A User Study on Electromagnetic Interactions with REBUS

Rebecca Superbo[1], Sebastian Cristian Gafencu[1], Niccolò Perego[1],
Alberto Bernardini[1], Luca Comanducci[1], Eleonora Oreggia[2]
[1]Dipartimento di Elettronica, Informazione e Bioingegneria. Politecnico di Milano, Milan, Italy
[2]School of Computing. Goldsmiths University of London, London, United Kingdom

***Abstract*—In this paper, we describe a user study on human interaction with REBUS, a digital interactive system and compositional tool which radically innovates the 100 years old Theremin (based on measuring capacitance fluctuations), generating an electromagnetic field (EMF) that forms an immaterial interface which can be manipulated by the movement of the hands and the body. In our research, a preliminary approach to this kind of interaction was proposed through the first public workshop on REBUS, in order to test the ground for further considerations. Based on the feedback gathered during the workshop, we designed a user study in which 10 participants were asked to play the REBUS and then answer questions about their feelings regarding the interaction. We argue whether REBUS can be fully defined as a musical instrument and how the interaction with the EMF, upon which the action of REBUS relies, is perceived by people with different musical backgrounds.**

***Index Terms*—REBUS, Electromagnetic field, Innovative musical interfaces, Media art, User study, Human-computer interaction.**

I. Introduction

It is widely acknowledged that the field of new musical interfaces has become an important landmark to assess the state of the art in human-computer interaction. Starting from the 50s and 60s, experimental technologies paved the way for novel forms of musical expression and experimentation [1]. While many contemporary systems explore modalities such as haptic feedback, motion tracking, or spatial sensing, relatively few leverage the potential of EMF as a medium for real-time, contactless interaction. Historically, instruments such as the Theremin and later the Radio Baton pioneered contactless musical interaction by using capacitance and radio frequency tracking. More recent explorations into EMF-based systems have examined its potential for spatialised, embodied interaction that bypasses traditional tactile interfaces.

REBUS builds on this lineage, offering a digital interactive system and compositional tool that uses EMF to create an immaterial interface manipulated by human movement. Previous research has shown that users can engage with EM fields in expressive and intentional ways, even in the absence of visual or tactile feedback, suggesting the viability of EMF as a performative medium [2], [3].

The disruptive changes in the design of new musical interfaces raise some questions regarding the existence of a distinction between New Interfaces for Musical Expression and New Interfaces for Controlling Sound [4], meaning that the mere presence of a finely calibrated instrument does not guarantee that it will be put to an expressive use [4]. Another point of enquiry is whether an expert player is able to execute skilled actions on an unfamiliar interface while keeping the focus on musical performance rather than on the technology itself [5].

The experiences and experiments reported in this paper are linked through the red line of trying to understand how a new type of technology can be presented, analysed and classified. Our research investigates how users interact with this system and how their musical background may influence their perception of the experience. To this end, we conducted an initial workshop followed by a user study involving ten participants with classical or electronic music backgrounds. The main questions that we wanted to address through the workshop are the following: *Is it possible for the REBUS to be fully classified as a musical instrument rather than merely a controller?*, and *Does the player's background influence their performance with the REBUS?*.

This paper is organized as follows: in Section II we provide the background context on top of which the user study relies; in Section III we discuss the workshop preliminary to the user study; Section IV analyses the proper user study, and the methodologies involved; we discuss the collected results in Section V and the future developments in Section VI.

II. REBUS Background

REBUS (Fig. 1) is a digital interactive musical system based on the three-dimensional interface offered by the EMF. Its current design is the result of several years of research, boxed inside a compact shell [2].

Various innovative approaches to touch-less sound control have been explored by the author of REBUS in previous works, such as Phantasmata, a performance that utilises a wide range of self-built oscillators modulated by lights captured through solar panels and light-dependent resistors [6], [7]. Further experiments explored the potential of invisible frequencies of the electromagnetic field for expressive performance, starting from a review comparing contactless interaction using the EM field as a sensor system with other gestural sensing techniques [3]. Since the human body acts as a significant obstruction, the electromagnetic field displays inherent properties that make it suitable at overcoming some of the limitations of other gestural systems based on ultrasonic distance, optical sensing, and digital video capturing, which

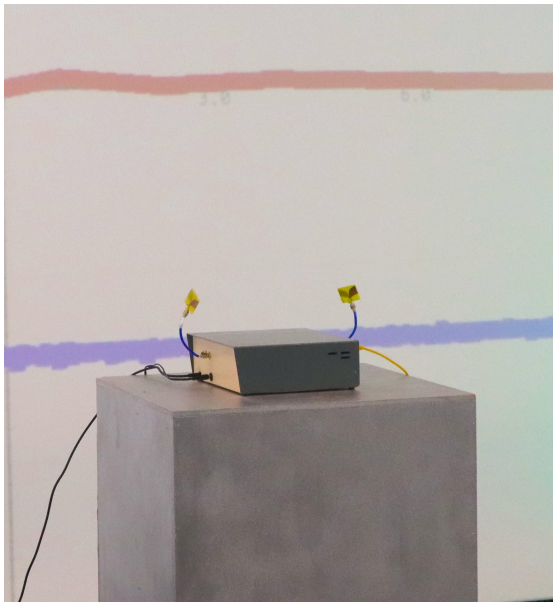

Fig. 1. Portrait of the REBUS instrument with electromagnetic signals projected in the background in the Sonic Immersive Media Lab (SIML) at Goldsmiths University of London. The system, designed for contacless interaction through electromagnetic fields, is positioned on a pedestal with its antennas extended.

are primarily constrained by their inability to maintain sensitivity past obstructions and tend to be directed towards a fixed point [2], [3]. The real-time detection of the field using state-of-the-art RF technology enabled the invention of a relatively simple system that captures changes caused by the presence and movement of objects within its range.

At first, this technology was used in a user study to investigate human behavior in a controlled interaction with a system composed of an EMF emitter, two receiving antennas, and two speakers and a sub, distributed in a room in a triangular pattern. Users were given a very brief description of their surroundings along with a set of simple tasks to complete. The results of this experiment suggested that it is possible to manipulate invisible inferences if a response is received by the person interacting and that subjective factors contribute to compensate for the invisibility of the interface [2], [3].

With the intention of achieving a compact and intuitive system, REBUS, in its current form, was designed as the miniaturized version of the system used in the aforementioned user study. An antenna emits the EMF and another receives it. The interference caused by movement or obstructions in the field is captured and processed in real-time by the device encapsulated into a metal box. The computational brain of the REBUS is a Bela board, an embedded computer specialised in DSP (Digital Signal Processing), which receives the analog values extrapolated by the EMF and can be programmed to use them for virtually unlimited musical purposes.

III. Workshop

The workshop, held on the 21st of April 2023, functioned as a preliminary investigation that focussed on coders as

Fig. 2. Participants experimenting with compositions on REBUS during the preliminary workshop. Photo by Samuele Albani.

agents. This was propaedeutic to the user study, helping us better assess which specific aspects of user interaction to explore. A description of this workshop and the subsequent user study, framed within a reflection upon the nature of musical instruments, can be found in [8]. The workshop also allowed us to define and develop our questions accordingly. To achieve this, it was necessary to witness and analyse the first-ever interaction between REBUS and a public set of *coders as agents* completely new to it (see Figure 2). Consequently, the structure of the user study emerged from the examination of this first approach. A secondary result was that new ideas were born in this phase, especially about the *compositions* (software that, uploaded on REBUS, defines the link between movement and sound) which formed the basis of the user study, with one of them entirely created during the workshop by software artist Claude Heiland-Allen. Another goal was to allow participants to code their own compositions in order to better comprehend their expectations and desires in relation to the instrument. Given the difficulty of communicating one's hopes on this kind of interaction, it is useful to observe a user create their own design and extract incommunicable information from this process.

The group of participants was composed of a combination of subjects, including a few students, having a background in computer science, math, or art, and aged roughly between 20 and 60 years old. It can be stated that most of them had a particular interest in music. The workshop extended through the entire day, from the morning to the late afternoon. Each participant, provided with a Bela, worked individually, occasionally exchanging tips and tricks with the other coders-composers. Every Bela board was equipped with two wires, aimed at emulating the functions of the two antennas of the REBUS. When a participant felt ready to try out their code onto the prototype, their composition was uploaded onto the REBUS and they were given the chance to test it and tweak it according to the desired result.

After the workshop, participants were contacted and asked to anonymously complete a feedback questionnaire about the

experiment. In particular, the form asked them to describe their experience with the REBUS, their expectations about it, and the limits in the way it interacts with the musician. From the analysis of said feedback some common themes and keywords emerged, such as “simplicity”, “immediacy” - referring to the intuitive nature of the electromagnetic interaction, “potential” - referring to the unlimited expressiveness of REBUS, “unpredictability” - both as a positive aspect, that makes the interaction one of surprise and discovery, and as a negative aspect, as some users lamented a lack of repeatability and determinism. Some interesting remarks emerged, with a user defining this form of interaction as a mapping from space to sound. While some participants spoke about “immediacy”, others were frustrated by the difficulty of reaching a “virtuoso” level, one of confidence and total control over the instrument.

IV. User Study

The user study took place on May 15th 2023. The room was equipped with REBUS, a 360 degrees immersive video projection, surround audio, and the recording equipment, as shown in Figure 3.

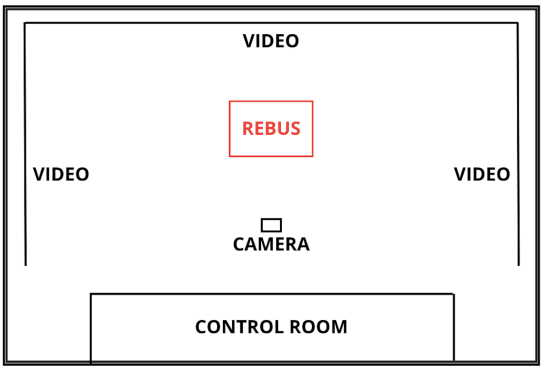

Fig. 3. User study setup: REBUS at the center, real-time EMF data visualization on surrounding walls, and a video-camera to record the study.

Participants were selected from an open call that targeted electronic or classical musicians, possibly violin or string players (see Figure 4). The decision of selecting only these two categories was made after reviewing the feedback forms filled in by the participants of the workshop, as previously described. We were led to believe that the analysis of such background could provide a clearer view of what the REBUS really is and, if defined as a musical instrument, what are its purposes and what kind of audience does it best interface with.

The user study was organized so that participants had to complete an *intro* form first, then interact with the REBUS for twelve minutes (three minutes per composition) and then fill in a final *outro* form. The *intro* form had the purpose of investigating the participants’ experience and opinions on musical instruments, to be compared with their answers to the *outro* form. To do so, participants had to specify their musical background, choosing between *classically trained musician* and *electronic music producer*. They also had to answer to

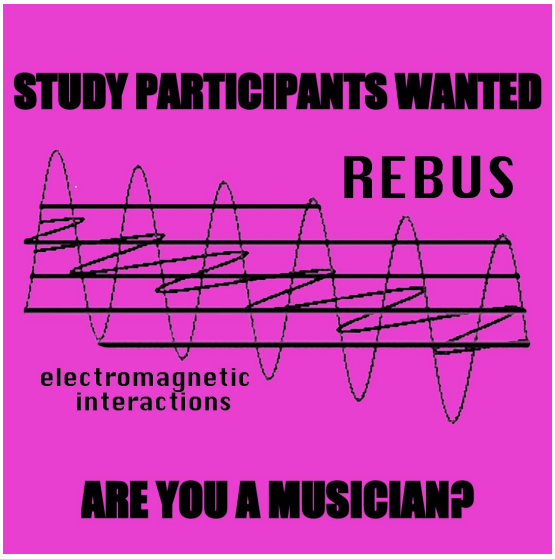

Fig. 4. Poster of the open call used to recruit participants for the study.

two open questions: “What is a musical instrument?” and “Can you control it?”.

Regarding the interaction with REBUS, each participant had to play with four different compositions[1] coded specifically for this user study in order to test different kinds of interaction. The users were free to play and explore each composition for three minutes, relying on the sound and the visualisation of the signals visualised upon the surrounding video projections, showing a live feed of the electromagnetic and the audio signals to guide the experience (see Figure 5 and Figure 6). Before explaining in detail each composition, it is worth noting that they all share the same mapping of the electromagnetic data, empirically and scientifically derived through repeated use and research by the author of the instrument.

Composition one is designed to generate sound in a stochastic manner. A waveform is defined by an arbitrary number of breakpoints whose duration and amplitude are randomly initialized. The waveform is then played (interpolating between breakpoints) and re-created, varying the generation parameters. The user controls the waveform alteration by acting on the barriers of the second-order random walk for the duration and amplitude values. What emerges is a control over pitch and timbre in an almost direct, but not completely predictable fashion [10].

Composition two, developed entirely during the workshop, is designed to exploit complex numbers in order to produce a compelling interaction in the urgency to tame the sound. The complex field rotates and decays, thus describing a spiral. When the spiral goes below a certain value, it gets re-triggered, making it perpetual.

Composition three explores a more complex interaction engaging with simple timbre, mimicking an arpeggiator. The user controls the speed and the base frequency (the fundamental)

[1]The code for the user study compositions can be accessed on the REBUS repository [9].

Fig. 5. Violinist taking part in the study (User 3). He explores the first task with two hands, playing with the sound by touching electromagnetic waves. This participant used mainly their ears to orientate in the invisible interface despite being immersed into the projection of the visualised electromagnetic and sonic data.

Fig. 6. Electronic musician and academic Atau Tanaka taking part in the study. During the exploration of Task 2 the participant (User 6) made extensive use of the visual feedback from the projected EM and sound signals to orientate his interaction with the electromagnetic invisible interface. Image used with permission.

of the arpeggio, together with the amplitude of the sound. The played notes are picked randomly within a parameterized set, based on semitones from the fundamental.

Composition four attempts to recreate a drum machine exploiting the interaction with the space through rhythm. The user's movement affects the velocity and timbre of the rhythmic samples and also triggers *ghost buttons*, i.e. invisible points mapped to be circumscribed between the REBUS antennas. These buttons turn on and off different features of the drum machine, like playing the samples backward or triggering a fill pattern. The *outro* form was given to participants once the twelve minutes of play ended. In a first section, users had to answer some questions in the Likert scale format, here represented as tuples *value1/value2*, about:

- How they perceived the interaction with the sound: *as a bodily sensation/as a result of movement*, *as a property of the space/as a property of the body*
- How they perceived the sound: *repeatable/repetitive*
- How they perceived the whole interaction with the REBUS over time: *unpredictable/virtuoso*

The second set of questions in the *outro* form was composed of four blank spaces, one for each composition, where participants had to describe their sensations, impressions and experience with each composition. A final open question asked comments upon their overall experience with REBUS.

V. Results and discussion

Results were gathered from the analysis of the forms and the ethnographic observation of the users interacting with REBUS.

A. Intro *form*

The 10 selected users were equally split in the two analysed categories: five classically trained musicians and five electronic music producers. Regardless of this distinction, they all presented a similar answer when asked to give a definition of musical instrument. Most users referred to it as a system or an object, physical or digital, that can produce sound in response to an input. This definition includes much more than just "classical" instruments, highlighting an open approach and mindset to music creation. An answer that summarises this view particularly well was "any object that can produce sound of any form. From a pencil to a cello, from a light bulb to a computer". None of the users, when asked if a musical instrument can be controlled, gave a negative answer. Five users selected "maybe", and five gave a positive response, without a correlation to their musical background. This can be a sign that an instrument is seen as something that is not always deterministic and predictable in its way of producing sound.

B. Outro *form*

Following the interaction with REBUS, each user completed the four Likert scale questions.

In the first two (Figure 7 and 8), participants were required to describe how they perceived the interaction with sound, from "as a bodily sensation" to "as result of movement", and from "as a property of the space" to "as a property of the body". In the former, we see a clear tendency to perceive the interaction as a result of movement, while in the latter, five users interpreted it as a property of the body, while three preferred a neutral response, saying it was "equally a property of the space and a property of the body".

The third question (Figure 9), revolving around the perception of sound itself, highlighted a partial or total repeatability of the sound for most users.

The fourth question (Figure 10) investigated the perception of the interaction with REBUS. Here, both unpredictability and virtuosity were almost equally selected.

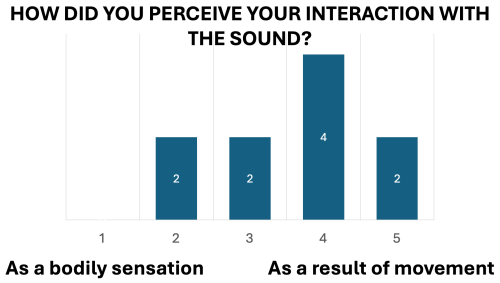

Fig. 7. Likert scale charts from the participants' feedback to the first question "How did you perceive your interaction with the sound?".

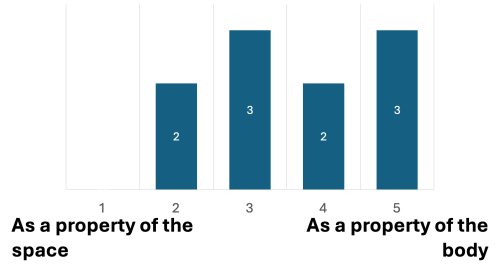

Fig. 8. Likert scale charts from the participants' feedback to the second question "How did you perceive your interaction with the sound?".

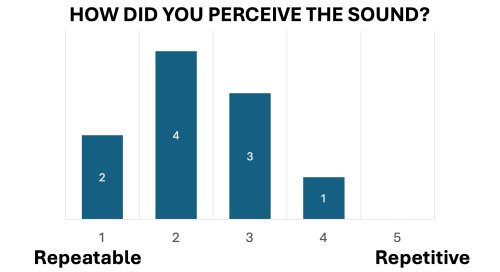

Fig. 9. Likert scale charts from the participants' feedback to the third question "How did you perceive the sound?".

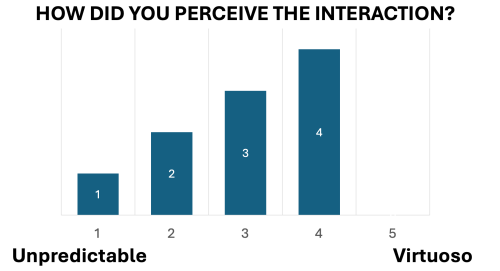

Fig. 10. Likert scale charts from the participants' feedback to the fourth question "How did you perceive the interaction?".

These last two inquiries revolved especially around the classification of REBUS as part of the musical instruments category. It is worth noting that the personal opinion of the users in these Likert questions seems to be disjointed from their musical background.

After completing this first part of the second questionnaire, the participants were invited to comment and feedback on the four compositions with four open questions exploring their interaction with REBUS.

Composition one was clearly marked by almost all users as the one they struggled the most with. The majority of them could not find a direct and clear relation in the changes their movements made to the sound. Some used the video projections, displaying a virtual oscilloscope figuring the sound and electromagnetic signals, to have more guidance and control. Still, some users felt a connection with the instrument and stated they "loved the unpredictability". Apart from a brief introduction, the users were given no instructions on how to play each composition loaded on REBUS, so it is understandable that some time was needed to adapt and comprehend which movements affected a composition more.

Composition two was interpreted and depicted as having a more direct response, described as "interactive and controllable" and "repeatable and immediate". As users gathered more experience with the instrument, they were able to move around with more confidence and find areas of interaction which offered more sensitivity than others, for example, many exploited the fact that covering by proximity the left antenna, which was emitting the electromagnetic waves, would greatly affect the sound. However, their ability to control REBUS would eventually "slip away" and then the instrument would become "hard to chase, like playing tag", as described by a user.

Composition three was mostly tackled in a different way if compared to the previous two due to its arpeggiator-like behaviour. To quote a user: "it felt like a game of getting the system to slow down". The ability to control the composition and make the sound emitted quieter or completely silent was appreciated by most users, but some non-classical musicians described it as "harder to interpret".

Composition four was drastically different from the others. This affected the experience of most users, who struggled to relate their movement and interaction to the rhythmic patterns created by the instrument. This lack of controllability or ability to recreate the sound played by the REBUS was especially lamented by most classical musicians. Vice versa, two electronic producers appreciated "distinct re-triggering" and "immediate results" of this composition.

Lastly, users were asked to define their performance with REBUS. Some lamented a wrongly limited approach to the device and wished they had more time. Contrasting opinions were expressed in regards to the controllability of the instrument, describing the interaction as either "balancing a chaotic system" and "dealing with something uncontrollable" or as "intuitive". Still, most of the users were intrigued by REBUS and wanted to further explore the possibilities it can offer, reporting it as "mysterious and challenging, but rewarding at the same time". More than one classical musician enjoyed the immediacy of playing with REBUS, claiming it felt "very natural". Merging these two concepts, we can recognize one of the most important characteristics of a musical instrument, often described as "easy to play, difficult to master". This

definition fits REBUS perfectly.

C. Ethnographic observation

In general, all users showed great effort in trying to explore the possibilities REBUS offered them. The short time available for each composition forced each participant to have a brief adaptation phase, followed by exploration. Every user experienced their ability to control the instrument incrementing over time. However, some of them adopted an "aggressive" approach to movement, which is only one of the possible forms of interaction.

Contrary to our expectations, regular users of electronic, experimental, and progressive instruments experienced difficulties and expressed concerns similar to those of other participants. During the study, a difference was brought to light between classical musicians who practice string instruments with respect to all other users. It seemed as if they accepted the difficulty and the challenges presented by REBUS and faced them openly. They presented higher sensitivity, maybe due to the abilities developed by playing string instruments such the violin or the viola. Also, their habit and naturalness to use both hands, each having a different function, might have given them an edge over the other test subjects. Surprisingly, there was no significant difference between classical musicians playing discrete non string instruments such as the piano and most electronic music producers.

VI. Conclusion and future work

Since its first public demo in conclusion of a keynote speech at "Nordic Sound and Music Computing" conference held in Stockholm (SE) on 20 November 2019, REBUS has proven in multiple contexts the valuable and innovative features it brings to the vast field of experimental musical interfaces. During our time working as part of the REBUS research team, we personally witnessed the interest it sparks in whoever is able to play it. Although the instrument had already been premiered with an (online) concert in 2020 [11], and the research had started several years before [2], this workshop marked the first public occasion allowing people other than the author to experience the instrument hands-on, not only playing with it, but also writing and testing original compositional code. Moreover, this event created the opportunity for us to gather important information on how to thoroughly plan the next steps.

The user study successfully gathered information regarding the two main questions the team had formulated. Although there is no possibility to have a definitive answer, users showed a very open mindset in the inclusion of REBUS in the category of musical instruments, rather than in the one of controllers. Participants also helped highlight aspects of REBUS that deeply characterise its nature and offered their perspective on the modes of perception of the interaction with it. Different backgrounds led some users to behave differently with respect to others, especially in the case of string players, which manifested some advantages in the interaction with the instrument. Unexpectedly, electronic music producers were not always at ease playing it, with noise musicians and modular synthesizers' gurus displaying a higher level of comfort and a more playful approach.

Future work is exploring different forms of electromagnetic interaction through improvements to the prototype, new software, the construction of a second prototype, and the exploration of this technique for serial production. These steps will allow for faster research progress, which is currently constrained by the limited access to the system.

Furthermore, building on the findings of the experiences narrated in this paper and on the previous research by the author of the instrument, the team is starting to investigate the perceptual and psychological dimensions of electromagnetic interaction, aiming to explore how human perception can be reconfigured through sustained engagement with electromagnetic phenomena, combining phenomenological inquiry and affective analysis. In a sense, the present study represents also the foundation for a wider investigation into how technology can mediate and transform our modes of sensing and understanding the invisible.

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References

[1] I. Poupyrev, M. J. Lyons, S. Fels, and T. Blaine (Bean), "New interfaces for musical expression," in *CHI '01 Extended Abstracts on Human Factors in Computing Systems*, ser. CHI EA '01. New York, NY, USA: Association for Computing Machinery, 2001, p. 491–492. [Online]. Available: https://doi.org/10.1145/634067.634348

[2] E. M. I. Oreggia, "Audiovisual performance composition using electromagnetic waves," Ph.D. dissertation, Queen Mary University of London, 2020.

[3] E. Oreggia, "Musical Applications of Electromagnetic Field Sensing," *Computer Music Journal*, vol. 48, no. 3, pp. 1–68, 2025.

[4] C. Dobrian and D. Koppelman, "The 'E' in NIME: Musical Expression with New Computer Interfaces." 01 2006, pp. 277–282.

[5] A. Guidi and A. McPherson, "Quantitative evaluation of aspects of embodiment in new digital musical instruments," in *NIME 2022*, June 16 2022, https://nime.pubpub.org/pub/aa39yd37.

[6] E. Oreggia and G. White, "When technology goes out of control," *Digital Creativity*, vol. 29, no. 1, pp. 51–67, 2018.

[7] xname. (2010 - 2017) Phantasmata: quasi-perceptual experience. Accessed: 10 July 2025. [Online]. Available: https://xname.cc/phantasmata

[8] E. Oreggia, "Exploring the Space Between Instrument and Controller," in *Sound and Music Computing Conference*. Zenodo, Jul. 2024, pp. 486–490. [Online]. Available: https://doi.org/10.5281/zenodo.14362248

[9] xname *et al.* (2023) REBUS. Electromagnetic Interactions. Code repository. Polimi. Accessed: 2 October 2025. [Online]. Available: https://github.com/xname/REBUS/tree/master/polimi-collab

[10] S. Luque, "The Stochastic Synthesis of Iannis Xenakis," vol. 19, 12 2009, pp. 77–84. [Online]. Available: https://doi.org/10.1162/lmj.2009.19.77

[11] E. Oreggia. (2019 - ongoing) REBUS. Electromagnetic Interactions. Accessed: 10 July 2025. [Online]. Available: https://xname.cc/rebus