Playing with resistance

Robert Ek
GEMM))) Gesture Embodiment and Machines in Music
Piteå School of Music at Luleå University of Technology, Sweden
robert.ek@ltu.se

ABSTRACT

Instrument design is not just a matter of hardware, it also concerns strategies for software mapping of input to output data. I will in this paper report on how an augmented clarinet that I, together with a team at LTU began developing in 2015 has continued to develop over the past seven years. The focus will be on the development of artistic applications within the system. Performers frequently describe the resistance of their instrument as a manifestation of the challenges they encounter when playing. One can argue that the goal of a skilled performer is to get rid of resistance, but it is in fact a central part of the relationship between performer and instrument. Acquiring technique and skill seems to be a way for the performer not to overcome resistance but to learn how the instrument responds to force. Realizing the importance of resistance in the artistic process we need to ask ourselves; how can we use this knowledge when creating new instruments? Returning to video documentation of performances with two different mappings and through stimulated recall analysis I seek a deeper understanding of how software, mapping and performance practice interacts, forming the basis of the artistic expression.

Author Keywords

Instrument design, Augmentation, Resistance, Mapping, Musical expression.

CCS Concepts

• *Applied computing* → **Performing arts**; *Sound and music computing*; • **Human-centered computing** → *HCI theory, concepts and models*.

1. INTRODUCTION

Instrument design is not just a matter of hardware, but also concerns strategies for software mapping of input to output data [17, 19, 18, 2]. Such intermedial translation through machine observation—capturing input data in forms of 'seeing', 'sensing', 'listening' etc.—is mediated by the input interfaces and executed in the same or another modality via output sources such as display monitors, loudspeakers, or other actuators. The software mapping of the data is an important factor in shaping the artistic expression. Since this intermedial translation can change and evolve between each performance, new instruments extend the scope of instrument design into being a part of the compositional practice. Hence, designing these systems not only requires technical knowledge, but also the skills of performance and composition. Such embodied artistic knowhow is deeply embedded in musical practice, and the accumulation of new knowledge thus adds to the tradition within which it operates. Even if technology is a facilitator, the goal is to express musical intention in novel ways. As observed by Waisvisz already in 2006, "[i]f our goal is musical expression we have to move beyond designing technical systems" [32]. This paper proposes a more holistic perspective on the technological, computational, and artistic skills that jointly form the potential for musical expression in new systems.

NIME'24, September 4–6, 2024, Utrecht, The Netherlands

Looking back at traditional Western classical instruments, like the clarinet, most of them were created centuries ago and have been perfected over time. It may be argued that most of them have entered a phase where no big changes are made, but still, they continue to afford the creation of new music. Such slow development, which has become characteristic of instruments in the art world of Western classical music, is beneficial for building a common knowledge of the affordances of each instrument. This is also true for instruments outside Western classical music but since my artistic practice is situated within this art world I leave this for other researchers to explore.

With the increasing role of computers in music making, advancements in technologies have sparked the development of digital music instruments (DMIs). While the number of new instruments is constantly increasing, one may wonder whether a focus on novel innovations prevents the slower in-depth development of user skills, otherwise characteristic of musician-instrument interactions. The fact that few papers within NIME focus on the continued development of existing NIMEs has been addressed several times [24, 9]. As argued by Cantrell [9], there is a tendency within NIME to focus on the technological development, and

> "[p]erhaps the most immediate and obvious is the presence of the 'new' demarcation. Similar to other monikers such as 'new media', the presence of a temporal qualifier points to an apriori limitation; that which is considered 'old' is to be excluded. In other words, the 'newness' here is technical, and the technical is prioritized." [9]

For an instrument to obtain further mature roles in a musical context, temporality is indeed a central factor, and more longitudinal perspectives on the exploration of how novel performance practices continue to expand the potential of 'old' NIMEs holds great potential. I will in this paper report on how my performative explorations of an augmented clarinet, that I—together with a team at Luleå University of Technology (LTU)—began developing in 2015, have contributed to the creation of a wider range of instrumental systems across the past seven years.

The bell of the clarinet is fitted with sensors, and it is now in its fourth iteration, which was completed in 2020. The second iteration was described in a paper at NIME 2016 [26]. By revisiting the project, I will seek to define the progress that has been made, both regarding hardware and software, but most importantly, the insights and understanding gained by working and performing in different instrumental systems created with this augmented clarinet. While the hardware is now sleeker in design and the data is much more reliable, due to a new sensor and better coding, it is this performative knowledge that is in focus in the present paper. In order to unpack how this system works, I have employed the qualitative method of stimulated recall analysis [31, 34] using video from two performances made with two different mappings to get a more detailed understanding of how they may be experienced from an artistic point of view.

2. METHOD OF STUDY

Stimulated recall can be viewed as a subset of introspective research measures in which the researcher accesses participants reflections on mental processes [23]. It is a common qualitative research method in human studies or humanities and was first described by [7] as a method for collecting data by activating a memory with the use of a recorded medium. The fundamental idea behind the method of stimulated recall is "…that a subject may be enabled to relive an original situation with vividness and accuracy if he is presented with a large number of cues or stimuli which occurred during the original situation." [7] The subject is asked to report on thought processes recalled while revisiting a situation through video and/or other stimuli. In music research, early implementations of stimulated recall can be found in studies of collaborative processes [3, 4, 5].

A key advantage of using video-based stimulated recall in music research is that it provides a methodological platform for performers and scholars to blend objective and subjective analytical approaches [34]. Reviewing the video from the two performances generated a number of qualitative observations related to the mapping within each system. The annotations from these observations provided both a first person and third person perspective on the artistic application of the two systems.

3. VIVE LA RESISTANCE

Performing with a traditional instrument is a multi-sensorial engagement, where the performer's body receives sensorial input through aural, visual, proprioceptive, and tactile stimuli. The process of learning an instrument is often described as incorporating a body schema, and the role of the instrument has been described as becoming increasingly transparent, like a blind man's stick in Merleau-Ponty's classic example. A common understanding is that a good instrument in the hands of a skilled performer transforms into an extension of the performer's body and is no longer seen as a separate physical object, in fact, "...it is difficult to know where the body ends and where the instrument begins" [1]. The instrument itself becomes a "transitional object" [8], a mediator between the corporeality of the physical object as an extension of the physical world and the musical imagination of the performer's mind.

A contrasting perspective frequently described by performers is that the resistance of their instrument is a manifestation of the challenges they encounter when playing [6]. Franziska Schroeder [28], also describes how the relation between instrument and performer is sometimes coherent but at other times rather experienced as a continuing battle, marked by constraints and resistance. Gorton and Östersjö relate such experiences to the formation of an artistic habitus, "a process that may call for ten thousand rehearsal hours" further analysing it as a matter of learning "to play with the resistances and the affordances of an instrument" [15]. Hence, while it may be argued that the goal of practicing an instrument is to overcome constraints and resistance, they are in fact central factors in the relationship between performer and instrument. Acquiring technique and skill seems to be a way for the performer not to overcome resistance but to learn how the instrument responds to force. Aden Evens argues that "technique is designed to place the instrument's resistance in contact with the musician, to allow him to feel the many dynamics it offers of force and sound" [12]. Hence, an instrument is more than just a tool. Musical expression emerges exactly through the resistance, which pushes back at the performer, just like the clay pushes back when being moulded:

> "Defined by its resistance, the instrument does not just yield passively to the desire of the musician. It is not a blank slate waiting for an inscription. Likewise, the musician does not just turn the instrument to his own ends, bending it to his will against whatever resistance it offers. Rather musician and instrument meet, each drawing the other out of its native territory." [12]

The more proficient a clarinet player gets, the more they tend to choose instrument, mouthpiece and reeds that will create resistance. If the setup of reed, mouthpiece, and the body of the clarinet is too free-blowing, the instrument will be difficult to control since responsivity and reliability is limited. If a setup is too resistant, it will restrict the potential for musical expression. However, a setup with a balanced working resistance will help create a rich, colourful sound and to play expressively. In a podcast, Steve Williamson, principal clarinettist in the Chicago Symphony Orchestra, discusses the importance of balance in the setup of a clarinet, and argues that:

> "…people don't realize that it's not just music… It should be work and, in order to work, you have to actually have a cooperative resistance in the mouthpiece and your reed. And usually, it takes more work than you think. But once you get on that you'll know if you go too far in one direction or not far enough." [33]

What then can be learnt from such observations of instrumental agency through resistance? How can the experience of resistance, characteristic of acoustic instruments, be implemented in the design of digital instruments, to obtain musician-instrument-relationships that engender creative meetings outside the native territories of both agents? Here, the intermediary category of augmented instruments, which takes a traditional instrument as point of departure, thereby retaining the resistance which characterized the acoustic instrument, can provide some useful insights.

4. AUGMENTED INSTRUMENTS

An augmented instrument may retain the felt tactile stimuli and resistance of an acoustic traditional instrument, which can be used in creating resistance in the mapping of the digital layers that are added to its expressive potential. However, as will be further discussed in the two cases below, the design of the mapping may strengthen or interfere with these qualities. For instance, when designing the remediation [27] of another modality, e.g., movement into another domain such as sound, the creation of augmented instruments poses particular challenges. When the mapping fails to recreate the original feedback between performer and instrument, contradictory relations may emerge, resulting in a split, and an experience of playing two different instruments, rather than one.

4.1 Audio as sensor input

One of the clearest ways of establishing a link between the resistance of the traditional instrument and its digital augmentation is to use audio from the instrument as control data in the digital mapping. "The sound of an acoustical instrument, then, can be thought of as data to be 'sensed' and analyzed. In this light, a microphone becomes sensor" [30]. When playing a crescendo on a clarinet, an increasing resistance can be experienced, this feature was used in the second system. This particular affordance of the instrument can be used in the design of an intermedial translation, for instance, to control the amount of complexity in the digital sonic output. Using audio as a source for controlling live electronics has proven to be successful and has been widely used by composers and performers. It is also commonly used in setups where a musician performs with a live-electronics setup using audio from one performer as input to their audio processing: this creates a kind of duo with two voices emanating from one source. In these instances, a kind of shared instrumentality is created [16].

4.2 Physical gestures as sensor input

Another common source of input data is the bodily movement of performers. This type of input data is the key feature in the MiM system and was used in both mappings to control different aspects of the sound manipulation. The theory of embodied music cognition suggests that the human motor system, body movements and gestures are essential to the way humans perceive music [21, 14]. This means that the physical acts that create movements and gestures, as well as the internal sensations associated with them, contribute to understanding and experiencing music. A central concept in embodied music cognition is that "an intentional level of musical interaction is established through corporeal articulations and imitations of sensed physical information provided by the musical environment" [22]. The assumption that gesture and corporeal imitation are fundamental constituents of musical expressiveness is at the heart of embodied music cognition [21]. Therefore, the physical gestures of a musician carry meaning in musical performance. But how can organic relations between gesture data and musical expression be obtained? While analysis of the relation between musical shaping and a performer's movements have confirmed such connections, [31] the design of interactive systems that successfully employ movement data demands a number of different steps. One challenge is to create systems that can detect movement qualities, second, this input data must be in the mapping and remediation into another modality. Here, through the study of the first-person perspectives from professional instrumentalists on resistance is in performing their instruments, further knowledge can be gained of how motion qualities can be coupled with the experience of resistance when creating software mappings.

5. SYSTEM DESIGN

The clarinet bell called Music in Motion (MiM) that we created in 2015 is now in its fourth iteration. For this iteration, which was completed in 2020, we designed and programmed our own PCBs together with Svensk Elektronikproduktion AB.[1] The heart of this device is a 9 DOF sensor from Bosch Sensortec (BNO055) that is capable of delivering sensor data over Wi-Fi at a rate of 100 Hz.

The sensor sends raw data in three axes from each of the three parts of the sensor, accelerometer, gyroscope, and magnetometer. It also calculates quaternions using onboard sensor fusion, which is very stable, and has a low rate of drift. The chip also provides a system for sensor calibration that delivers a value about the quality of calibration.

The sensor chip is connected to a microcontroller[2] and a Wi-Fi transmitter,[3] and also provides two programmable buttons and LEDs that display charging and connection status. The microcontroller programmed by SEP has two options for connection, either connected via an existing network router or as a standalone SoftAP.[4] The movement data is transferred over the network to a host computer where it can be used in various software. A part of the development has been to create a Max package[5] containing a collection of externals and abstractions (patches). The abstraction that receives the sensor data provides besides raw data also information about the calibration of the sensors, rate of transfer and device ID.

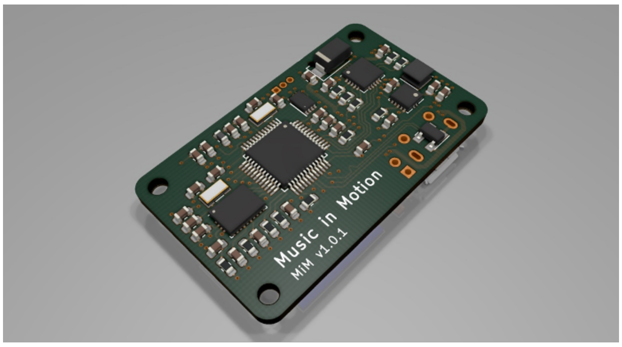

Figure 1. Drawing of circuitry layout.

The MiM package contains functions (provided as Max externals) for the calculation of intensity, stillness and kick, a set of abstractions for static posture detection using GMM (Gaussian Mixture Model) [13], as well as abstractions for the generation of CV (Control Voltage) to control Eurorack modules.

This system has been used in multiple artistic scenarios, and I argue that each time it is used with a new form of intermedial translation it becomes a new instrument with its own set of affordances.

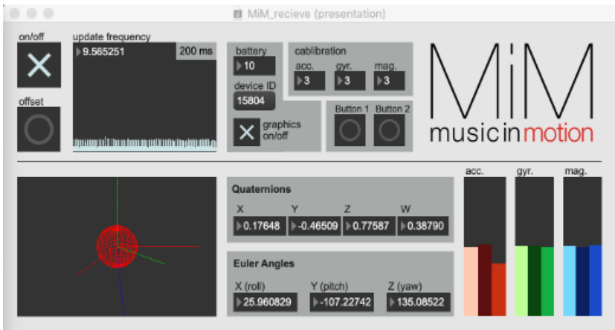

Figure 2. MAX abstraction for the incoming data.

6. MAPPING STRATEGIES

How then may an input modality and the remediated sounding output be mapped so that the performer experiences a connection between the resistance of the instrument and the sonification of physical gestures? In the design of augmented musical instruments, mapping of the input data from bodily movements as a control parameter into output data used for sound synthesis, is called gesture mapping [20]. This mapping is the crucial link used in designing the relation between action, sound control and generation mechanisms. In a recent publication Jensenius observes how "[m]any acoustic instruments are based on one to-many or many-to-one mappings" [18] and Hunt et al. argue that this type of coupled mappings are frequently perceived by

[1] https://www.svenskelektronikproduktion.se/
[2] ARM® Cortex®-M0+ SAM D21E Microcontroller IC 32-bitar 48MHz 64KB (64K x 8) FLASH 32-TQFP (7x7)
[3] ATWINC1500 MR210PB WiFi 802.11b/g/n 2,4GHz (21.7x14.7)
[4] SoftAP is an abbreviated term for "software-enabled access point". This is software enabling a device which hasn't been specifically made to be a router into a wireless access point.
[5] https://github.com/musicinmotion-dev/MiM

users as more intuitive and expressive than simpler one-to-one mappings [17].

Figure 3. Picture of the sensor mounted on a clarinet bell.

In the following section, I will review two different systems that I have used in concert performances and consider different strategies in the design of the gesture mapping that connects bodily movements and sounds. The two systems both use granular synthesis, but have very different approaches, both technically and in how the interaction within each system is designed. There are also three years between the cases, which provides an opportunity to consider the impact of long-term development. Subsequently, I returned to video documentation of performances using the two systems and through stimulated recall analysis sought a deeper understanding of how software, mapping and performance practice interact and form the basis for the artistic expression.

6.1 Two separate voices

The first system uses CataRT, which is a corpus-based concatenative real-time sound synthesis system that can be considered a content-based extension of granular synthesis [29]. The CataRT system uses a selection of audio files (corpus) that are segmented and categorized according to predefined descriptors. These grains can then be played using proximity within the descriptor space. CataRT is a well-known system and is often used in free-space gesture interfaces as an interactive exploration process for sound synthesis.

In this implementation, I use two movement features extracted from the MiM bell sensor to navigate through the grains organized in a two-dimensional representation of a parameter space according to predefined descriptors. To get a quite evenly disbursed field I chose periodicity connected to elevation of bell and energy connected to intensity of movement. Different movements activated specific grains that served as a base for improvisation. For the corpus I selected audio material that originated from clarinet recordings, both bass clarinet and Bb clarinet as well as electronically generated sounds.

The stimulated recall was carried out using a single video extracted from a concert performance [10]. A general observation was how the mapping in this system seemed to generate a one-way communication, and in an annotation, it is observed how "it is quite obvious that this system does not change or even draw out new sounds from the clarinet. It is two separate sound sources that at best interacts with each other." [stimulated recall annotation, Ek] Under such conditions, my improvisation on the clarinet is responsive to the sounds from the CataRT synthesis, activated by my movements. The video also reveals how I need to move a lot in the opening to generate enough sound from the granular synthesis, to enable a sonic counterpart to the slow figurations in the clarinet. This exaggerated movement I found unidiomatic, since the movement needed to control the electronic sounds was counterintuitive to the musical shaping in the clarinet. However, there are moments when this system works better, as observed when I "move away from the energetic part in the beginning, I immediately create more space. More room to listen to what grains my gestures activates and having time to respond to them." To conclude, it appears to me that the scope for interaction was exhausted by the materials displayed in this short clip.

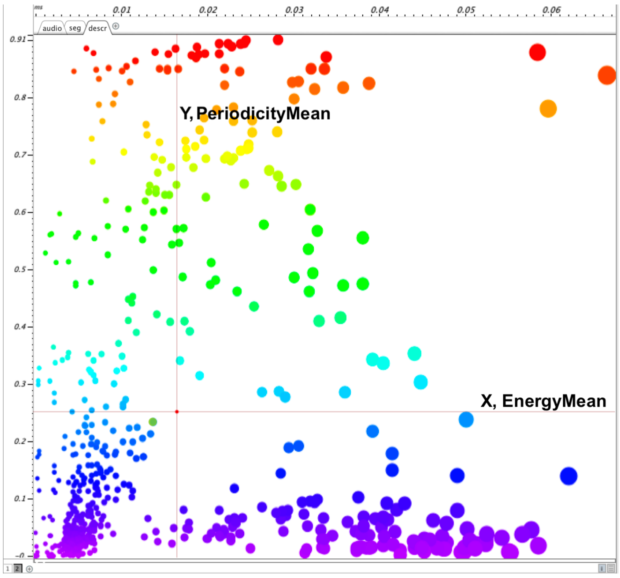

Figure 4. CataRT grain distribution and selected descriptors.

The sounds created in the CataRT synthesis are not clearly related to the sounds from the acoustic clarinet and further do not create any connection to the resistance of the clarinet. This results in a system that in many ways appears like two separate voices: the acoustic clarinet unaffected by the system reacting and sounding like a normal clarinet, and a second voice originating from the gesture controlled granular synthesis that generates a floating sonic space; unfortunately, without the sensation that the two voices are connected.

6.2 Mapping for resistance

The second system was initially created in 2022 and focuses on non-pitched sound material from the clarinet, like tongue rams, key clicks, and different types of air sounds. The audio input from the clarinet is fed into a modular synthesizer where it is processed. The module mainly used in this patch is the Mutable Instruments Beads,[6] a texture synthesizer working with granulation. The sensor data from the physical gestures are converted to control voltage (CV) to manipulate parameters in the modular setup. I use two types of gestural information to control this system, namely bell elevation and tilt. The elevation controls the size of the grains which in this patch results in pitch modulation of the grains. This is mapped so that lowering the bell will result in a lower pitch and a denser sonority. The tilt controls the amount of feedback in the granular loop. This physical gesture, to tilt the clarinet, is a rather unusual movement that creates a sense of resistance. Coupling this with feedback, where a stronger resistance in the physical gesture results in larger feedback and more complex

[6] "Beads is a granular audio processor. It creates textures and soundscapes by playing back layered, delayed, transposed and enveloped fragments of sound ("grains") taken continuously from the incoming audio signal" (Mutable Instruments, 2022).

sound, clearly connects to the resistance of the instrument. The patch also uses the incoming audio as sensor data, to generate a different CV signal: here it's directly connected to the resistance in the clarinet. This CV signal controls the density in the grain generation, the more air pressure I apply to the bore in my clarinet, the denser the generated sounds get. These three parameters are also coupled to each other so that they behave differently in relation to each other's current state. The result is a system that provides clear connections between the clarinets resistance, input modalities and the remediated sounding result. In one way the data fed into this system are quite rudimentary, especially the gestural input but how they interact with each other and the felt connection to the instrument's resistance results in a system that feels and behaves in a complex and expressively rich way.

Creating this system was informed by my use of the MiM sensor bell for more than seven years. Given the extensive time I have spent working with the sensor component of the system, my awareness of how certain bodily movement creates particular gestural input is rather detailed. This understanding, combined with the knowledge gained through analysing performance videos through an embodied perspective, helps me to make informed decisions in the process of designing the mapping that controls the intermedial translation.

In my analysis of the video documentation [11] from one of the performances with this system, the stimulated recall reveals many differences. In the second system, almost every observation made reveals a much more dynamic relation between mapping and performance practice. This could be an indication as to why the system feels more connected to the clarinet, compared to the first system, and why it is easier to be expressive within it. As observed in the stimulated recall analysis:

> "[T]he interaction within this system moves from … two poles. Adding a lot of different non-pitched material at the same time as I am physically moving a lot. Resulting in a complex and rich sound. After that I go into another state where I stay with a small amount of material listening attentively while using gesture to reshape the sonic output." [stimulated recall annotation, Ek]

In another moment of the video, I can see and remember experiencing a connection to the resistance of the clarinet, "You can see how I have a close connection between minute differences of resistance in each sound played on the clarinet, adding some small gestures instinctively to shape the sound further." [stimulated recall annotation, Ek] I also note that my body language suggests that I am in an expressive state with an intimate connection to the created sonic output. These signs are connected to my personal understanding of my body language and possibly material for another study.

I've used this system in a series of live performances over the last two years and only made minor changes to the system during this period. It provides a good balance between unpredictability and control, and the relative predictability allows for learning and developing performative skills. However, the system never gives itself easily to the performer and requires practice much like when learning a traditional instrument. Hence, to learn to play the system, a deepened awareness of the feedback loop between listening and responding is necessary. During an interview after a performance, I made the following observation of how I experience working within the system:

> "It's very enjoyable. It's a place in my mind where the whole of me listens inwards. And this is the same whether I play clarinet without this electronic system or playing with it. It's just a sense of tuning into your listening, tuning in to your desire to express yourself." [personal interview, Ek, 2023].

Furthermore, I refer to how the listening is connected to my physical gestures, "I'm shaping the sound with gestures. But I don't experience the gesture… it is my listening that is guiding these gestures, the change of my physical body. It's completely guided by my inner listening". [personal interview, Ek, 2023] To conclude, this felt connection between gesture and sound, when performing within the system, may constitute the strongest evidence of a successful integration of its constituent components.

7. DISCUSSION

Revisiting the two systems using stimulated recall has revealed how a well-balanced system seems to generate a stronger connection between performer and instrument, in ways very similar in augmented instruments as compared to the examples of the balance in the setup of a clarinet. Hence, the second system provided examples of how the resistance of a conventional clarinet and the mapping of the augmented interactions can provide such a balance. This study indicates that a musician's first-person knowledge of performing a particular instrument, in this case a clarinet, is crucial in the design of the intermedial augmentation. When designing these systems, in addition to knowledge about the instrument, a deep understanding of motion qualities and their meaning in music performance is required.

Looking at the relationship between instrument and performer in this way it becomes clear why the search for tactile feedback in novel digital instruments represents something of a holy grail. However, as demonstrated with the two use-cases, I believe that, rather than merely providing tactile feedback, a successful design is dependent on the wider musical perspectives found in the concept of resistance. As Evens puts it "for there is no music without resistance and struggle. To move from desire to expression requires an effort and is never guaranteed short of this effort" [12]. It becomes evident that to get the most out of a novel interface, investing time and effort is crucial, and to reach an understanding of the connections to performance practice requires a long-term engagement with the interface.

8. FUTURE WORK

This article focuses on the exploration and interaction design over time in two distinct instrumental systems using an augmented clarinet. I believe that the observations made can be useful in creating other types of instrumental interfaces besides augmented traditional instruments. Understanding the connection between a traditional instrument and its augmented remediated digital counterpart may help to create digital instruments that respond and resist in similar ways.

9. ETHICAL STANDARDS

This paper complies with the ethical standard of the NIME conference [25] and does not present any conflict of interest.

10. REFERENCES

[1] P. Alperson. The Instrumentality of Music. *Journal of Aesthetics and Art Criticism*, 66(1):37–51, 2008. https://doi.org/10.1111/j.1540-594X.2008.00286.x

[2] M. Baalman, C. Salter, & S. J. Norman. Composing interactions: An artist's guide to building expressive interactive systems. *V2_Publishing*, 2022. https://catalog.lib.uchicago.edu/vufind/Record/12755636

[3] D. T. Bastien & T. J. Hostager. Jazz as a process of organizational innovation. *Commun. Res.* 15, 582–602, 1988. https://doi.org/10.1177/009365088015005005

[4] D. T. Bastien. & T. J. Hostager. Cooperation as communicative accomplishment: a symbolic interaction analysis of an improvised jazz concert. *Commun. Stud.* 43, 92–104, 1992. https://doi.org/10.1080/10510979209368363

[5] D. T. Bastien. & J. Rose. Cooperative activity: the importance of audiences, in *Revisiting symbolic interaction in music studies and new interpretative works*. ed. N. K. Denzin (Bingley, UK: Emerald Group), 21–36, 2014.

[6] O. W. Bertelsen, M. Breinbjerg, & S. Pold. Instrumentness for creativity mediation, materiality & metonymy. *Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition - C&C '07*, 233. (2007). https://doi.org/10.1145/1254960.1254992

[7] B. S. Bloom. Thought-processes in lectures and discussions. *J. Gen. Educ*. 7, 160–69, 1953.

[8] D. Burrows. Instrumentalities. *Journal of Musicology* 1. 5 (1):117–125, 1987. https://doi.org/10.2307/763827

[9] J. Cantrell. 2017. Designing intent: Defining critical meaning for nime practitioners. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, pages 169–173, 2017. Copenhagen, Denmark. Aalborg University Copenhagen.

[10] R. Ek. Video documentation. 2019. Retrieved from YouTube, Jan 20th, 2024. https://youtu.be/EiLCIbFupy0?si=04rxhDyOS3WUThKz

[11] R. Ek. Video documentation 2022. on Retrieved from YouTube, Jan 20th, 2024. https://youtu.be/5OBZSFhxZAE?si=EuuratcpIlJEjJk5&t=151

[12] A. Evens. Sound Ideas: Music, Machines, and Experience, *University of Minnesota Press*, Minneapolis, MN. pages 160-162, 2005.

[13] J. Françoise, N. Schnell, R. Borghesi & F. Bevilacqua. Probabilistic Models for Designing Motion and Sound Relationships. In *Proceedings of the International Conference on New Interfaces for Musical Expression*. London, UK, 2014.

[14] R. I. Godøy & M. Leman. Musical Gestures: Sound, movement, and meaning. (1st ed.). *Routledge*. 2009. https://doi.org/10.4324/9780203863411

[15] D. Gorton & S. Östersjö. Choose Your Own Adventure Music: On the Emergence of Voice in Musical Collaboration. *Contemporary Music Review*, 35(6):579–598, 2016. https://doi.org/10.1080/07494467.2016.1282596

[16] R. Harlow, M. Petersson, R. Ek, F. Visi & S. Östersjö. (2021). Global Hyperorgan: a platform for telematic musicking and research. *NIME 2021*, pages 1–15, 2021. https://doi.org/10.21428/92fbeb44.d4146b2d

[17] A. Hunt, M. M. Wanderley, & M. Paradis. The importance of parameter mapping in electronic instrument design. *International Journal of New Music Research*, 32(4):429–440, 2003. https://doi.org/10.1076/jnmr.32.4.429.18853

[18] A. R. Jensenius. Sound Actions: Conceptualizing Musical Instruments. *The MIT Press*, 2022. https://doi.org/10.7551/mitpress/14220.001.0001

[19] L. Jäger and J. H. Kim. Transparency and Opacity. Interface Technology of Mediation in New Media Art. In: transcript; Seifert, Uwe; Kim, Jin Hyun; Moore, Anthony: *Paradoxes of Interactivity. Perspectives for Media Theory, Human-Computer Interaction, and Artistic Investigations.* Bielefeld: transcript 2008, 44-61. DOI:10.25969/mediarep/2708

[20] J. H. Kim. From Interactive Live Electronic Music to New Media Art. *Paradoxes of Interactivity: Perspectives for Media Theory, Human-Computer Interaction, and Artistic Investigations*, edited by Uwe Seifert, Jin Hyun Kim and Anthony Moore, Bielefeld: transcript Verlag, 2008, pp. 282-297. https://doi.org/10.1515/9783839408421-014

[21] M. Leman. Embodied music cognition and mediation technology. Cambridge, MA, USA: *The MIT Press*. 2007.

[22] M. Leman & P. -J. Maes. The role of embodiment in the perception of music. *Empirical Musicology Review*, 9(3-4):236–246, 2014.

[23] A. Mackey. & S. M. Gass. Second language research: methodology and design. Mahwah New Jersey: Lawrence Erlbaum Associates, Inc, 2005.

[24] R. Masu, F. Morreale, A. R. Jensenius & W. T. Rau. The O in NIME: Reflecting on the Importance of Reusing and Repurposing Old Musical Instruments. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, article 14, 2023. https://www.nime.org/proceedings/2023/nime2023_14.pdf

[25] F. Morreale, N. Gold, C. Chevalier, and R. Masu. NIME Principles & Code of Practice on Ethical Research, Jan. 2023.

[26] C. J. Normark, P. Parnes, R. Ek & H. Andersson. The extended clarinet. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, 162–167, 2016. http://www.nime.org/proceedings/2016/nime2016_paper0034.pdf

[27] N. Schnell. Playing (with) Sound: Of the Animation of Digitized Sounds and their Reenactment by Playful Scenarios in the Design of Interactive Audio Applications. PhD thesis, University of Music and Performing Arts, Graz, Austria, 2013.

[28] F. Schroeder. Network[ed] listening-towards a de-centering of beings. *Contemporary Music Review*, 32(2–3): 215–229, 2013. https://doi.org/10.1080/07494467.2013.775807

[29] D. Schwarz, G. Beller, B. Verbrugghe, S. Britton. (2006). Real-Time Corpus-Based Concatenative Synthesis with CataRT. Proceedings of the 9th International Conference on Digital Audio Effects, DAFx 2006.

[30] A. Tanaka. Sensor-Based Musical Instruments and Interactive Music. in Roger T. Dean (ed.). *The Oxford Handbook of Computer Music*, Oxford Handbooks (2011; online edn, Oxford Academic, 18 Sept. 2012). 2012. https://doi.org/10.1093/oxfordhb/9780199792030.013.0012

[31] F. Visi, S. Östersjö, R. Ek & U. Röijezon. Method Development for Multimodal Data Corpus Analysis of Expressive Instrumental Music Performance. *Frontiers in Psychology*, vol. 11, 2020. https://doi.org/10.3389/fpsyg.2020.576751

[32] M. Waisvisz. Panel discussion moderated by michel waisvisz,'manager or musician? about virtuosity in live electronic music'. In *Proceedings of the 2006 International Conference on New Interfaces for Musical Expression*, page 415, 2006.

[33] S. Williamson. podcast: the Candid Clarinetist ep.18, Sam Rothstein interviewing Steve Williamson. 2020-10-27. Retrieved 2024-01-30, from https://www.youtube.com/watch?v=yiMgkFpLLMU

[34] S. Östersjö, N. T. Thủy, D. G. Hebert, H. Frisk. Shared Listenings: Methods for Transcultural Musicianship and Research. *Cambridge University Press*, 2023.