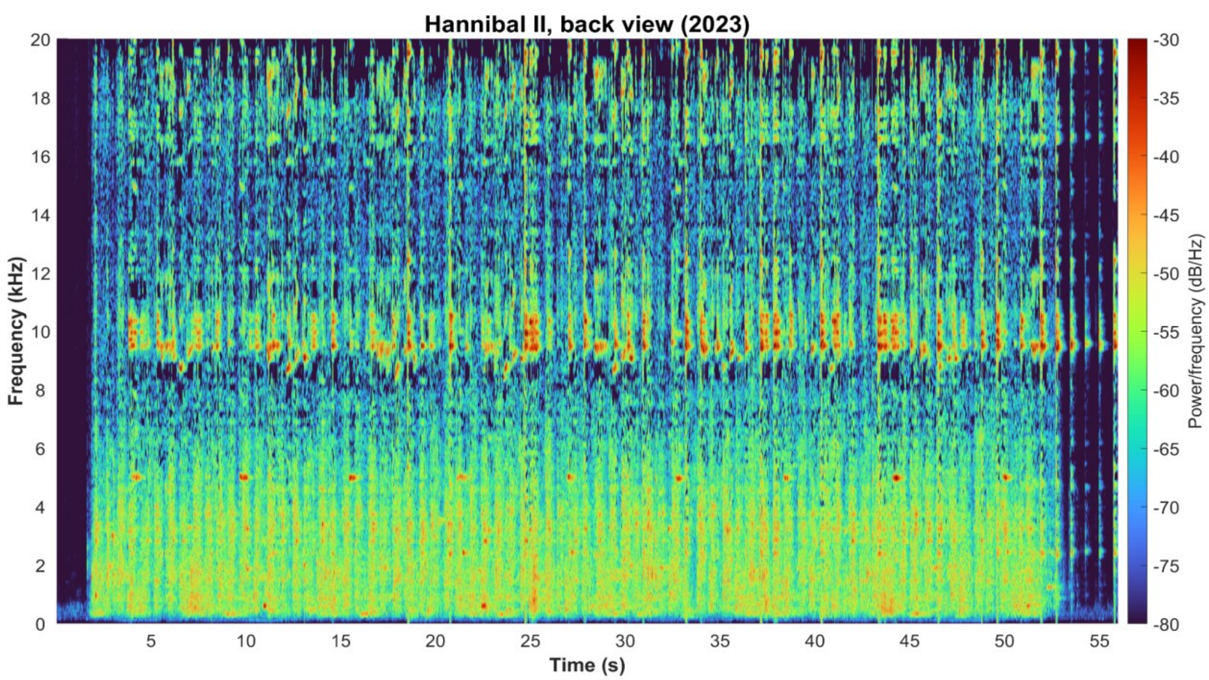


Figure D7

Spectrogram of Matrac*, front view.*

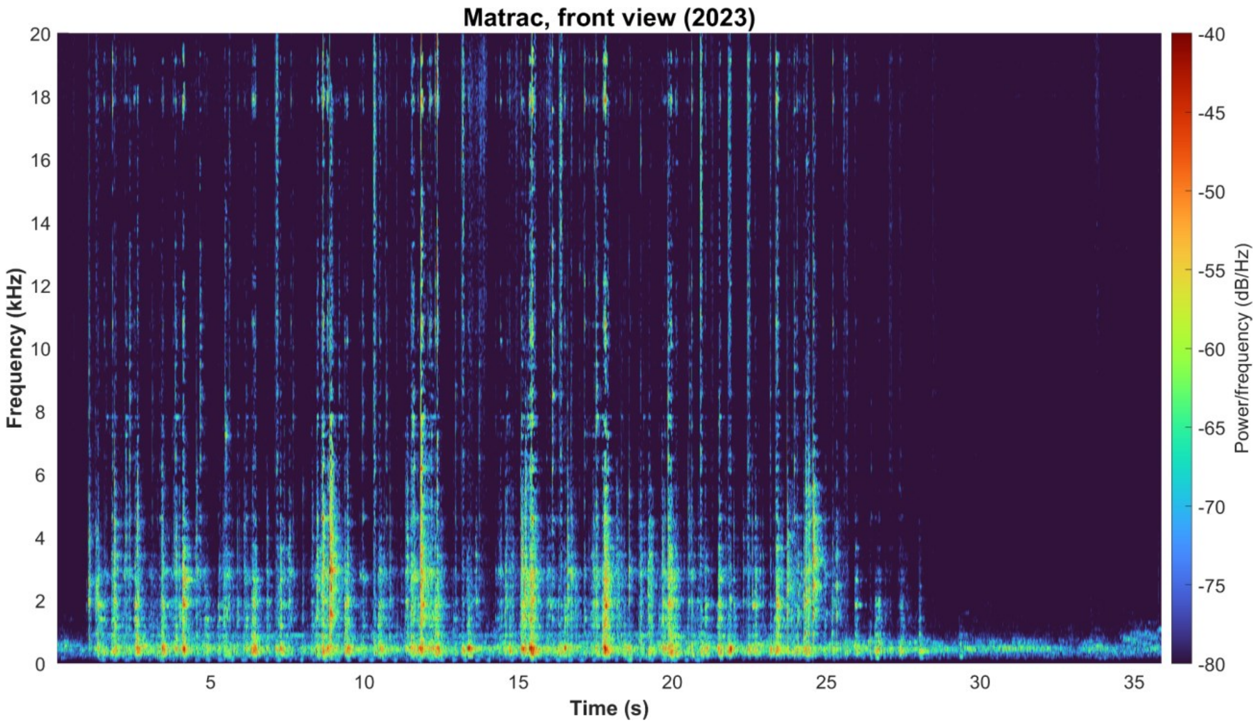


Figure D8

Spectrogram of Matrac*, with the camera focused on the double pendulum.*

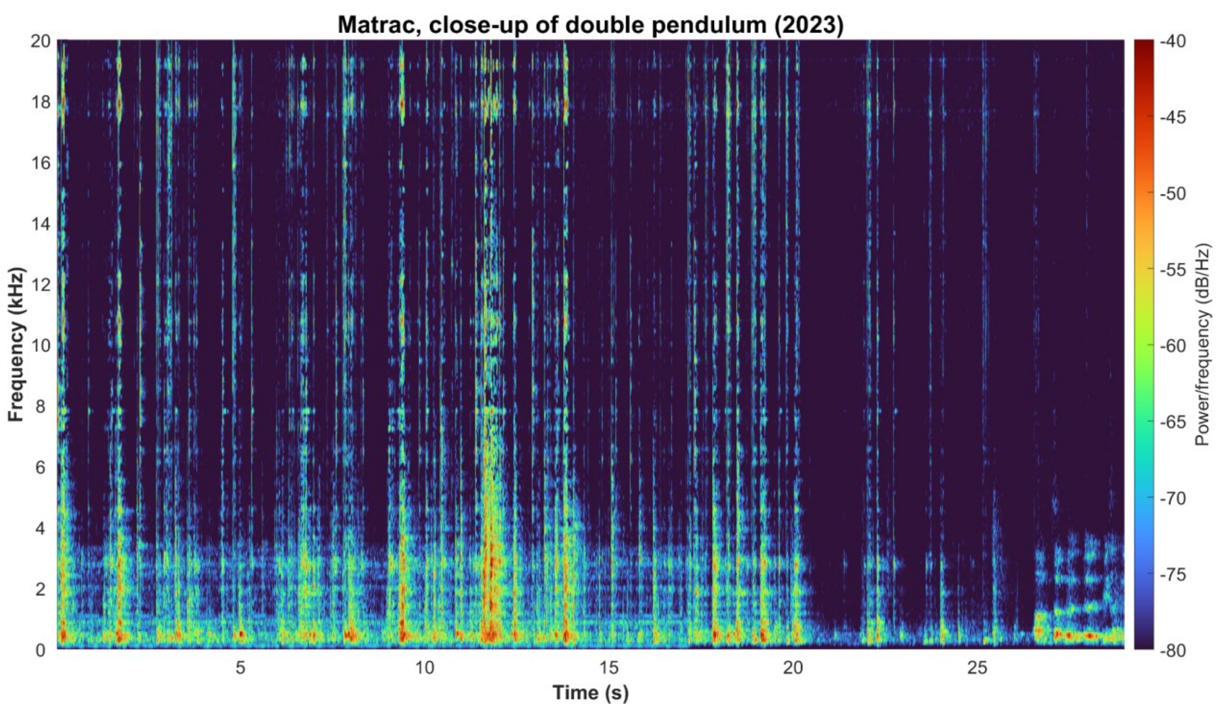


Figure D9

Spectrogram of Matrac, *side view.*

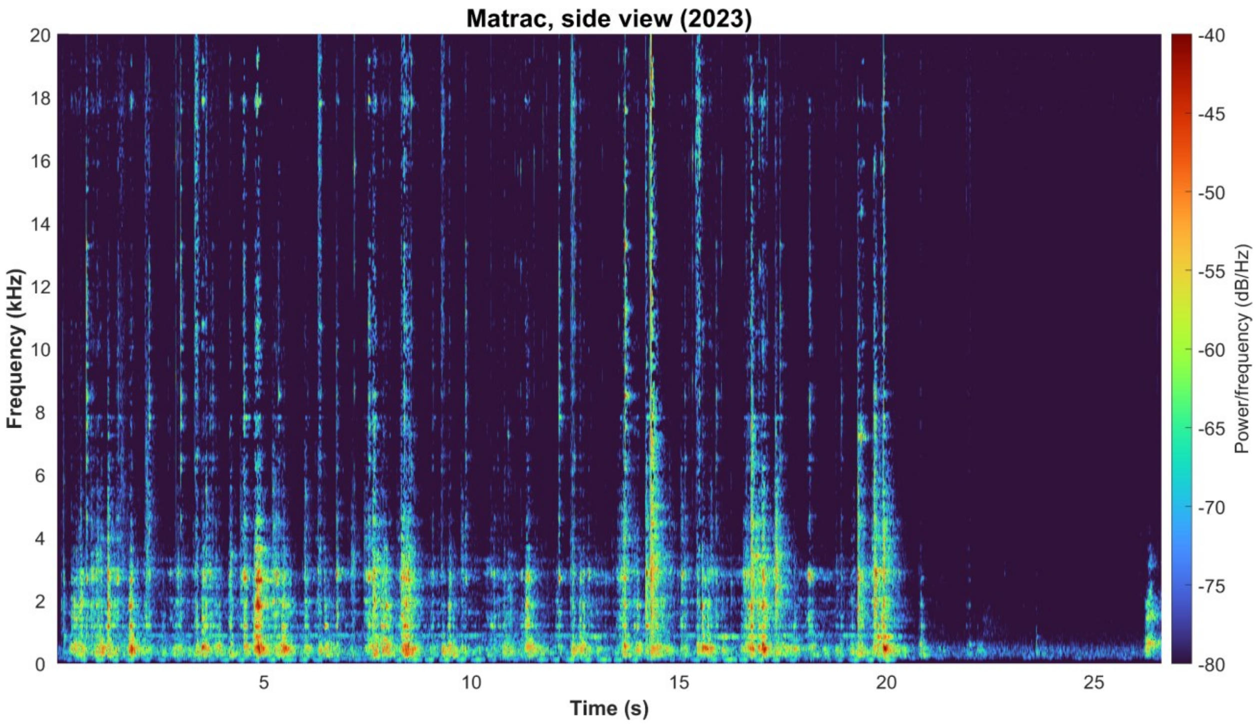


Figure D10

Spectrogram of Santana*, front view.*

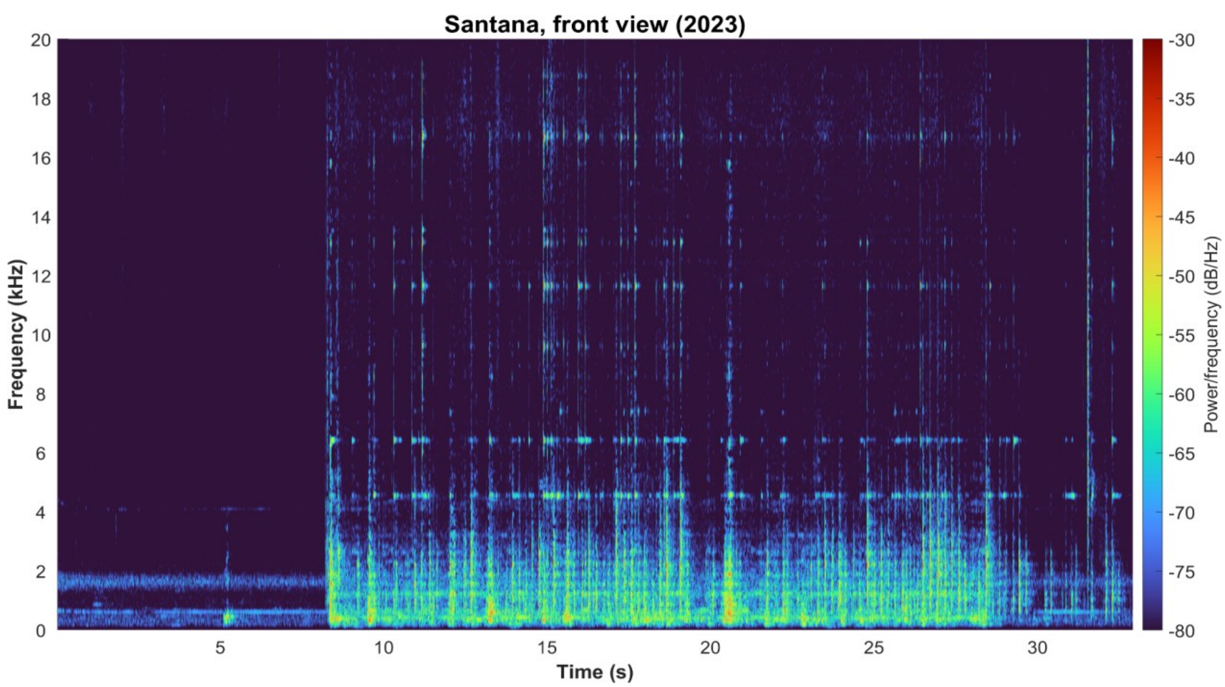


Figure D11

Spectrogram of Santana*, side view.*

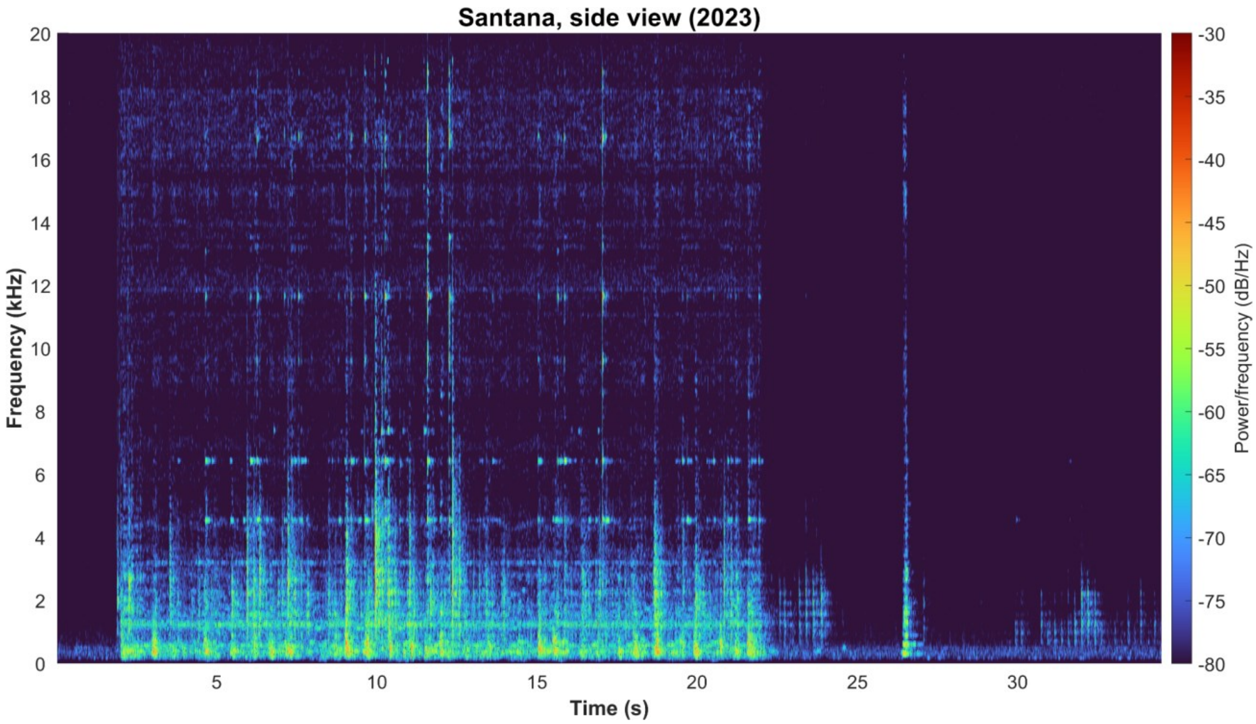


Figure D12

Spectrogram of Santana*, with the camera focused on the joint between the motor and wheel.*

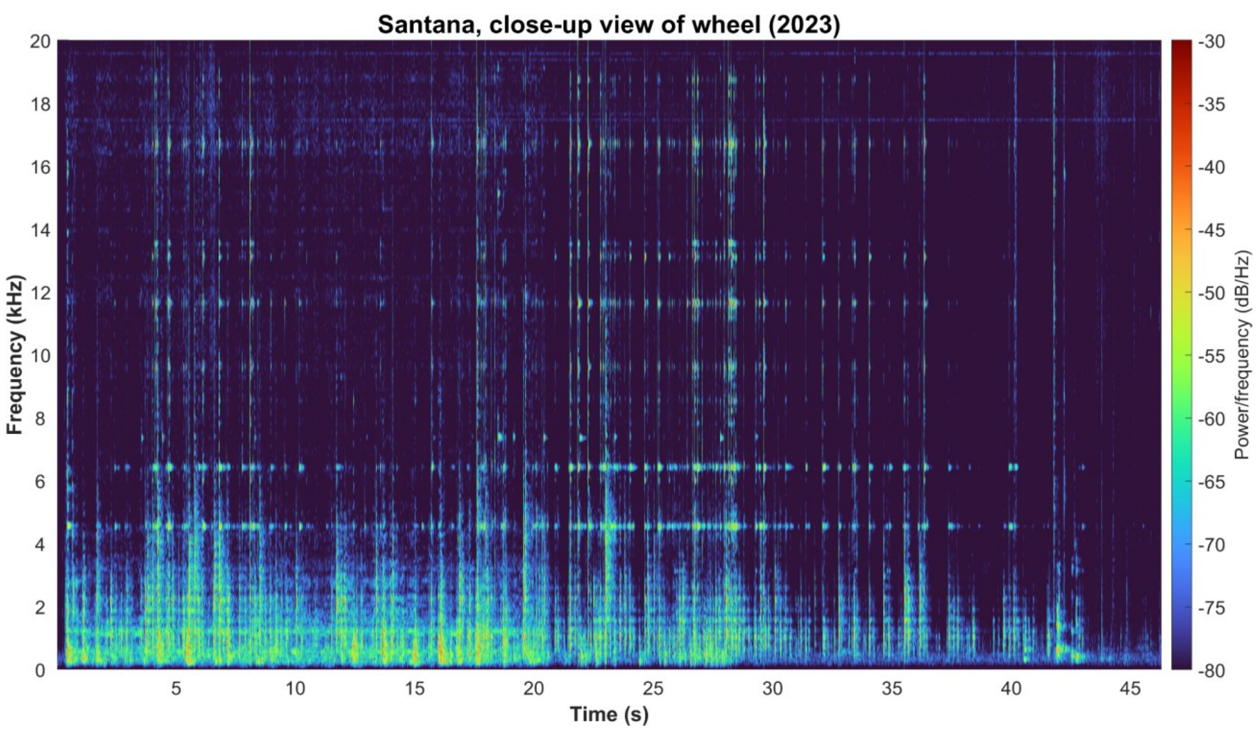
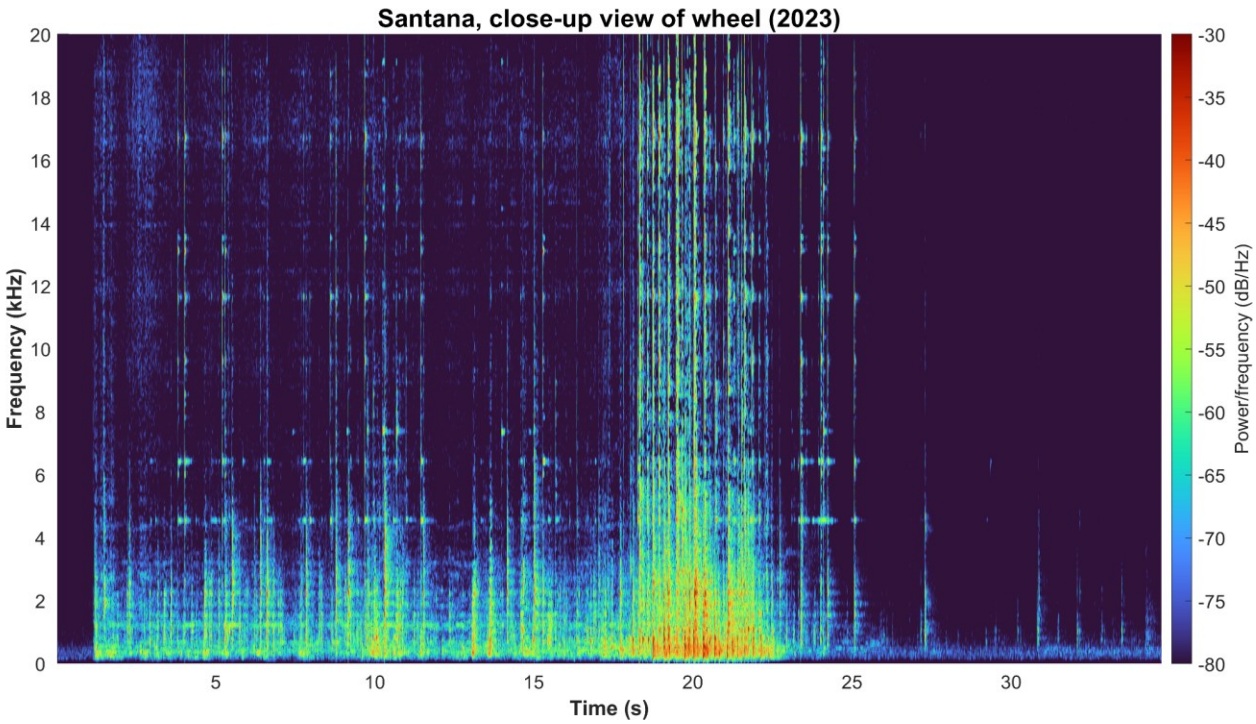


Figure D13

Spectrogram of Santana*, front view. On this run, the wheel began to resonate with the motor at around 17 seconds, making the entire sculpture shake violently.*



Appendix E: 2017 spectrograms

The following is a collection of all spectrograms generated from the 2017 IQP data. It is important to note that we did not collect the data in these spectrograms, but rather converted the raw acoustic camera data into spectrograms for easier visualization.

Figure E1

Spectrogram of Hannibal II*, front view.*

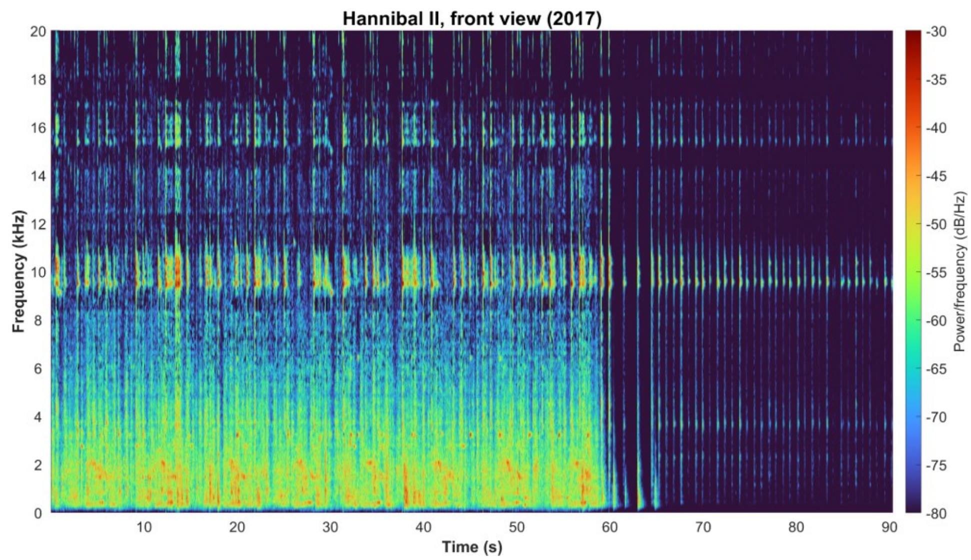


Figure E2

Spectrogram of Hannibal II*, side view.*

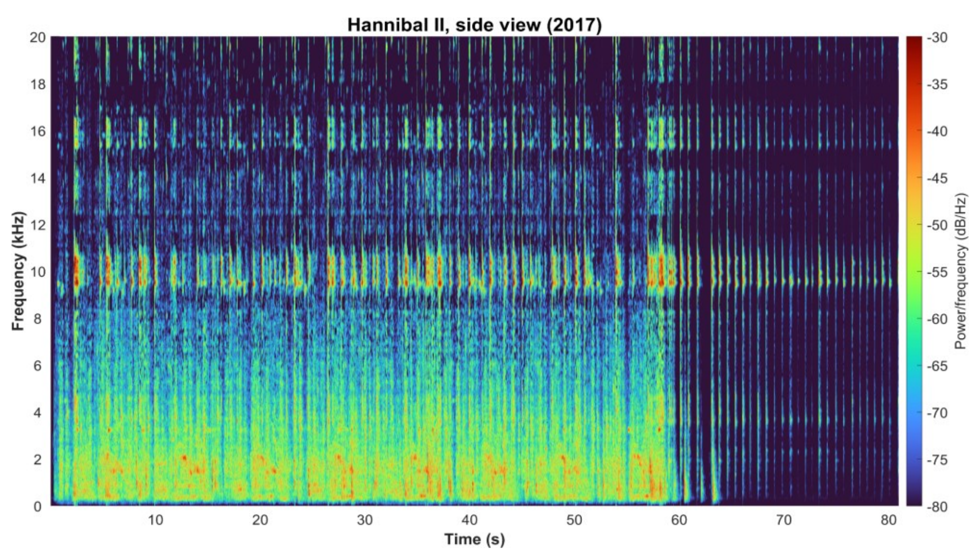


Figure E3

Spectrogram of Matrac*, front view*.

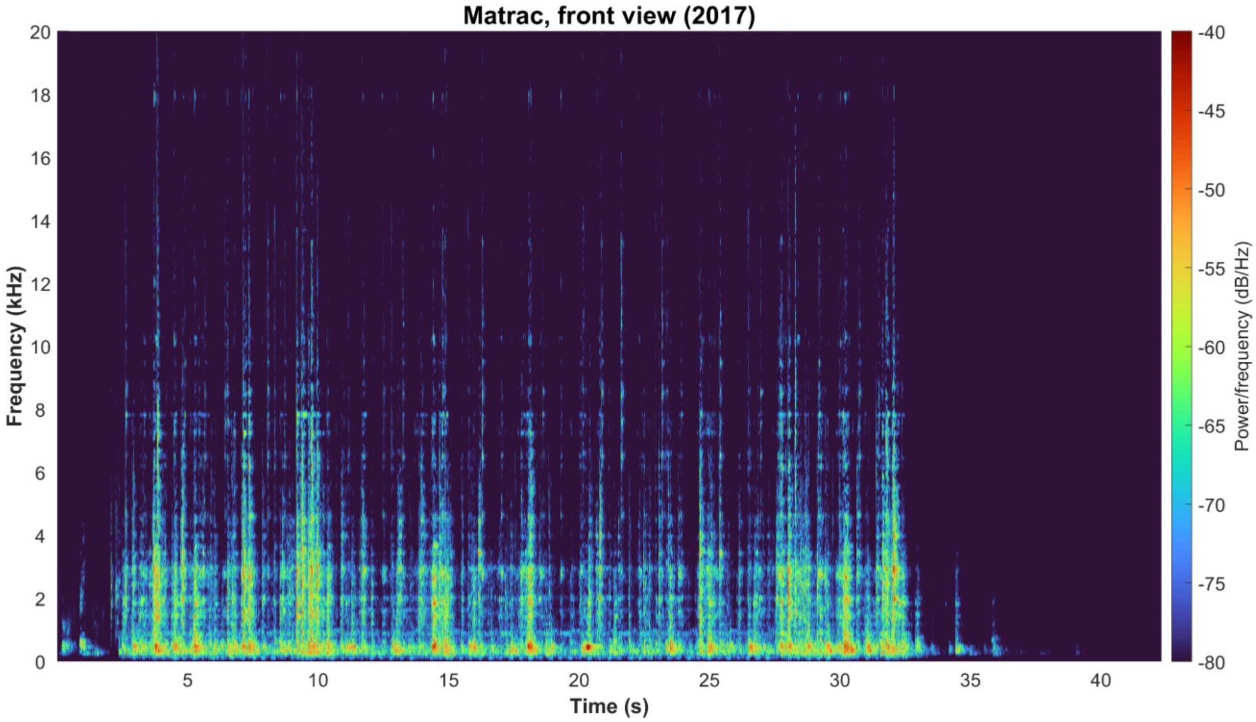
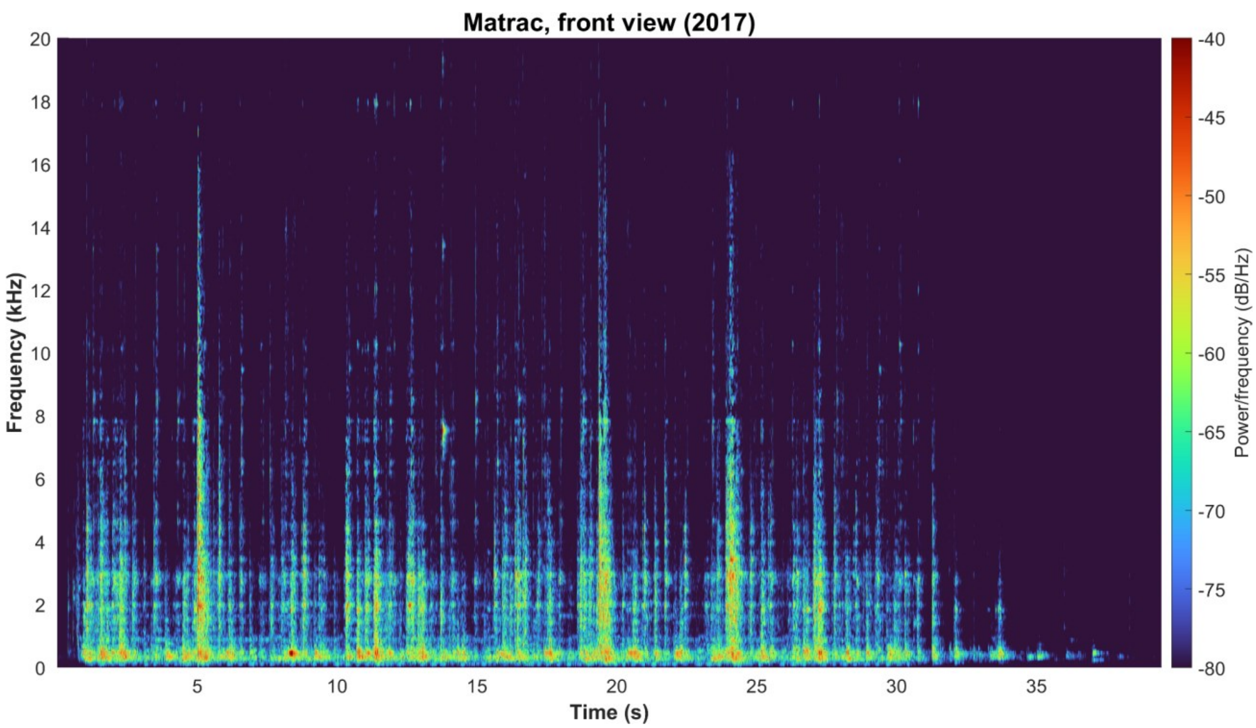


Figure E4

Spectrogram of Matrac*, front view (alternate take)*.



Appendix F: Interview Guide for conservation experts

Note: Often during interviews, we felt it was important to ask additional or follow-up questions that are not necessarily included here. We also needed to omit questions to be respectful of the interviewee's time.

Interview with Jean-Marc Gaillard, conservator at the Museum Tinguely:

Goal: Learn methods and considerations for art conservation

1. May we record this meeting?
2. Can we include your name or would you prefer to remain anonymous?
3. We are creating a video to be displayed in the Museum, would we be able to potentially use parts of this recording in it?
4. Describe your experience with art conservation
5. What inspired you to get into conservation?
6. How if at all has your outlook on conservation changed over the years?
   a. What led to that?
7. What are some conservation techniques that you apply?
8. How do you identify wear in an art piece?
9. Do you check the artwork regularly? If so, how often?
10. What would you say was your most challenging project?
11. What do you think about the reality that artwork like that of Jean Tinguely can change over time?
12. Do you feel that it should be conserved exactly in its original form or be allowed to naturally evolve because of wear?
13. What did you do with Tinguely's art?
14. Is there a record of conservation steps taken with the art?
15. What challenges did Tinguely's art present?
16. How did the moving nature of Tinguely's art affect conservation?

17. We’ve read that Tinguely would make changes to the art when maintaining it.What do you think about that? Do you think that you should be able to or is your job just to preserve it as it was when he died?
18. What considerations did you take into account with conservation of his art?
19. What, if any, role did sound play in the conservation steps that you take?
20. Have you ever used acoustic cameras or other forms of acoustic imaging, even just listening to the parts yourself, to help with art conservation? If so, what signs show wear?
    a. (If asked to clarify with examples of signs: high frequency, changes in frequency, length of time that a part was making a certain sound, etc.)
    b. If no: What do you think about the use of an acoustic camera?
21. Would you be willing to be contacted for a possible follow-up interview?

Interview with Roland Wetzel, director of the Museum Tinguely:

1. May we record this interview?
2. May we include portions of it in the exhibit video?
3. If we have follow-up questions, is there a way that we can contact you?
4. What is your role as director of the museum?
5. How would you describe the Museum Tinguely’s purpose?
    a. (i.e. toward education, the artwork, visitors, etc.)
6. What kind of visitors attend the museum? Age? Engineering or related interests?
7. How do visitors interact with the exhibits?
8. Are you the person that we should talk to with questions regarding the video and infographic?
9. What is the museum’s preferred video duration and video requirements?
10. What information should be included in the video vs the infographic? Our interpretation is that the video is to showcase the use of the camera and how the art is decaying, while the infographic is just about restoration and conservation.
11. What style should we go for with the infographic? We’ve seen some info around the museum that is all text, but we would like to have it be more image based.

12. What language(s) for both the video and infographic? For the video, we can only do english. For the infographic, we may be able to ask our sponsors to translate into German, French, and Italian.
13. What target audience should we gear our exhibit toward?
14. How should we deal with incorporating third-party work in either the video or infographic that is either public domain or has a copyright that allows for use in the exhibit?
15. What is your relationship with the conservator(s) like?
16. How do you think that Tinguely's art should be maintained? Should parts be replaced?
17. How important is keeping the art looking the same? Sounding the same?
18. How do you balance conservation with allowing people to see or interact with the art?
19. How would you define conservation and restoration, and how do they differ, if at all? What is the importance of this difference?
20. What are the complexities of conserving and restoring an artwork from the director's point of view? Is the artwork devalued if it is restored?
21. Is the duty of conservationists at the museum to precisely maintain Tinguely's art as it was when he died, or to keep his machines functional even if some aspects of them change?
22. What would happen if an artwork stopped working or a piece broke off while it was operating in the museum? Would attempts be made to fix it, or would this be considered changing the artwork beyond its original form?
    a. What happens to works that cannot be fixed without significantly altering it or replacing parts? Would you say at this point that the art is no longer as the artist originally intended?
23. Have you considered how longer you will be able to continue restoring the artworks? At the point where restoration or conservation efforts are no longer useful will you keep the artwork still? Or will you continue to play the artwork until it breaks?
24. What are your thoughts on the use of the acoustic imaging to prevent wear before it is more noticeable and to create a record of changes?

Interviews with Marc Egger, conservator, and (separately) Reinhard Bek, conservator:

Goal: Learn about different techniques and approaches to the conservation of kinetic sculptures as well as another point of view on acoustic imaging as a tool to help the conservation of the sculptures.

1. May we record this meeting?
2. Can we include your name or would you prefer to remain anonymous?
3. We are creating a video to be displayed in the Museum, would we be able to potentially use parts of this recording in it?
4. What is your role within the Fachhochschule?
5. How is your experience with kinetic art conservation? Is it theoretical or practical?
6. Have you worked on any specific artwork that you would like to share?
    a. Have you worked on any pieces by Jean Tinguely?
7. Are you familiar with acoustic imaging?
    a. if not provide short explanation
8. How do you think acoustic imaging can be useful for the future of kinetic art conservation?
9. How do you approach your classes when teaching art conservation?
10. What techniques in kinetic art conservation are more common nowadays?
11. What is your experience, if any, with the Museum Tinguely in Basel? Are you aware of their conservation strategy?
12. Do you think Museum Tinguely is doing a good job conserving the artworks?
    a. Or do you think they are overworking them? (follow up)
13. What techniques would you propose to the Museum Tinguely to better conserve the artworks?
14. How would you analyze an artwork for wear? Is it difficult to spot wear in an artwork like Jean Tingely's?
15. What challenges does Jean Tinguely's artworks present?
16. What is your opinion on the conservation of Jean Tinguely's artworks?
17. Do you think they should be conserved or restored?
18. How is sound important to identify wear in a kinetic sculpture?
19. Have you ever encountered the stick-slip phenomenon as a cause of wear in pieces?

a. How do you identify it as a problem?
b. How would you mitigate it?

Appendix G: Interview consent script

As a group of students from Worcester Polytechnic Institute (WPI) in Massachusetts, United States, we would like to invite you to participate in an interview for our research to learn more about the conservation of Jean Tinguely's art. The purpose of our research is to create an exhibit for the Museum Tinguely to explain acoustic imaging and how it can be applied for art conservation. The kind of information that we aim to get from the interview is your experience and knowledge in the area of art conservation. We anticipate that the interview should take about sixty minutes.

This is a collaborative project between the Swiss Federal Laboratories for Material Science and Technology, the Haute-Ecole Arc, the Museum Tinguely, and WPI, and your participation is greatly appreciated. Information from our project will be published in a publicly available academic document at the end of our term and we can share a copy of our results if you are interested. No names or identifying information will appear in any of the project reports or publications unless you give us consent to do so.

Your participation in this interview is completely voluntary and you may withdraw at any time. This also means that you can skip any questions that you want. Do you have any questions for us about this interview?

For more information about this research and the rights of research participants, you may contact us by email at gr-tinguely@wpi.edu or the Institutional Review Board (IRB) Manager (Ruth McKeogh, Tel. 508-831-6699, Email: irb@wpi.edu) or Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu). Thank you very much!

Appendix H: Video planning and structure

Objectives of the video:

1. Explain how the decay of the machines is happening and why
2. Explain acoustic imaging
3. How acoustic imaging helps identify how the sculpture decays. And therefore how it is useful to conservation and restoration.

Stages of video production:

1. Initial development - what the video is about and who is the target audience. Goal of the video
2. Pre-production - storyboarding.
3. Production - Follow the planned script created during pre-production.
4. Post-production - Edit the video, include the most relevant information. Cut unnecessary stuff. Voice overs and animations.
5. Distribution

Planning Video checklist:

1. Define the goal of the video
2. Identify audience
3. Define the message of the video
4. Define the type of video
5. Storyboard of the project
6. Script of the project
7. Schedule video recording
8. Video editing

Checklist answers:

1. The goal of the video is to illustrate and explain how an acoustic camera is helpful in identifying which parts of the machine are decaying and how and for what reason the decay is happening.

2. The audience is museum visitors. Museum visitors vary in culture and age prominently. Meaning that all of them will have different learning backgrounds. For that reason it is important to do a video all visitors can understand and enjoy.
3. The message of the video is to convince the museum and the visitors that the acoustic camera can be a tool for the aid of conservation of Kinetic Sculptures.
4. The type of the video is educational as we want to make the audience learn about the acoustic camera and the decay of kinetic sculptures.

Scripting/storyboarding:

- Cut everything that is not helping the objectives and final goal
- Add dialogue, key frames, ideas and additional animations.

Things to keep in mind:

- Style of the video - we should see the other videos around the museum and try to do a similar style if needed.
- (While visiting one of our website sources we realized that…)Have in mind the outcome of the video. Do not get lost in production and start adding things that are not necessary. “Throw out the learning objective and focus on what you want the learner to actually do.”
- Where is the video going to end up? - the museum. This will help
- Add proper citations to external footage and/or data
- The more messages the video has the less the audience will likely understand or remember them.

Video structure:

1. Intro cutscene with title and sponsor’s logos.
2. Footage of the machines and voice over introducing kinetic sculptures.
3. Close up footage to pieces that clearly look old and run down. (voice over that starts identifying the problem)
4. Footage of “people” analyzing the artwork (voiceover explaining that the machines take checks. How do restorators know that it’s wearing down.) + Footage of interviews + If some interviewers don’t want to show up in the video they can put important quotes on the screen.

5. Footage of machines working. (voice over talking about that sometimes is difficult to determine where wear is coming from, from just the sight. (although the museum has very professional restorators))
6. Footage of how an acoustic camera works (voice over explaining how an acoustic camera works)
7. Footage of the software (voice over explaining the specifics of how the software creates spectrograms and how the spectrograms are important)
8. Footage of us using an acoustic camera to analyze the artwork (voice over explaining the importance of the acoustic camera analyzing the artwork)
9. Footage of thoughts from the restorators of the use of the acoustic camera to analyze the artwork.
10. Acknowledgements section

Appendix I: Video storyboard

Figure I1

First page of Storyboard 1.

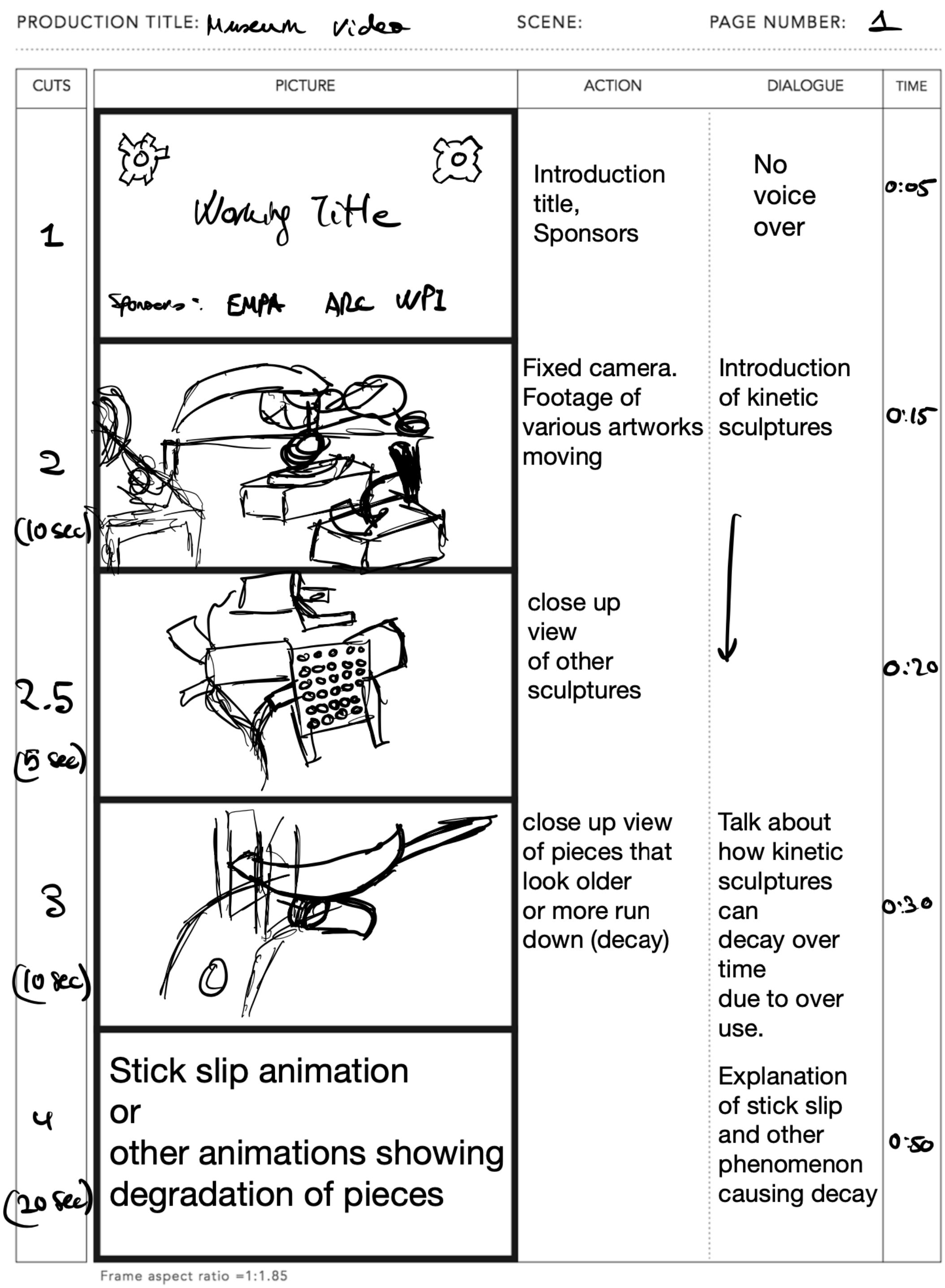
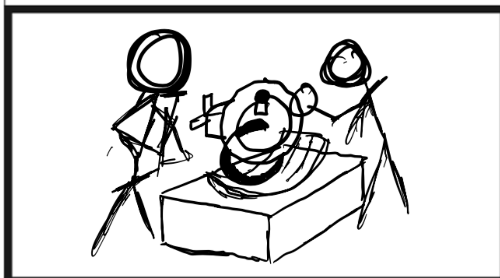
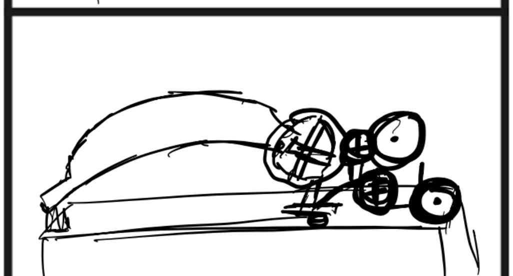
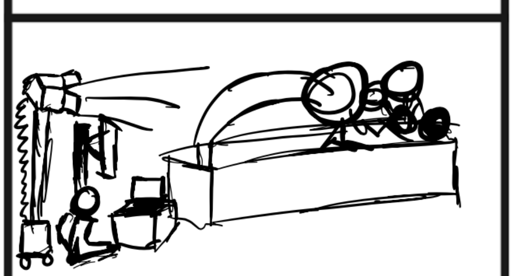


Figure I2

Second page of Storyboard 1.

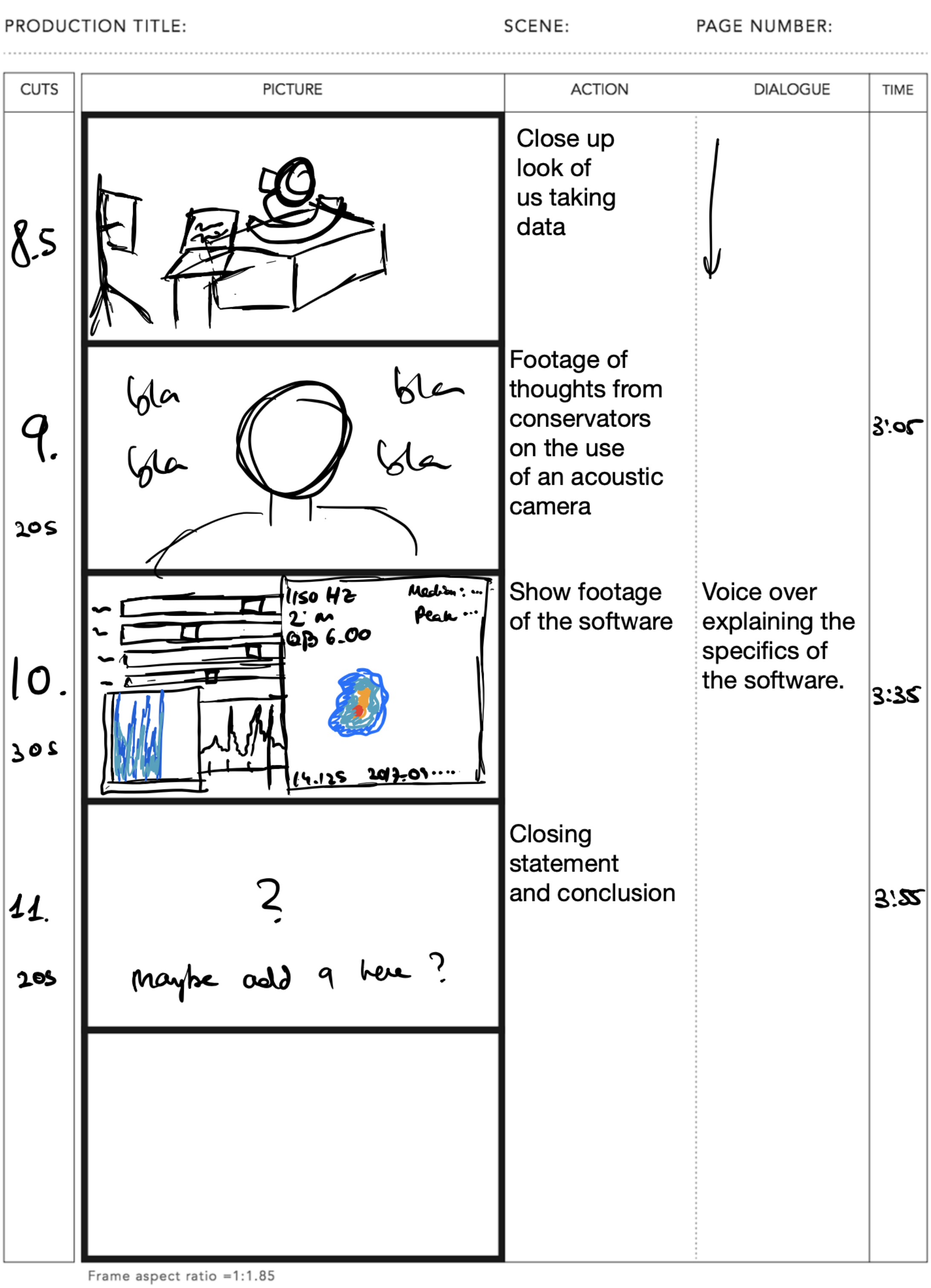
PRODUCTION TITLE: SCENE: PAGE NUMBER: 2

CUTS	PICTURE	ACTION	DIALOGUE	TIME
5 20s		Conservators analyzing an artwork and working on the conservation/ restoration of an artwork.	Talk about techniques of conservation or restoration	1:10
5.5 15s		Small fragment of the interview with Jean Marc.	Fragment about how they now when to undertake conservation methods. And if they do monthly or yearly checks on the artworks	1:25
6 10s		Footage of machines that we are analyzing	Talk about that it can be difficult to determine wear from just sight. Even though the museum has very professional conservators.	1:35
7. 40s	External video is preferable: Video with animation of how acoustic camera might work.	Footage of how an acoustic camera works	Voice over explaining how the acoustic camera works.	2:15
8. 30s		Footage of us using an acoustic camera to analyze the artwork.	Voice over explaining the importance of the acoustic camera to analyze the artwork.	2:45

Frame aspect ratio =1:1.85

Figure I3

Third page of Storyboard 1.

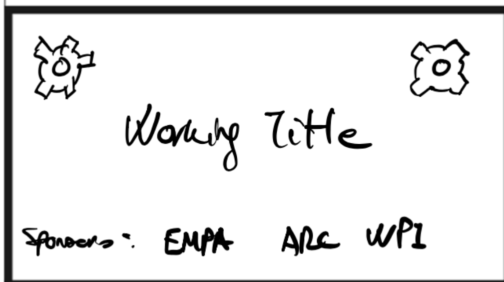
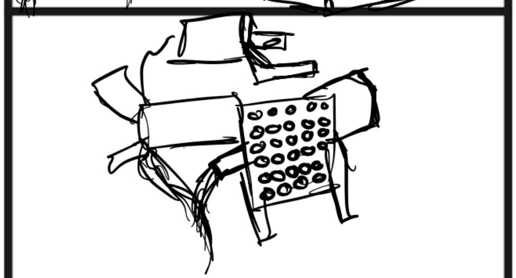
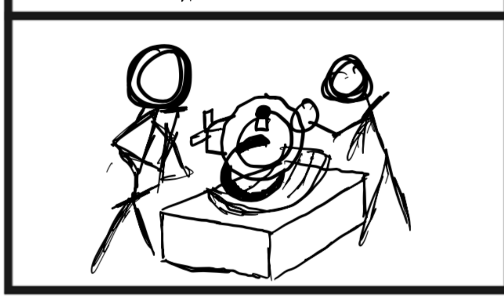


As mentioned in the Results section, our storyboard changed while we were discussing which takes were better. In our new storyboard we merged scene 4 into scene 3 since their message was similar and that would help smooth the rhythm of the video. Merging scene 4 with 3 created a different number for every scene, to be more clear the scene number with the explanation of changes will be from storyboard 1. We also decided to add some footage of us taking data for scene 7 that would talk about how an acoustic camera worked. The original plan was to look for some animation online that showed how the acoustic camera worked but we chose to change that because of copyright reasons. We thought it would be best to shoot our own footage. Another noticeable change is that we moved scene 10 of the first draft before scene 8. Scene 10's goal was to explain the software of the acoustic camera and how the data is useful therefore, it made more sense to move that scene after we talk about the acoustic camera. Since we would talk about the software after scene 7 the close up footage of us taking data in scene 8.5 was moved to a new scene called 7.5 to make a smoother transition. Finally, the last change we did was to end the video with an acknowledgements scene (scene 10).

Figure I4

First page of Storyboard 2.

PRODUCTION TITLE: Museum video SCENE: PAGE NUMBER: 1

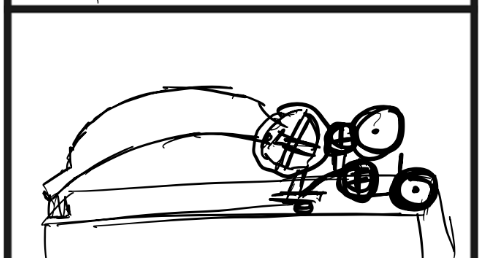
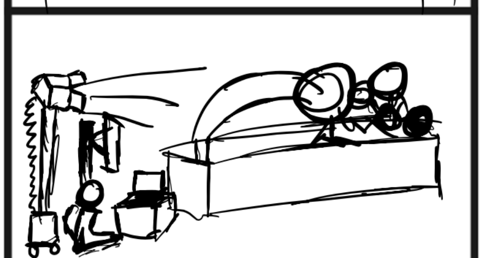
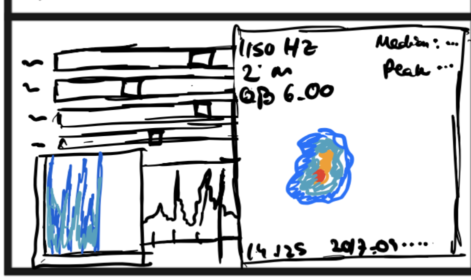
CUTS	PICTURE	ACTION	DIALOGUE	TIME
1		Introduction title, Sponsors	No voice over	0:05
2 (10 sec)		Fixed camera. Footage of various artworks moving	Introduction of kinetic sculptures ↓	0:15
2.5 (5 sec)		close up view of other sculptures		0:20
3 (20 sec)		close up view of pieces that look older or more run down (decay)	Talk about how kinetic sculptures can decay over time due to over use.	0:40
4 20 s		Conservators analyzing an artwork and working on the conservation/ restoration of an artwork.	Talk about techniques of conservation or restoration	1:00

Frame aspect ratio =1:1.85

Figure I5

Second page of Storyboard 2.

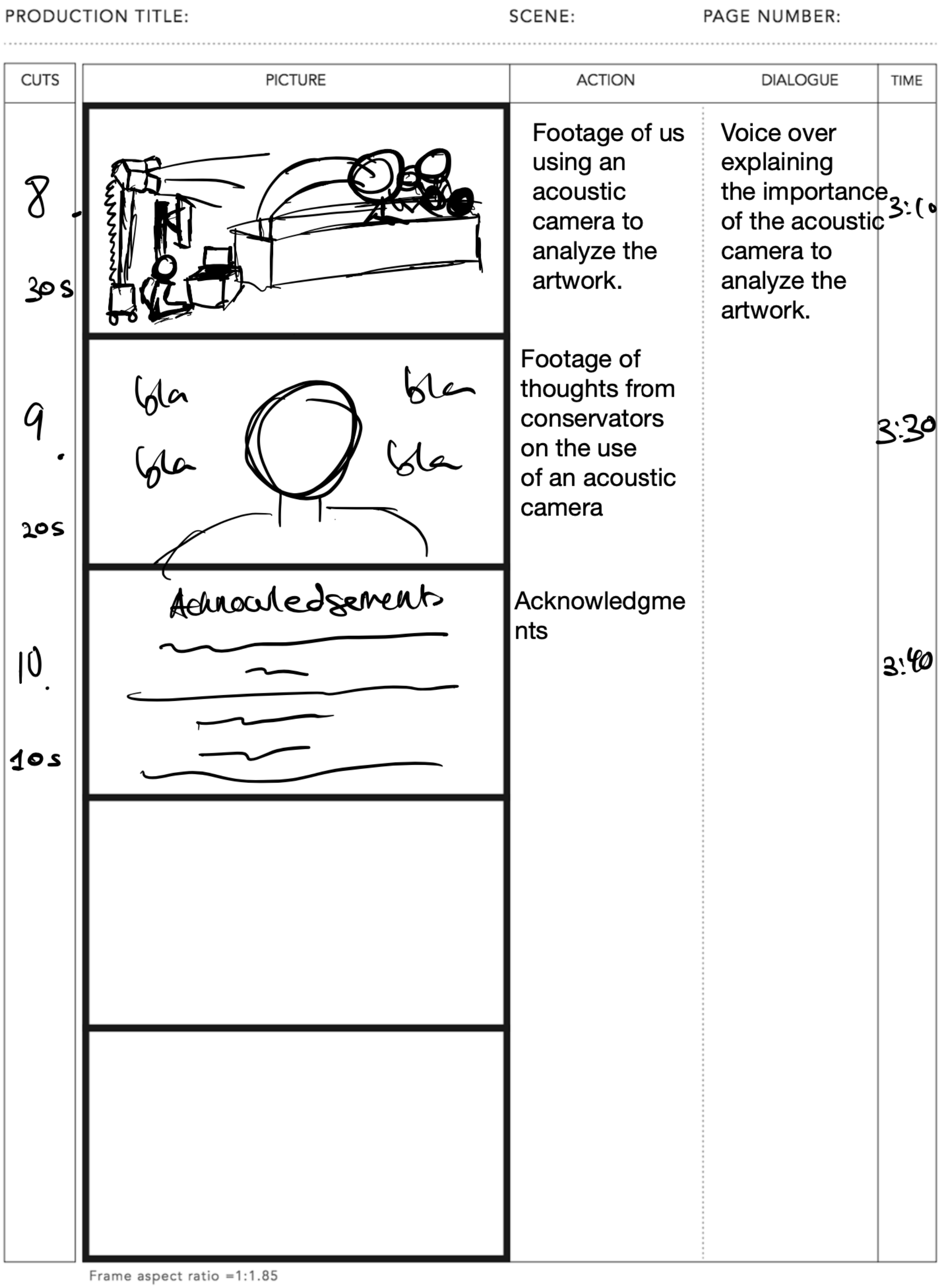
PRODUCTION TITLE: SCENE: PAGE NUMBER: 2

CUTS	PICTURE	ACTION	DIALOGUE	TIME
4.5 20s		Small fragment of the interview with Jean Marc.		1:20
5 10s		Footage of machines that we are analyzing	Talk about that it can be difficult to determine wear from just sight. Even though the museum has very professional conservators.	1:30
6. 40s		Footage of how an acoustic camera works	Voice over explaining how the acoustic camera works.	2:10
6.5		Close up look of us taking data	↓	
7. 30s		Show footage of the software	Voice over explaining the specifics of the software.	2:40

Frame aspect ratio =1:1.85

Figure I6

Third page of Storyboard 2.



Appendix J: Video script

NOTE: This script is based on storyboard 2

<u>Scene 1 – Introduction scene; title and sponsors.</u>

Goal: To introduce the sponsors and transition into scene 2

Script: No script

Music: Introductory music.

Sound effects: Bird sounds and metal sounds.

Visual effects: Animated gears moving and logos.

<u>Scene 2 - 2.5 – Introduction to Jean Tinguely sculptures</u>

Goal: Introduce Jean Tinguely's sculptures and their very uniqueness.

Script: "The museum Tinguely in Basel has the largest collection of Jean Tinguely's sculptures. Jean Tinguely's sculptures are unique pieces of art since they rely on movement and engineering. Because of this they are called "Kinetic sculptures". Some of these sculptures range from the late 1950's to the early 1990's. They are old pieces and therefore delicate."

Communication method: Voice over.

Music: Video music

Sound effects: None

Visual effects: None

Scene 3 – Decay of the sculptures

Goal: Show how the sculptures are decayed and explain how they decay over time.

Script: "As a result of the movement and the age of the materials, some parts of the sculptures wear down over time. Scientists and the conservation staff at the museum have analyzed the artworks and concluded that one cause of the wear in the artworks is due to friction between some pieces. Wear creates changes in the sculptures that range from making different sounds to moving differently than it used to."

Communication method: Voice over.

Music: Video music.

Sound effects: None

Visual effects: None

Scene 4 – 4.5 – Conservation techniques applied on the artworks.

Goal: To show and explain conservation techniques on the artworks. And add part of the interview with Jean-Marc talking about restoration techniques.

Script: "Conservators have many different techniques to conserve the sculptures. One of which you can see throughout the museum. The "mushroom" buttons that activate the movement of the artworks have a waiting time every time they are used. This ensures that the sculptures are not constantly moving and reduces the rate that they wear down. There are other preservation techniques, including cleaning up the artworks, greasing moving parts, and repairing or replacing damaged parts." (this will link with parts of the interview of Jean-Marc)

Quotes:
“Even to make parts new, just copies of the parts because they’re too worn down. To try out, to try to get back to the sound or back to the movement. “
“It must be all. The movement, the sound, and the look. It has to be at least near as possible to the artist.”

Communication method: Voice over and interview audio.

Music: Video music.

Sound effects: None

Visual effects: Signaling mushroom buttons.

Scene 5 – Limitations on determining wear.

Goal: Explain how it can be difficult to determine wear.

Script: “Conservators in the museum are very talented in detecting if a kinetic sculpture is malfunctioning. However, there are a lot of sculptures that have been running for many years. Remembering how they all look and sound can be a difficult task, but there is a technology that could help them in the future.”

Possible quotes:
“You know the sound a machine does … that’s an experience thing”
“I know these machines since some 40 years or more. And they change the sound for sure, but that’s not a 100% thing but it’s an impression I have”

Communication method: Voice over.

Music: Video music.

Sound effects: None

Visual effects: None

Scene 6 - 6.5 – How an acoustic camera works.

Goal: To explain how an acoustic camera works in a general form. Add analogy if possible.

Script: "Recently, a device called an acoustic camera has been used to detect where sounds originate. This device has a video camera in the middle of a supporting square with an array of microphones in a swirl form to capture audio.
The microphones receive the audio and use math to pinpoint where specific sound frequencies originate."

Communication method: Voice over

Music: Video music

Sound effects: None

Visual effects: None

Scene 7 – Analyzing the software and results.

Goal: To show how the data gathered by the software can be read.

Script: "The software of the camera creates a heatmap that helps visualize the range of frequencies and how loud a sound is. The software can be used to select a specific frequency to determine where that frequency is coming from. If there is previous data, it is possible to compare that data with the one from the present to see if the frequencies of a specific point have changed. If a frequency has changed, it means that something in the sculpture changed or wore down and it might be worth checking out."

Communication method: Voice over

Music: Video music

Sound effects: None

Visual effects: None

<u>Scene 7.5 – Comparison of results.</u>

Goal: To show how the data can be compared to analyze the artwork.

Script: "Here is an example: This video compares acoustic recordings from 2017 to 2023. The sculpture emitted the same frequency in a different location in 2017 than in 2023, which suggests that something in the sculpture changed or wore down."

Communication method: Voice over

Music: Video music

Sound effects: None

Visual effects: None

<u>Scene 8 – Importance of an acoustic camera for conservation</u>

Goal: Illustrate the importance of an acoustic camera to help conserve the artworks.

Script: “The acoustic camera can help pinpoint where degradation on the sculpture might be occurring. This information can help conservators save time analyzing the artworks. Furthermore, this device is non-invasive, meaning that the camera does not need to touch the artwork in order to analyze it.”

Communication method: Voice over

Music: Video music

Sound effects: None

Visual effects: None

<u>Scene 9 – Thoughts on the acoustic camera by Jean-Marc</u>

Goal: Show the thoughts Jean-Marc has with the acoustic camera

Script: Depends on the interview video

Communication method: Interview audio

Music: Video music

Sound effects: None

Visual effects: None

<u>Scene 10 - Acknowledgments</u>

Goal: To acknowledge all the parties involved in the creation of the video.

Script: “We greatly appreciate all the help provided by the museum in letting us analyze and record the sculptures. We are also grateful to our other sponsors…”

Music: Video music

Sound effects: None

Visual effects: None