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Beyond the instrument: a systematic review on the technological expansion of acoustic performance

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ABSTRACT

This article presents a systematic review of technologically expanded acoustic instruments, focusing on systems that expand traditional Western musical instruments without compromising their acoustic identity. Drawing from 40 peer-reviewed publications (2015–2025), the study analyses the technological, performative and evaluative strategies used to mediate instrumental interaction. A comprehensive categorisation framework is proposed, covering types of expansions, interaction modalities, technologies, software, performance contexts and evaluation methods. The findings highlight a predominance of gesture-based multimodal systems, real-time audio processing with Max/MSP and a strong emphasis on expressivity and performer-system co-agency. While diverse in technical implementation, these systems share common goals: enhancing expressivity, redefining performer-instrument relationships and expanding the boundaries of acoustic performance through interactive media. However, the review also reveals a lack of unified evaluation methodologies and a conceptual fragmentation that limits cross-study synthesis. The article contributes to the epistemological structuring of the field by proposing an operational framework for comparing, documenting and evaluating technologically expanded acoustic instruments and positions its findings as a foundation for future practice-based and theoretical research. This study contributes to the consolidation of a rapidly evolving domain at the intersection of performance, digital lutherie and interaction design.

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Expand; instrument; performance; technology; systematic review

1. Introduction

This article presents a systematic analysis of the use of expanded technologies applied to the performance of technologically expanded traditional acoustic instruments. In this context, traditional acoustic instruments are defined as those belonging to the Western written music tradition, with a particular focus on the orchestral and chamber repertoire. This includes orchestral instrument families, as well as guitar, piano and harp, whose presence is significant both in the classical repertoire and in widely disseminated pedagogical and performative contexts, such as conservatories and music schools across the Western world.

The term, *technologically expanded instruments*, refers to the integration of computational systems, sensors and actuators that enhance the expressive and interactive capabilities of acoustic instruments, while preserving their fundamental sonic identity – that is, as long as the sound continues to be produced by the resonating body of the instrument, even if its activation is partially automated. Over the past decades, this practice has evolved through multiple approaches, including tangible interfaces, non-intrusive capture systems, real-time sound processing and the integration of artificial intelligence, among others, promoting new modes of interaction between performer, instrument and technology. Despite the growing body of artistic and scientific production on technologically-expanded instruments, conceptual and terminological fragmentation persists, along with a lack of systematic studies that consolidate the state of the art – particularly with regard to traditional Western instruments. Accordingly, this analysis aims to contribute to a more rigorous and comprehensive framework for the field of technologically expanded acoustic instruments, offering a solid conceptual and methodological foundation for future research and the advancement of contemporary artistic practice.

2. Methodology

The choice to conduct a systematic review in this study responds to the need to critically synthesise a growing

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and fragmented body of literature on technologically expanded traditional acoustic instruments. In this context, traditional acoustic instruments are defined as those belonging to the Western written music tradition, with a particular emphasis on the orchestral and chamber repertoire. This category also includes the piano, guitar and harp, which are widely disseminated in Western educational and performance practices. Systematic reviews make it possible to aggregate and evaluate available evidence in a rigorous and transparent manner, providing a comprehensive and reliable overview of the state of the art in interdisciplinary fields (Snyder, 2019). While well established in the social and applied sciences, systematic reviews have been increasingly adopted in artistic and technological domains, where traditional narrative reviews do not ensure the same level of methodological rigour or reproducibility (Booth, Sutton & Papaioannou, 2016). In this regard, the systematic approach not only facilitates the identification of gaps and emerging trends but also contributes to the development of robust theoretical frameworks in hybrid contexts, such as technology-mediated musical performance. This review operates qualitatively, as the selected articles describe performative systems and artistic practices rather than presenting statistical comparisons, with the aim of generating a critical conceptualisation of the field.

Given the qualitative and interpretative nature of the studies analysed – which describe performative systems, artistic practices and experiential processes without recourse to statistical data or controlled experimental models – the SANRA (Scale for the Assessment of Narrative Review Articles) was adopted (Baethge, Goldbeck-Wood, & Mertens 2019). This methodology provides a structured and internationally recognised framework for evaluating the quality of narrative reviews, ensuring clarity of exposition, argumentative consistency and methodological coherence throughout the process. The SANRA scale is organised into six main criteria: (1) justification and relevance of the article for the reader; (2) concrete definition of the focus or formulation of research questions; (3) description of the literature selection process; (4) referencing; (5) scientific reasoning; and (6) appropriate presentation of data.

Finally, in addition to the formal criteria defined by the SANRA scale, certain methodological limitations of this review must be acknowledged. These arise from the use of a single database (Google Scholar) as the source for article retrieval, which may have led to the exclusion of relevant publications not indexed by the platform. Although no formal risk-of-bias tool was applied – given that the nature of the topic calls for a predominantly descriptive and reflective analysis – systematic and transparent screening strategies were adopted in order to mitigate potential bias in article selection and interpretation, thereby ensuring the consistency and relevance of the final corpus.

2.1. Justification of the article's importance for the readership

This review is of particular relevance to researchers, artists and educators engaged in technology-mediated musical performance – a rapidly developing field that still lacks critical systematisation. Although the number of technical and performative proposals involving technologically expanded acoustic instruments has grown significantly over the past decade, scientific production remains dispersed across distinct disciplinary areas and marked by heterogeneous conceptual frameworks. In this context, the present review seeks to offer a structured foundation for understanding the main technological strategies, interaction modalities and emerging performance contexts, thereby contributing to the theoretical and artistic consolidation of the field.

2.2. Statement of concrete aims or formulation of questions

This investigation is guided by four main research questions, formulated based on the analysis of the selected literature:

(1) What are the main technological strategies employed in the expansion of traditional acoustic instruments?
(2) Which technologies and software environments are most commonly used in technologically expanded systems, and how do they contribute to performative mediation?
(3) In what ways do interactive systems transform instrumental performance practices?
(4) What methods and metrics are used to evaluate these practices in artistic and experimental contexts?

2.3. Description of the literature search

The search strategy was designed to encompass the widest possible range of studies relevant to the field of technologically expanded traditional acoustic instruments. Three main search terms were used: 'augmented instruments' performance ($n = 271$ publications), 'augmented acoustic instrument' ($n = 9$ publications) and 'augmented performance' and 'musical instrument' ($n = 53$ publications), all queried through Google Scholar due to its broad indexing of interdisciplinary and artistic domains. Although these were formally

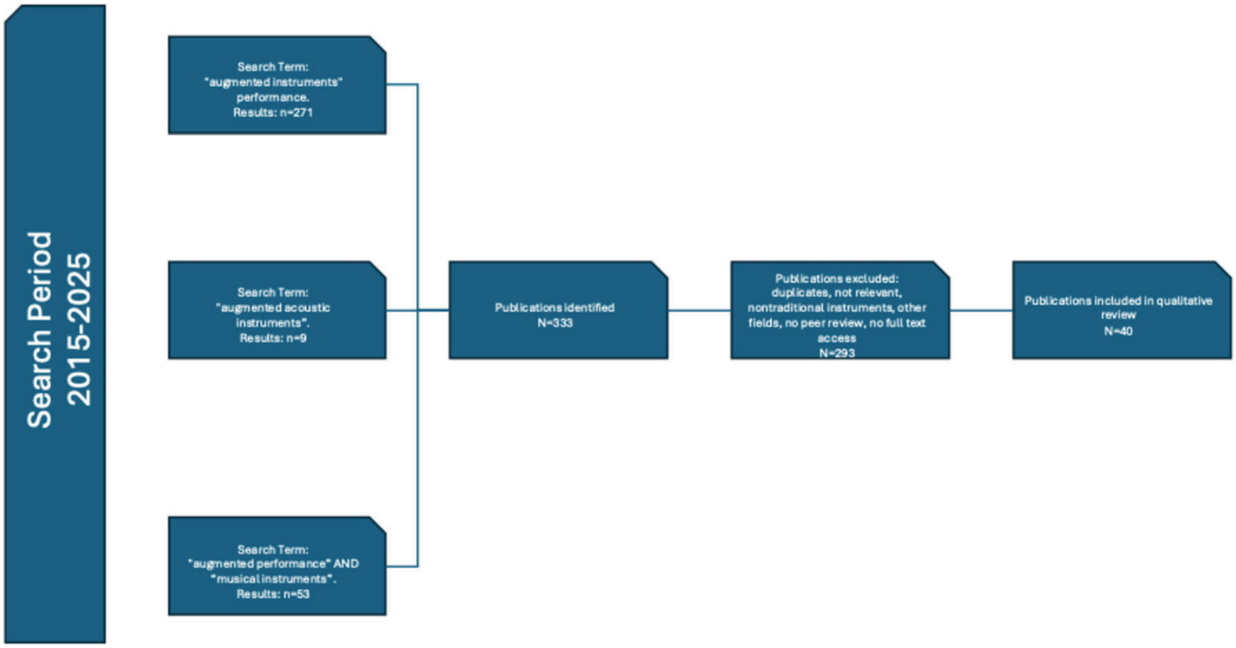

Figure 1. Literature search and screening process for included articles (2015–2025).

distinct expressions, their compound structure enabled the retrieval of publications with varied terminological and conceptual frameworks, extending beyond the explicit use of the term 'augmented instruments'. No automatic filters were applied beyond the time range of 2015 to 2025, allowing for the inclusion of diverse approaches, provided they met the predefined criteria. Screening was conducted manually in three stages: (1) removal of duplicates; (2) title and abstract analysis to exclude thematically irrelevant works; and (3) full-text review to verify methodological compliance and performative relevance within the scope of technologically expanded traditional acoustic instruments.

Exclusion criteria comprised non–peer-reviewed works, studies focusing exclusively on digital or electroacoustic instruments without a traditional acoustic component, publications without full-text access and works from disciplinary areas unrelated to the subject of study. As a result, 40 peer-reviewed publications were selected and form the analytical corpus of this systematic review (see Figure 1).

2.4. Referencing

The review incorporates a diverse and up-to-date set of references drawn from peer-reviewed scientific journals, international conference proceedings and doctoral dissertations. Most claims and observations are substantiated through indirect citations and explicit references, ensuring academic rigour and argumentative transparency.

2.5. Scientific reasoning

The analytical framework is based on a systematic comparison of each case, organised according to the following categories: instrument, type of expansion, interaction modality, technology used, software, performance context, evaluation method and key findings. The interpretation of the data follows a consistent logic, linking emergent patterns to the research questions and supporting the arguments through specialised literature and artistic practice.

2.6. Appropriate presentation of data

The results are presented in a structured manner through tables that enable direct comparison across cases. Each study is contextualised with concise full-sentence descriptions, organised into standardised categories that provide a clear and in-depth synthesis of the technological, performative and evaluative dimensions.

3. Technologically expanded acoustic instruments

The twentieth century brought a significant conceptual shift in organology, marked by the development of musical instruments equipped with complex systems aimed at innovation and timbral diversification. Composers began to explore these possibilities more consciously, even creating specific notational forms for new gestures and sound materials (Magnusson, 2019). The idea of technologically expanding acoustic instruments emerged from this creative drive, further propelled by the growing accessibility of computational resources. One of the foundational milestones was Tod Machover's work in the 1980s with hyperinstruments – systems that combined sensors, sound synthesis and computers to amplify the expressive potential of musical gestures (Machover, 1992). In the 1990s, sonification also became an emerging field of research, particularly in social and environmental contexts, expanding modes of listening through interactive technological devices (Battier, 2022). From this point on, a variety of approaches proliferated under different designations: augmented instruments – acoustically played instruments enhanced through sensors, digital processing, or gestural mapping, without compromising traditional performance technique; interactive instruments – those incorporating responsive digital systems that interpret, transform, or amplify the performer's actions in real time; actuated instruments – equipped with actuators or mechanisms that directly intervene in sound production, either transforming the instrument physically or exciting it without traditional contact; and hybrid instruments – combining acoustic and digital components in interdependent ways, forming instrumental ecosystems with mixed compositional, performative, or material logics. These categories represent diverse articulations between performer, instrument and computational system, with varying degrees of mediation, responsiveness and autonomy.

Since the early twenty-first century, physical gesture has taken on a central role as a parameter for expressive control, becoming a common pathway for real-time interaction (Wessel et al., 2002). According to Turchet (2018), augmented instruments integrate both sensors and actuators, rejecting the separation between augmentation and actuation. This review adopts a compatible understanding, while opting for the term technologically expanded acoustic instruments to emphasise the growing diversity of performative configurations and strategies of digital mediation. In line with this, Magnusson (2017) proposes a relational and heterarchical organology in which the performer does not exercise total control over the system; rather, instruments are conceived as evolving assemblages whose properties emerge from usage and performative interaction, rather than from a fixed technical design. In this sense, any attempt at rigid categorisation proves insufficient when faced with the experimental and evolving dynamics of the field. The relationship between performer and instrument thus becomes co-agential rather than hierarchical: it is the performative experience itself that continuously shapes and reconfigures the system. As Davis (2017) argues, actuated instruments such as the Feral Cello demonstrate that instrumental performance can trigger internal transformations within the system, allowing it to evolve through practice rather than merely from its original design.

The broader media context has also influenced this trajectory. When expanded musical performance is viewed as a form of multimodal communication, it aligns aesthetically with McLuhan's (1964), distinction between 'hot' and 'cool' media: the more layered the performance, the greater the semiotic demand placed on the audience. Furthermore, the centrality of the computer in new media, as theorised by Manovich (2001) - including its numeric representation, modularity, automation, variability and transcoding - has left a profound imprint on the domain of technological instrumental expansion. The computer became both accessible and central to multiple media, leading to what Jenkins (2016) describes as a participatory culture, where new processes are often shared online or through other publication formats.

Another relevant dimension is Manovich's later theorisation of software culture (2013). Both software and microcontrollers have assumed a central role in this field, and Manovich's metaphor of the *metamedium* resonates with the multiplicity of artefacts developed for expanded musical systems. In other words, he compares Darwinian evolution to the natural selection that software undergoes – an idea that can also be extended to technological expansion in instrumental performance, where many systems are created but only a few persist due to various constraints. An additional outcome of this evolution is the increasing use of artificial intelligence (AI) in performance and instrumental expansion: many software platforms already include AI processes, and numerous systems aim to develop computationally assisted or autonomous partnerships in performance. Taken together, these shifts point to a broader transformation in the perception of communication itself, suggesting that instrumental musical performance – at least in part – has mirrored and participated in this technological-cultural evolution. This expansion does not refer solely to the amplification of acoustic instruments, but more broadly to the evolution of technological ecologies and the ways in which society engages with them. Within this paradigm shift, machines have increasingly ceased to function merely as tools and have become performative partners, co-constructing the artistic process. In many of the systems analysed, technologically expanded instruments operate not as passive extensions of the performer but as relational agents, implying new modes of subjectivation and expression. This aligns with Rosi Braidotti's notion of affirmative posthumanism, in which subjectivity is conceived as distributed, dynamic and technologically entangled – no longer centred on the humanist ideal of autonomy, but rather constituted through interconnections, material flows and affective intensities, Braidotti (2006). Similarly, Haraway's (1985) cyborg figure embodies a hybrid ontology that refuses categorical separations such as human/machine and nature/culture, proposing instead a model of symbiotic co-agency rooted in embodied practice and situated knowledge. The technologically expanded instrument is, in this sense, a cyborg artefact: a 'partial being' that mediates between physical gesture and algorithmic agency, disrupting traditional hierarchies of control and virtuosity. Ferrando (2014) further reinforces this perspective by framing posthumanism as an ontological condition in which all entities – human and non-human – exist within a network of intra-action. In her words, 'there is no absolute 'otherness'; we exist in a material net in which everything is actually connected and potentially intra-acting'. In the context of expanded acoustic performance, this implies that the musical act is no longer the expression of an isolated subject, but the emergent outcome of a posthuman assemblage: an entangled ecology of body, instrument, code and space–time.

Finally, it is important to emphasise that this review does not establish normative distinctions between different modes of technological implementation. Regardless of the nature of the devices involved—sensors, actuators, feedback systems, artificial intelligence, among others—all analysed systems are considered valid forms of technological expansion of the acoustic instrument.

4. Analysis

This section presents the analysis based on the parameters defined in Table 1, as previously introduced in section 2.5.

4.1. Instrument

In the instrument category, it is important to note that although 40 publications were analysed, some refer to the expansion of more than one instrument, resulting in a total of 45 instruments considered – see Figure 2. Among the analysed works, certain instruments appear more frequently, namely the clarinet (including bass clarinet), trumpet, guitar, violin and percussion.

However, if we exclude authors with more than one publication included in the analysis, the list of most frequently expanded instruments changes: the clarinet and the violin emerge as the most recurrent; each appears in four publications. It is also worth noting the absence of certain instruments, which, in the context of a symphony orchestra, would be expected – such as the viola, oboe, bassoon, tuba, among others.

4.2. Type of expansion

In this category, the analysis of the selected publications resulted in the identification of four main types of expansion, as shown in Table 2. The first type refers to sensor-based augmentation: systems that use sensors (such as motion, pressure, proximity, touch, or electromyography) to capture physical gestures or performative variables, mapping them to control digital processes. These systems preserve traditional acoustic performance while adding expressive or interactive layers without physically modifying the instrument. The second type concerns actuation or feedback: instruments that incorporate mechanisms of physical actuation or audio and vibratory feedback. The acoustic sound is amplified, modulated, or redirected into the instrument's body through transducers, loudspeakers, or excitation systems, creating material feedback loops between performer and instrument. The third type involves acoustic-technological hybridisation: configurations in which the acoustic sound is processed in real time through synthesis, sampling, or digital manipulation. The resulting sound blends acoustic and electronic characteristics, without necessarily involving sensors or physical feedback and emphasises sonic and aesthetic fusion. Finally, the fourth type concerns symbolic or compositional augmentation: systems that use sound or gesture analysis to generate or transform compositional structures in real time, based on descriptors, artificial intelligence, or symbolic logic. In these cases, expansion acts upon the structure of the performance itself, rather than on the immediate sonic output.

Thus, a clear tendency can be observed toward the use of sensor-based augmentation as well as instrument actuation with corresponding feedback. Despite this categorisation, it is important to acknowledge that some systems may fall into more than one category, as in the case of the MAD Clarinet 3.0 project (Travasso & Marques, 2024), whose system predominantly involves acoustic-electronic hybridisation based on the capture and processing of the clarinet's sound, but also incorporates a logic of symbolic compositional augmentation derived from that captured sound. The categories identified here – sensor-based augmentation, actuation/feedback, acoustic-electronic hybridisation and symbolic/compositional augmentation – should therefore be understood as descriptors of the dominant technological vectors in each system, rather than as mutually exclusive typologies. Many projects operate in areas of overlap and were grouped here according to their most salient technical element. Finally, it is important to stress that these classifications serve an analytical function only, with no prescriptive methodological intent. Throughout this article,

Table 1. Systematic review.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Conforti and Güsewell (2015)	Paetzold recorder	Sensor-based augmentation (hyperinstrument approach)	Fingering and air pressure sensors mapped to sound processing and control parameters	I-CubeX sensors (magnetic field sensors for keys, piezoresistive air pressure sensors), custom-built hardware	Max/MSP, I-CubeX library	Contemporary live performance performed by the PRIME Recorder Ensemble in collaboration with young composers.	No formal comparative evaluation; the system was developed and tested in performances and workshops; it was evaluated through iterative prototyping and composition workshops.	This study demonstrated that key movement and air flow gestures can control live electronics, creating extended sonic possibilities while preserving the instrument's acoustic identity; the system enabled fine-grained gesture tracking and dynamic sound control.
Dahlstedt (2015)	Piano	Acoustic-electronic hybridisation (sound processing, virtual resonance, feedback loops)	Keyboard playing	Microphones, speakers, Moog Piano Bar (MIDI), Nord Modular G2, virtual resonators, feedback networks	Not specified	Solo and ensemble improvisation: concert performances in the UK, Japan, Singapore, Australia and Sweden.	Long-term artistic practice by the author and an experienced pianist: qualitative evaluation based on idiomatic playing patterns.	Developed an augmented hybrid piano integrating improvisation with dynamic mapping; we enabled control of complex sound engines directly from traditional playing techniques; we achieved organic interaction between acoustic and processed sounds without external controllers.'
McPherson (2015)	Piano	Continuous key-angle sensing, surface touch sensors	Piano playing (traditional and exploratory gestures)	Optical sensors (for key angle), capacitive touch sensors, microcontrollers	Not specified	Solo and ensemble performances, laboratory experiments	Qualitative assessment based on performer s' feedback and interaction studies	Enabled nuanced expressive control and extended sonic possibilities; sensors captured subtle performer actions without altering traditional playing techniques.
Kallionpaa (2016)	Piano	Electromagnetic augmentation (Magnetic Resonator Piano)	Traditional piano playing, extended techniques, pedal control	Magnetic Resonator Piano System: electromagnetic actuators, pedal sensors, control electronics	Not specified	Solo performances of commissioned works in classical and experimental contexts	Qualitative artistic reflection and analysis of performance outcomes	Demonstrated the expansion of the piano's acoustic capabilities through controlled resonance; allowed nuanced interaction without altering traditional playing techniques.
Neill (2016)	Trumpet	Electroacoustic hybridisation with MIDI control, pitch-to-MIDI conversion, continuous controllers, live sampling	Trumpet playing, pitch variation, button pressing	Custom-built Mutantrumpet with MIDI sensors, audio interface, live electronics	Not specified	Solo and ensemble performances in electroacoustic contexts	Long-term artistic practice and iterative prototyping	Created the Mutantrumpet as a hybrid acoustic-digital instrument, expanding performance possibilities.
Normark et al. (2016)	Clarinet	Sensor-based gesture control and visual feedback	Traditional clarinet playing + motion gestures	Inertial sensors (IMU), touch buttons, LED strip, wireless communication (Wi-Fi), 3D-printed augmented bell	Max/MSP	Artistic performance in chamber music and experimental contexts	Qualitative evaluation by a professional clarinetist	Enabled gesture-based audio transformation and visual feedback without altering the traditional clarinet playing technique; improved artistic expression through pitch shifting, filtering and visual augmentation.
Pardue (2016)	Violin	Sensor-assisted learning tools (bow tracking, pitch tracking)	Bowing (pressure, position), finger placement on strings	Near-field optical sensors, custom fingerboard sensor, electret microphone	Custom Max/MSP patches, VSTs	Learning contexts with beginners and experts.	Mixed-method evaluation: expert pilot study and beginner studies	Developed a low-latency system for pitch and bow tracking; demonstrated its potential to support violin learning through interactive aural and visual feedback, while discussing the challenges of managing feedback complexity in pedagogical contexts.
Reid et al. (2016)	Trumpet	Non-intrusive gestural sensing (removable sensors capturing embouchure, valve use and instrument orientation)	Trumpet playing (valve displacement), hand tension, instrument orientation	Optical sensors (VCNL4000), force sensing resistors (FSR), accelerometer (ADXL335), Arduino Fio, XBee wireless communication	MIGSI Mapping (Max/MSP standalone app), OSC protocol	Solo and ensemble performances, including improvisation and telematic works	Initial testing with 3 trumpet players: qualitative assessment of playability and expressivity	Developed a removable, minimally invasive sensor system for trumpet, enhanced expressivity without altering acoustic playability, enabled continuous gestural control over electronic processing and demonstrated usability in live performance

(*continued*).

Table 1. Continued.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Davis (2017)	Cello	Actuation via DSP-driven feedback through instrument body; gesture-responsive sound transformation	Improvisation with mutual adaptation between performer and system	Pickup, laptop, speakers, actuators, Zsa.Descriptors, IRCAM Gesture Follower	Max/MSP, IRCAM Gesture Follower	Solo improvisation (e.g., *Gemmeleg*), semi-structured with a responsive system	Practice-based research; philosophical reflection	Rejects instrumental mastery; promotes emergent co-agency; system alters its sonic output based on gesture recognition and DSP changes, prompting continuous performer response
Portovedo et al. (2017)	Saxophone	Hybrid augmentation combining sensors embedded in the saxophone with wearable motion sensors on the performer	Traditional saxophone playing combined with gesture control	Ribbon sensor, trigger, pressure sensor, accelerometer, gyroscope, keypad, Myo Armband	Not specified	Solo and ensemble contemporary performances	Qualitative analysis based on artistic practice and system development	We developed an augmented saxophone system allowing real-time gestural control of sound processing, which enabled nuanced interaction between physical performance and digital sound manipulation.
Rimoldi and Manzolli (2017)	Flute	Hybrid augmentation combining gestural and sonic feature capture	Instrument motion (pitch, roll, yaw), ancillary gestures, audio feature extraction	Triaxial accelerometer, gyroscope, magnetometer (MARG sensors), ultrasound sensor, FSR, audio analysis tools	Pure Data	Simulated performance tests; no live artistic context presented.	Simulated evaluation using iterative machine learning adjustment	Developed the Metaflute, an augmented flute system employing unsupervised learning to dynamically adapt gesture-sound mappings; enabled nuanced expressive control through motion and audio features; demonstrated adaptive, performer-driven interaction through experimental performance contexts.
Rossitto et al. (2018)	Acoustic Guitar	Smart augmentation with embedded sensors and wireless communication	Guitar playing, body gestures	Embedded sensors (unspecified), Bluetooth communication.	Not specified	Initial exploratory workshops and rehearsals	Qualitative user practice with musicians	Explored how musicians initially engage with augmented guitars; identified challenges in playability and design affordances for smart instruments in artistic contexts.
Evaristo Gonzalez Sanchez et al. (2018)	Acoustic Guitar	Embedded augmentation with infrared sensors and actuators	Proximity detection (stillness-based), tactile feedback	Embedded infrared sensors, actuators, Bela platform	Pure Data	Interactive installation (Sverm–Resonans)	Qualitative observation during installation	Enabled microinteraction with acoustic guitars in an immersive installation context, blending tactile gestures with responsive sonic feedback
Sullivan et al. (2018)	Harp	Gestural augmentation for real-time control of audio effects	Natural harp playing gestures and ancillary gestures (hand/arm motion)	Wireless motion sensors (ESP8266 microcontroller, MPU-9250 IMU), Wi-Fi (UDP), OSC protocol	Max/MSP (including Max for Live), GRM Tools	Solo harp performance with gesture-controlled electronics in a composed work	Exploratory case study involving rehearsal and iterative design with a professional harpist.	Designed a lightweight wireless gesture control system for the harp; mapped the harpist's natural playing gestures and ancillary gestures to control audio effects; demonstrated integration into a new performance work.
Eldridge and Kiefer (2019)	Cello	Electroacoustic feedback via embedded speaker and transducer	Gesture-based control, string vibration, gain modulation, live coding input	Electromagnetic pickups (CycFi), built-in speaker, vibrational transducer, Sony car amplifier, custom 3D-printed mounts	SuperCollider (for adaptive DSP and live coding)	Solo and duo improvisation, installation pieces, live coding concerts	Practice-based iteration, installation observation, qualitative reflection on performer interaction	The system enables rich gestural and generative feedback interaction; supports performer-agency through tactile control and coding; facilitates hybrid acoustic-digital expressivity in both concert and installation settings.
Lupone et al. (2019)	Gran cassa (Feed-Drum®), Membranophone (SkinAct), Alto Saxophone (WindBack), Flute (ResoFlute)	Acoustic feedback and vibration actuation	Traditional playing with controlled acoustic feedback and vibrational responses	Vibrational actuators, microphones, acoustic sensors, feedback systems	Max/MSP and Pure Data	Contemporary live performances	Practical evaluation and iterative development	Enabled controlled acoustic feedback and vibrational modulation, expanding the expressive range of traditional instruments without altering fundamental playing techniques

(*continued*).

Table 1. Continued.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Pardue et al. (2019)	Hybrid system: stick electric violin (interface) + physically isolated acoustic violin body (resonator), called *Svampolin*	Hybrid acoustic-electronic system with physical decoupling of the interface and resonator enables sound substitution rather than additive layering.	Interaction occurs through traditional violin techniques – bowing and fingering – preserving the tactile and ergonomic familiarity of an acoustic violin.	The system includes a custom electrodynamic polyphonic pickup, neodymium magnets under each string and a low-noise preamplifier (OPA1612-based). Signal processing is performed using a Bela Mini embedded computer, with sound actuated via a Tectonic TEAX32C30 vibration actuator attached to the acoustic body. A class-D amplifier (TPA3118) powers the actuator. Foam is used to isolate the interface from the resonator and minimise mechanical feedback.	The Bela platform runs a modified version of the Yin pitch detection algorithm and a customised version of Autotalent for real-time pitch correction. Additionally, custom real-time segmentation and regression algorithms are used to analyse and regulate tone quality based on physical string behaviour.	The svampolin is designed primarily for music education, particularly for beginner violinists, providing enhanced motivation through improved intonation and tone. It also holds potential for use in interactive performance and experimental music contexts.	Evaluation involved qualitative testing with expert and novice violinists, analysis of signal adherence to physical models of bowed strings and informal assessment of motivational impact and perceived tonal improvement.	The system enables digital transformation of sound while preserving physical technique. It shows strong potential for supporting musical learning through real-time correction, though overreliance on automated feedback may hinder error awareness. Overall, the design presents promising applications in education and performance.
Reid et al. (2019)	Trumpet	Sensor-based augmentation that preserves acoustic sound while enabling gestural control of digital processes, focusing on temporal displacement and layered interaction	The performer plays the trumpet using traditional acoustic technique (blowing, fingering), while the system captures valve movement, pressure and motion data to trigger or modulate electronic responses	Optical valve sensors, force-sensitive resistors (FSRs), 3-axis accelerometer, wireless data transmission, OSC routing, Max/MSP interface, optional mechatronic integration	Max/MSP modular system with TRIP, TCO and granular synthesis engines	Solo and ensemble performance settings, improvisation and composed works exploring temporal feedback, delay and transformation	Practice-based development across four years with compositional case studies, iterative performance testing and performer feedback.	Supports multi-layered temporal interaction without compromising acoustic technique; enables dynamic, expressive hybrid performance practice through sensor-based mapping and emergent behaviour
Granieri (2020)	Acoustic Piano	Hybrid acoustic–digital augmentation (audio processing controlled by ancillary gestures)	Ancillary hand and arm gestures above/around the keyboard controlling sound processing while playing	Radar-based hand-gesture sensing (Google Soli), gesture recognition via machine learning, (OSC communication)	OpenFrameworks (gesture capture and analysis), Pure Data (audio processing)	Pianistic performance scenarios explored through controlled user testing	User study with questionnaires and qualitative feedback	Non-invasive ancillary gesture control enables expressive modulation of audio processing without altering pianistic technique, though gesture-recognition reliability impacts perceived control
Ko & Oehlberg (2020)	Violin	3D printed conductive PLA fingerboard with touch sensors and FSR-triggered control	Left-hand finger pressure sensing (string contact) + right-hand preset triggering (FSRs)	Conductive PLA strips, Arduino MKR1000, JST/IDC connectors, OSC wireless protocol	Max/MSP (with OSC)	Solo and duet interactive audiovisual performances ('Dream State', 'Kindred Dichotomy')	Autobiographical design + technical testing (resistance, materials) + artistic performance feedback	Robust and modular augmented violin preserves traditional technique, enables advanced mapping and gesture-driven interaction, is stable over time and is adaptable to compositional needs and visual.
Reed and McPherson (2020)	Voice	Biosignal-driven augmentation using facial and neck surface EMG to control synthesis and transformation in vocal performance	sEMG electrodes placed on the face, neck and jaw detect muscular activation patterns during singing; signals are mapped to real-time control of synthesis and sound processing while leaving the acoustic voice unaltered.	8-channel sEMG sensor array, custom preamplifier and filtering circuitry, external audio interface, laptop for acquisition and synthesis	Max/MSP (real-time mapping and synthesis), sEMG data acquisition patch	Live proof-of-concept performance with vocalist: the system is mapped to drive real-time synthesis parameters.	Prototype demonstration and informal performance feedback; no formal user study or structured evaluation	Non-invasive sEMG enables real-time expressive control over sound synthesis without interfering with vocal technique, expands performance possibilities using physiological gesture and is suitable for hybrid vocal-electronic interaction.
Ulfarsson and Melbye (2020)	Double Bass	Embedded feedback system with integrated real-time DSP for acoustic-electronic hybrid sound generation	The performer uses standard acoustic techniques (bowing, plucking); string vibrations are captured by individual pickups and processed through a feedback loop with speaker re-excitation.	Cycfi Nu4 pickups (1 per string), Bela board with CTAG Face extension, 8" 150W speaker mounted on resonator plate, onboard amplifier, potentiometers for control, internal power system	SuperCollider (embedded on Bela for DSP and control signal routing)	Solo and duo sessions with Melbye: the system was used in informal artistic exploration rather than staged performance.	Practice-led iterative design in close collaboration with the performer; no formal user study.	FAAB extends the double bass's sonic vocabulary through controlled feedback; preserves acoustic playability; enables emergent behaviours shaped by performer-technology interaction; supports improvisatory and experimental performance practice

(*continued*).

Table 1. Continued.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Martelloni et al. (2021)	Acoustic Guitar	Conceptual exploration based on gesture mapping and player feedback (no prototype tested)	Percussive fingerstyle gestures (zones on body: wrist, fingers, thumb) + string tapping	Wrapped guitar performance test; speculative discussion of actuators (e.g. E-Bow), gesture mapping and AI co-performers	Not specified	Discussion-based study with experienced guitarists specialised in percussive fingerstyle; includes gesture mapping and speculative design input	Semi-structured interviews (n = 5), wrapped guitar constraint test, thematic analysis, speculative design task	Players favour expressivity, spontaneity and physical nuance; the value of idiomaticity and gesture-based exploration; augmentation must avoid over-automation and performance.
Freire et al. (2021)	Nylon-string guitar	Symbolic transcription and interactive transformation system driven by real-time audio descriptors	Performer plays guitar normally; audio features (e.g., onset, pitch, timbre) are extracted and used to control symbolic transcription and trigger transformations via pedal.	Hexaphonic piezo pickups (RMC, LRBaggs), Focusrite audio interface, DI boxes, AKG C-411 contact microphone, pedal controller	Max/MSP, Kontakt (VST), custom Max externals for transcription and control	Solo improvisations and real-time performance demonstrations; pedagogical and compositional applications	Practice-based testing with performer feedback; no structured empirical evaluation	System captures and manipulates guitar performance at symbolic level; supports variation and mapping strategies; maintains the playability of the acoustic instrument while enabling digital interaction.
Lupone et al. (2020)	Flute	Internal microphones and acoustic-electronic feedback via resonant pipe and gesture-triggered control	Performer plays the flute acoustically; internal microphones capture the signal; thumb pressure on the piezo sensor triggers the control; the spatial relation to the external resonant speaker modulates the feedback behaviour.	6 internal electret microphones, MEAS piezo-film sensor under thumb, aluminium resonant pipe with embedded speaker and jointed chamber, MIDI foot pedals, power amplifier	Max/MSP (feedback control, filter banks, FM processing, spectral transformations)	Solo performance ('Èleghos', 2014) with flutist Gianni Trovalusci; developed and tested in rehearsals	Iterative artistic practice development; no empirical data collection	ResoFlute enables acoustic-electronic hybrid feedback shaped by gesture and proximity, expanding the expressive potential of the flute while preserving traditional playability.
Michalakos (2021)	Acoustic instruments (adaptable system)	Electroacoustic interaction framework using real-time game-based audio processing	Performers respond to audiovisual game prompts while playing acoustic instruments, with real-time audio being captured and processed through game logic.	Microphones, soundcard, computer with Max/MSP, projection/display system, game controllers	Max/MSP (custom patches for audio capture, transformation and rule-based game interactions)	Workshops and live ensemble improvisations using structured game-based interactions	Practice-based iteration; artistic reflection; no formal empirical protocol	Game structures scaffold improvisation and interaction; system adapts to different acoustic instruments without modifying them; fosters listening, agency and group creativity
Thorn (2021)	Violin	Multimodal augmentation using motion and proximity sensors for audiovisual improvisation	Performer plays acoustically; motion and proximity sensors detect gesture and spatial movement; data mapped to real-time audiovisual transformations	Wearable motion sensors, proximity sensors, real-time audiovisual processing unit, computer, projection system	Max/MSP (custom patches for gesture tracking, audiovisual mapping and feedback control)	Solo and group improvisations with augmented violin in interdisciplinary performances	Exploratory artistic practice: no structured empirical study	The augmented violin expands gestural and spatial expressivity; the system enables embodied interaction with audiovisual elements; performer agency is enhanced through multimodal feedback.
Arslan et al. (2022)	12-string guitars, drum kit and trumpet (all acoustically played and physically augmented)	Actuated acoustic instruments controlled via Spatial Augmented Reality (SAR) shapes	Musicians intersect virtual 3D shapes projected around the instruments using either instrument or hand gestures; intersections control excitation parameters of actuators.	Surface speakers (non-specified) for guitars and drums, Dayton Audio DAEX25VT-4 for trumpet, solenoid valve, depth cameras, projectors, air compressor, Pure Data patch, SAR projection system	Pure Data (signal generation and actuator control)	Structured improvisation with two musicians and four augmented instruments across multiple artist residencies	Performance-led research with ethnographic observation, co-design and semi-structured interviews	Spatial AR enables embodied interaction with actuated instruments through proprioception; instruments support subtle gestural control and redefinition of sonic roles; co-design was essential for artistic appropriation
Leung (2022)	Trombone	Sensor-based movement tracking system embedded into trombone to control sound layering and audiovisual mapping	Orientation and movement are tracked via Joy-Con's IMU (gyroscope, accelerometer); mapped in Max/MSP to control granular audio processing and visuals in a 3D space.	Nintendo Switch Joy-Con (IMU), Bluetooth wireless connection, Max/MSP patch, granular engine, 3D visual interface, physical mount for sensor attachment	Max/MSP (incl. mugranular and audiovisual mapping)	Live performance at Concordia University (Montreal, Nov 2021); collaboration with choreographer; autobiographical work with integrated movement and audio	Artistic-exploratory method with performer-choreographer collaboration; practice-based refinement; no structured empirical data collection	Mubone expands trombone performance through movement-driven control; facilitates choreomusical dialogue and distributed authorship; movement data enhances expressiveness through audiovisual interaction and autobiographical narrative

(*continued*).

Table 1. Continued.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Travasso (2022)	Clarinet	Acoustic augmentation and interactive multimedia (sound effects + generative visuals)	Physical positioning, clarinet playing, motion detection, pitch tracking	Motion sensors, microphone, computer	Max/MSP	Solo performance	Artistic practice, iterative prototyping	Enabled real-time audiovisual interaction; explored multimodal performer-system dialogue through bodily gestures and sound input
Bardin (2023)	Clarinet	Embedded sensor augmentation system for finger pressure and touch tracking in acoustic clarinet performance	Capacitive and force sensors embedded along tone holes detect finger contact and pressure; signals are processed by the onboard MCU and sent wirelessly for real-time mapping	Cypress PSoC 6 MCU, capacitive touch sensors, force-sensitive resistors (FSRs), Bluetooth LE, flexible printed circuit boards, Li-ion battery, 3D-printed enclosure integrated into clarinet body	PSoC Creator (firmware); external mapping/synthesis environment (unspecified)	Lab-based functional testing with a clarinetist; system demonstration; no public performance documented	Latency and signal quality tests, validation with performer, qualitative observations on playability and usability and no structured empirical study.	Cyberinet augments clarinet without compromising traditional playability; supports finger pressure sensing and touch tracking; modular design enables retrofitting acoustic instruments for hybrid interaction
Panariello and Percivati (2023)	Bass Clarinet	Electroacoustic feedback system using embedded microphone and bell-mounted speaker with real-time audio processing in SuperCollider	The performer modulates the acoustic signal through fingering, embouchure and vocal tract shaping; the feedback system analyses and transforms the resulting sound in real time.	Super-cardioid miniature microphone (internal), plastic neck extension, 5" woofer (8Ω, 40W) mounted on a wooden frame at the bell, stereo amplifier and soundcard.	SuperCollider	Solo performance of the piece 'WYPYM – Were You Part of Your Mother?' premiered in 2023 and was developed through performer–composer collaboration.	Practice-based iterative prototyping and live testing; there is no formal empirical study; documentation occurs through the creative process.	Feedback loops transform the acoustic instrument into a co-creative system; nonlinear interactions modify timbre and pitch; performers adapt technique to system response; open-source and DIY approaches foster experimental extended techniques.
Savery (2023)	Violin	Wireless sensor-based augmentation mounted on violin bow for audiovisual control	Right-hand fingers manipulate a bow-mounted potentiometer and a 4-button keypad; the accelerometer and the force sensor capture the gesture; the data are wirelessly transmitted to control the audio and visuals.	Arduino Fio, XBee ZB Zigbee wireless module, 3D-printed bow casings, Adafruit slide potentiometer, 4-button keypad, 3-axis accelerometer, force sensor, Flora Neopixel RGB LEDs	Max/MSP (incl. Jitter), Arduino IDE	Two performances: solo violin audiovisual piece and duet with robotic painting arm (sensor-driven); both documented in 2022	Practice-based development; iterative testing; qualitative reflection on mapping usability and sensor ergonomics	The system enables expressive real-time control of audio and visuals from the bow; it has minimal invasiveness; it has identified usability issues with sensor position and cognitive load; future directions include modular and adaptable mapping strategies.
Stifjell (2023)	Various acoustic instruments (tested with bass flute, brass and piano)	Modular electroacoustic feedback augmentation using embedded microphones, signal processing and internal loudspeakers for hybrid sound production	Performer input captured by internal microphones (contact, piezo, electret), processed in real-time and fed back through exciters or internal loudspeakers mounted on the instrument's body	Piezo, electret and contact microphones, Helpinstill and PiezoBarrel pickups, AD828 preamp, MCP3008 ADC, XH-M190 power amp, Raspberry Pi 4b, MT3608 converter, rotary encoders, RNBO-compatible breadboard circuit	Max/MSP with RNBO; modular patch library; future use of Pure Data and SuperCollider proposed	In-lab prototype testing; future integration is planned in compositions for acoustic instruments; no public performance has been reported.	Iterative prototyping and modular system testing: no formal empirical study, but documented hardware/software trials across instrument types.	FLAPIBox provides low-cost, adaptable electroacoustic augmentation, enables real-time feedback-based hybrid sound through the instrument's own body and an open-source approach that supports cross-instrumental application and accessibility.
Ek (2024)	Clarinet	Multimodal augmentation integrating movement sensing and audio analysis is used to control live electronics via gesture and acoustic input.	Bell elevation, tilt and movement (via BNO055 sensor); audio input (air pressure, extended techniques) used as data for CV mapping; performer responds through auditory feedback	MiM sensor bell, Bosch BNO055 IMU, ARM Cortex-M0+ microcontroller, ATWINC1500 Wi-Fi module, custom PCBs, Mutable Instruments Beads (Eurorack module)	Max/MSP (incl. MiM externals, abstractions and CataRT)	Live solo performances (2019–2023) with two mapping systems; studied through video documentation and stimulated recall analysis	Stimulated recall analysis with performance video review; self-annotation of gesture-sonic interactions; long-term practice-based refinement of mapping systems	Clarinet resistance shapes gestural control; second system links resistance and gesture through feedback-rich mapping; artistic expressiveness depends on tuning mapping design to instrumental affordances; augmentation benefits from long-term embodied engagement

(*continued*).

Table 1. Continued.

Reference	Instrument	Type of Expansion	Interaction Modality	Technology Used	Software	Performance Context	Evaluation Method	Key Findings
Travasso and Marques (2024)	Clarinet	Acoustic-electronic hybrid (solid vibration-based Tangible Acoustic Interface, sound processing, AI-generated harmonic/melodic responses)	Pitch and duration capture	Piezo vibration sensor, Zoom H6 interface, computer	Max/MSPand Logic Pro	Solo performances	Qualitative assessment of interactive potential, based on artistic practice	Developed a hybrid clarinet-computer system using solid vibrations to trigger harmonic/melodic responses; performer controls effects (reverb, delay, intervals); system explores real-time adaptive interaction with probabilistic AI logic
de Cecco (2025)	Unspecified acoustic instrument (AMI prototype with microphone and spectral analysis)	Real-time audio-driven system integrating instrumental gesture, spectromorphology and compositional control in a perceptual feedback loop	Spectral and temporal descriptors drive mappings to compositional morphologies; performer adapts gesture in response to auditory feedback (no physical sensors or motion capture)	Microphone-based capture, real-time spectral and temporal analysis, classification of gesture types (energetic, indicative, textural)	Not specified	Conceptual framework with prototype diagrams and implementation scenarios; no documented public performances or case studies	Theoretical development and conceptual design; no empirical user testing or case-based evaluation	Proposes an alternative AMI paradigm grounded in perceptual interaction and sound morphology; bypasses motion capture in favour of acoustic features; establishes a foundation for gesture-driven real-time composition and spatialisation through feedback.
Hamilton et al. (2025)	Historical Italian Harpsichord (replica)	Non-invasive optical sensing system for MIDI triggering with full mechanical authenticity (no soundboard activation)	Mechanical keypress displaces jack; infrared reflectance captured to generate velocity-independent MIDI notes; haptic resistance preserved	49 QRE1113 optical sensors, 7 CD4051BE multiplexers, WS2812 RGB LEDs, Arduino Nano 33 BLE, FRAM chip, rotary encoder, modular PCBs, gradient reflectance stickers, 3D-printed optical baffles, Mac Mini (host), iPad interface	Arduino IDE, MIDI Monitor, Kontakt	Museum exhibit (Museo San Colombano – Tagliavini Collection); interactive public installation with emphasis on accessibility and heritage	3-key prototype refinement, iterative calibration, expert consultation (instrument maker and performer), informal feedback ($n = 20$ museum users)	Instrument preserves historical tactility while enabling safe digital interaction; system is open-source and designed for reproducibility; limitations in MIDI expressivity and sample dynamics acknowledged; valuable model for inclusive and heritage-driven augmentation
Wolstanholme et al. (2015)	Snare Drum	Acoustic feedback augmentation	Indirect physical interaction through playing dynamics and muting	Piezo microphones, tactile transducers	Custom Max/MSP patch	Experimental performance contexts	Technical validation and experiential analysis	Demonstrated the creation of sustained and controllable feedback tones on a snare drum; developed a flexible modular system; highlighted challenges in intuitiveness and low-frequency control.
Souchal and Schwarz (2025)	Trumpet	Real-time audio-driven augmentation controlling additive synthesis, resonators and convolution (no physical sensors)	Sound descriptors (pitch, loudness, periodicity, AC1, centroid) drive audio transformations; footpedals and MIDI controller enable additional preset and parameter control	Arturia MiniLab MIDI controller, footpedals, microphone-in-speaker audio feedback routing, real-time audio descriptors (pitch, AC1, centroid, etc.), CNMAT resonators , HISSTools convolution tools	Max/MSP	Solo improvisation-based performances (Impromptissimo, Aleph Theatre); long-term collaboration and residency-based development	Practice-based and autoethnographic methodology, logbook reflection, iterative public testing and technical adaptation	Establish 'controlled unpredictability' as an aesthetic; real-time sound-driven mappings promote agency and spontaneity; the performer integrates and adapts to emergent behaviours; feedback becomes an expressive resource rather than a constraint.

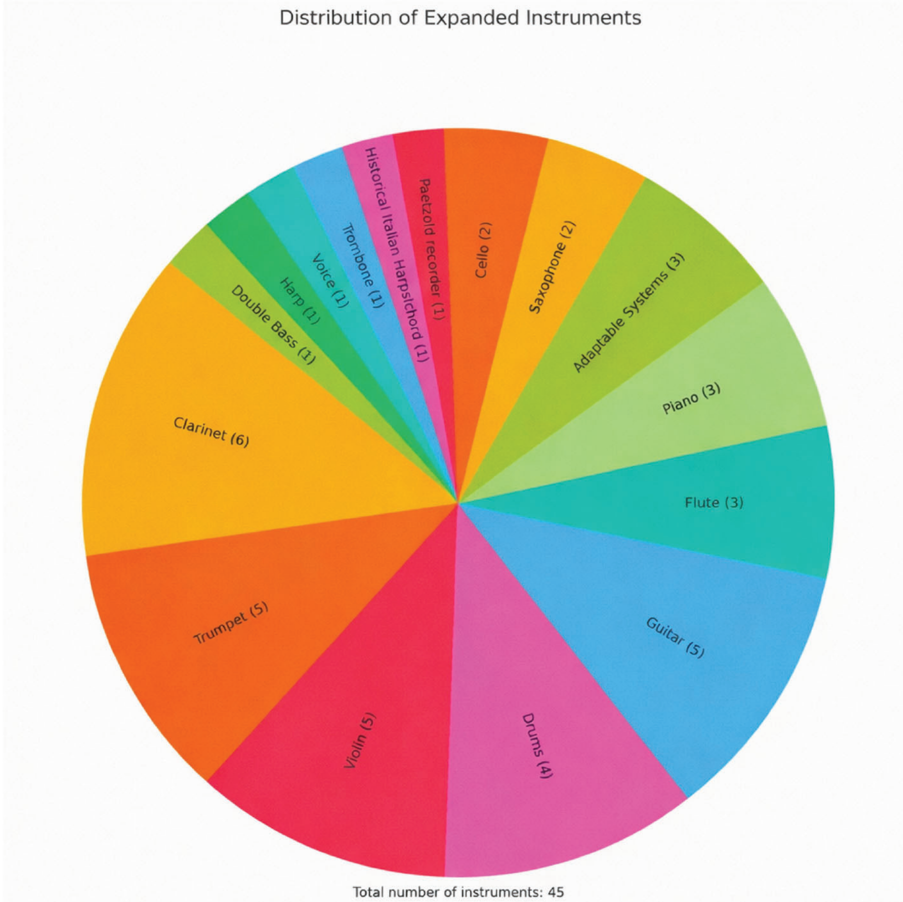

Figure 2. Expanded instruments.

Table 2. Type of expansion.

Type of expansion	Number of devices
Sensor-based augmentation	20
Actuation/Feedback	11
Acoustic-electronic hybridisation	7
Symbolic / Compositional augmentation	2

Table 3. Interaction agent.

Interaction agent	Number of publications
Instrumentalist	18
Instrumentalist (system feedback)	15
Instrumentalist and autonomous system	5
Public	2

all these approaches are assumed to belong to a common expanded field – the technological sonic expansion of traditional acoustic instruments.

4.3. Interaction modality

Before advancing to the analysis of interaction models, this section examines the interaction agent – that is, it identifies who is granted the possibility to interact with the system of technological sonic expansion (see Table 3).

This analysis reveals that performers are the primary interaction agents favoured by system designers. Only one system significantly diverges from this tendency by enabling audience interaction in an independent manner. The system in question is an installation featuring suspended acoustic guitars, presented by Gonzalez Sanchez et al. (2018), which operates through an inverse physical movement logic: once the presence of a person is detected, the less physical movement there is, the more sound the installation produces. Various sounds are triggered by using the guitars as resonating chambers. The same system, in terms of interaction modality (see Table 4), falls into the category of inverse control via audience response. Within this parameterisation, there is a clear predominance of systems that respond to the performer's physical movement or acoustic output, often coupled with resonant feedback mechanisms. These are systems that, based on the performer's gestures or sounds, generate tangible physical responses through the instrument's body, involving vibration, pressure, or direct acoustic excitation. This response resonates within

Table 4. Interaction modality.

Interaction modality	Number of publications
Gesture/sonic-based multimodal interaction	24
Tactile interfaces	2
Embodied resonant feedback	10
Audio-descriptor driven	1
Spatial interaction	1
Public triggered	2

the instrument itself, affecting both the performer's perception and their subsequent gestural behaviour.

Among the less common systems, those developed by Ko and Oehlberg (2020) and Bardin (2023) are categorised as tactile interfaces. The former is based on interaction through direct physical contact between the fingers of the left hand and the neck of the violin, allowing for precise detection of both location and pressure intensity. These data are used to control real-time sonic and visual transformations. The latter involves capacitive, and force sensors embedded in the tone holes of the instrument. This configuration enables the detection not only of finger presence but also of the pressure applied to each point, translating this data into control parameters for sound and visual mappings. In relation to the audio-descriptor driven model, the system by Freire et al. (2021) was identified. It uses a guitar with a hexaphonic pickup and a set of audio descriptors extracted in real time – such as onset, pitch and timbre – to feed symbolic transcription and musical transformation mechanisms. No motion, touch, or pressure sensors are embedded in the body of the instrument. The entire interaction logic is based on the analysis of sound produced during conventional performance, meaning the system operates on symbolic and sonic parameters derived exclusively from acoustic execution. As for spatial interaction, Michalakos (2021) proposes a playful approach to electroacoustic improvisation, structured around real-time audiovisual games. The performers – this being an adaptable system that can be used with any instrument – interact with visual and sonic rules that are spatially projected and dynamically evolve throughout the performance. Although they play conventional acoustic instruments, their performative attention is distributed across multiple sources: the sound they produce, the projected visual environment and the logic of the game that guides the ongoing transformations. The interaction is therefore fundamentally spatial, in the sense that it depends on the performer's relationship with an expanded performative space, where rules, stimuli and feedback are projected and distributed. Regarding inverse control, the previously mentioned system by Gonzalez Sanchez et al. (2018) is included in this category.

The Feedback Cello, designed by Eldridge and Kiefer (2019), exemplifies in a paradigmatic way the overlap between interaction categories. It simultaneously falls under gesture/sonic-based multimodal interaction – as its dominant mode – embodied resonant feedback, and tactile interfaces. On one hand, the instrument is manipulated through conventional and extended gestures, such as bow movements, finger pressure and gain adjustments via pedals, forming a responsive and expressive gestural-sonic system. On the other hand, the interaction produces a closed loop of physical response: the sound captured by pickups is routed back into the instrument's body through embedded transducers and loudspeakers, generating tangible vibrations that alter the performer's gesture in real time. This physical resonance – sensitive to position, intensity and timbre – becomes an active agent in the performance, destabilising the conventional distinction between control and response. The duality between gesture and physical return is further intensified by the presence of algorithmic actuation, in which adaptive DSP processes model the sonic and vibratory behaviour of the instrument independently of direct performer input. Additionally, the performer interacts directly with the instrument's body as a sensitive surface, responding to variations in contact, friction and pressure. This physical sensitivity transforms the cello into a non-conventional tactile interface, actively participating in sound shaping. As such, the system simultaneously articulates performative control, physical feedback and embedded tactile response, justifying its inclusion across multiple categories and illustrating the complexity of expanded instruments as interactive ecosystems. A final noteworthy aspect of this example is that the system may be operated solely by the instrumentalist, but also in a co-authorship context, where a second performer acts upon the system's behaviour through real-time live coding. This feature places the Feedback Cello within an expanded interaction model that may be classified as human–human computer-mediated interaction.

4.4. Technology

In terms of technology, for the purpose of effective categorisation, five categories were established (see Table 5): various sensors, encompassing projects that predominantly use sensors of any type; actuators/physical feedback, referring to projects that incorporate a physical computational response directed into the instrument; sound captures, involving systems that rely primarily on audio input as their source; microcontrollers/embedded systems, referring to the use of microcontrollers to generate internal processing or control functions; and augmented reality/spatial interaction, which includes projects operating within the domain of augmented or spatially mediated environments.

Table 5. Technology.

Technology	Number of publications
Various sensors	23
Actuators/physical feedback	8
Sound captures (microphones/pickups)	5
Microcontrollers/embedded systems	2
Augmented reality/spatial interaction	2

Three systems were classified under specific technological categories outside the dominant ones. The first, developed by Ko & Oehlberg (2020), falls within the category of microcontrollers/embedded systems due to its use of an Arduino MKR1000 with embedded tactile and force sensors integrated into the neck of a violin. This setup enables the detection of finger pressure and the wireless transmission of control data. Its low-power, autonomous and configurable architecture reflects an embedded processing logic that eliminates the need for large-scale external computing systems, making it a representative example of this category. In the category of augmented reality/spatial interaction, two studies stand out. The work by Michalakos (2021) presents a game-based musical improvisation system in which performers respond to visual and sonic stimuli projected within an expanded performative space. The musicians' relationship with the system is spatial in nature, involving the interpretation of distributed visual rules and transformations that shape the resulting sound. Arslan et al. (2022), on the other hand, developed a system based on Spatial Augmented Reality in which virtual three-dimensional shapes are projected around acoustic instruments equipped with embedded actuators. Gestural intersections with these forms activate vibratory sonic responses via physical exciters, all controlled through the Pure Data environment.

Once again, although each project has been categorised according to its most prominent technological feature, hybrid systems that span multiple categories are present. To illustrate this overlap, the system developed by Panariello and Percivati (2023) is analysed here. This project revolves around a bass clarinet augmented with feedback. It combines, on one hand, sound capture via a supercardioid microphone positioned inside the body of the instrument, and on the other, physical feedback delivered by a speaker mounted on the bell, forming a tangible acoustic feedback loop. The captured sound is processed in real time within the SuperCollider environment, using adaptive algorithms that analyse and transform the sonic material based on descriptors such as entropy and spectral centroid. The processed response is then sent back into the instrument, shaping its resonance and requiring an active and responsive mode of listening from the performer. Although classified under the sound captures category, the system far exceeds this dimension, functioning as a living co-creative structure in which performer and system influence each other in unpredictable and tactile ways. The clarinet thus becomes simultaneously an interface, a resonator and a diffuser, clearly exemplifying the complexity of inter-category relationships in contemporary technologically augmented instrumentation.

4.5. Software

Software, as a fundamental mediator between input, processing and performative output, plays a decisive role in the systems analysed. Table 6 shows a clear predominance of the Max/MSP environment, often used in conjunction with variants such as Max for Live or RNBO. Nevertheless, a significant number of publications do not specify the software infrastructure employed.

In addition to Max/MSP, SuperCollider and Pure Data, two projects stand out for their use of customised software solutions built on embedded systems. In the case of Pardue et al. (2019), the Svampolin system employs the Bela Mini platform, on which modified versions of the Yin algorithm (for pitch detection) and AutoTalent (for pitch correction) are executed, alongside additional modules specifically developed to model the vibratory response of the strings. This approach reflects a level of customisation that goes beyond mere patch configuration, involving source code adaptation and dedicated algorithmic integration. Meanwhile, the system proposed by Ko & Oehlberg (2020) uses an Arduino MKR1000 solely as an interface for data collection and transmission, capturing finger pressure through capacitive sensors and FSRs. The data is transmitted via OSC protocol to Max/MSP/Jitter, where all creative and performative processing takes place. This project exemplifies a convergence between low-level environments (firmware) and high-level performative platforms, highlighting the distributed nature of many contemporary augmented systems.

Table 6. Software.

Software	Number of publications
Max/MSP (incl. Max for Live & RNBO)	22
Not specified	8
Pure Data	4
SuperCollider	3
Other/Custom	1
Arduino IDE/Firmware	2

4.6. Performance context

The performance context refers to the experimental environment in which the analysed systems were tested or deployed. Since many of these systems were used in multiple formats, Table 7 reflects the number of times each context was explored, resulting in a total that exceeds the number of publications. However, due to the difficulty in verifying this information with precision based on the available documentation, the table should be interpreted primarily as evidence that a wide range of performative environments were explored to test or apply the various technological sonic expansions under analysis in this article. An example of this limitation is the expectation that most systems were initially tested in a controlled laboratory setting before being implemented in public performance context. Yet very few publications explicitly mention these testing or validation phases.

Despite the diversity of performative exploration, it is important to highlight the system developed by Hamilton et al. (2025), which represents a paradigmatic example of a non-performative context. The system was conceived as a permanent installation at the Museo San Colombano in Bologna. The interface was designed to provide the general public with a tactile and sonic experience of a historical harpsichord, without compromising the mechanical integrity of the instrument. Using infrared optical sensors, pressure applied to the keys triggers high-quality MIDI samples, preserving the haptic fidelity of the original keyboard. The installation allows any visitor to activate digital sound without requiring musical training, functioning as an accessible and educational mediation system.

4.7. Evaluation method

The evaluation method of each performative system resembles the performance context in that multiple projects may have been assessed through more than one method—as shown in Table 8—and for various reasons, those methods are not always extensively detailed in the publications.

Among the systems analysed, the project proposed by de Cecco (2025) stands out for adopting a purely conceptual and theoretical approach, distancing itself from any form of empirical or performative evaluation. The article proposes an architecture for instrumental expansion based on spectral analysis and sound morphology, linking acoustic descriptors with compositional parameters in real time. However, according to the publication, no functional prototype is presented, nor are there any documented tests, performances, or user observations. The reflection focuses on the construction of a cognitive and perceptual model for interactive audiovisual systems, supported by explanatory diagrams and theoretical argumentation. This approach highlights the role of speculative research within the field of augmented instrumentation, contributing to the formulation of abstract and heuristic models rather than to the validation of technical or performative solutions. It is therefore an exceptional case within the analysed corpus, illustrating the relevance of non-implemented perspectives in the construction of new instrumental epistemologies. Finally, the article by Reed and McPherson (2020) remains the only one classified under the category 'Not specified'. Although the system described – based on EMG surface sensors for vocal control – was demonstrated in a live performance, the article does not present any form of empirical or observational evaluation. There is no reference to testing with external performers, nor is there structured feedback, interviews, or formal reflection on usability, expressivity, or system effectiveness. The description focuses primarily on the technical components and proof-of-concept demonstration, which justifies its exclusion from the remaining evaluative categories.

Table 7. Performance context.

Performance context	Number of publications
Solo performance	29
Ensemble performance	6
Interative installation	10
Pedagogical/Educational	5
Laboratory testing/technical validation	10

Table 8. Evaluation method.

Evaluation method	Number of publications
Practice-based / Artistic Research	28
Qualitative Feedback / Observation	28
Technical Validation / Lab Testing	18
Not specified	1
Speculative / Conceptual	1

4.8. Key findings

Regarding the key findings presented in Table 9, the most represented category is technical extension and control, followed closely by expressivity and performative nuance. However, as with previous categories, several projects span more than one key area of knowledge. Given the centrality of this section within the article, two publications will be highlighted as examples for each identified knowledge domain.

4.8.1. Technical extension / expanded control

As previously noted, the most frequently identified form of knowledge emerging from technological sonic expansion stems from the prioritisation of preserving and

Table 9. Key findings.

Key findings	Number of publications
Technical Extension / Expanded Control	30
Expressivity / Performative Nuance	26
Physical Feedback / Tactile Resonance	17
Co-authorship / Mutuality / System as Agent	10
Spatiality / Movement / Choreography	7
Inclusion / Accessibility / Installation	6
Learning / Pedagogy / Didactic Support	3
Transcription / Symbolic Representation	1

amplifying gestural nuance and instrumental expressivity as a central goal of technological intervention. In McPherson (2015), the TouchKeys system is presented as a sensitive extension of the traditional keyboard, capable of capturing the continuous angle of the keys and surface touch. These data are translated into expressive control of sound parameters and real-time effects, without altering conventional piano technique. This approach allows performers to retain traditional playing methods while accessing fine control over articulation, dynamics and timbre, thus enhancing expressivity without compromising the instrument's tactile familiarity. Complementarily, the hybrid system developed by Portovedo et al. (2017) for saxophone combines sensors embedded in the instrument with body motion capture devices, enabling the mapping of expressive performer gestures to expand sonic interaction. Although originally designed to address technical challenges in performing electroacoustic works, the system proves effective in broadening phrasing, expressive contour and gestural responsiveness in performance, subtly integrating bodily movement as a vector of musical expressivity.

4.8.2. *Expressivity / performative nuance*

In some augmented instrumentation systems, the focus does not lie in extending technique or introducing new modes of execution, but rather in deepening gestural sensitivity and amplifying the nuance already present in traditional performance. In the Magnetic Resonator Piano, described by Kallionpaa (2016), the strings' resonances are activated by electromagnetic fields that respond directly to conventional pianistic gestures. This system allows subtle variations in articulation, pedal use and dynamics to produce precise and sustained resonant transformations, reinforcing expressivity without altering the idiomatic technique of the piano. The relationship between gesture and response becomes richer and more perceptible, fostering refined listening and deep interpretative engagement. Complementarily, the TRAVIS II, a later development of the system by Ko & Oehlberg (2021), integrates capacitive and force sensors (FSRs) into the neck of the violin, enabling precise detection of finger position and pressure intensity. These data are transmitted via OSC to a Max/MSP patch, where they are mapped to real-time audio and visual effects. The main advantage of this system lies in its ability to translate minimal gestural variations into continuous and sensitive computational responses, without compromising traditional instrumental technique. The violin retains its physical and sonic identity, but becomes more responsive to the performer's intent, promoting enhanced expressivity that emerges directly from conventional acoustic gesture.

4.8.3. *Physical feedback / tactile resonance*

The integration of physical feedback as an essential interactive element in augmented instruments is particularly evident in systems that incorporate vibratory transducers and internal acoustic feedback mechanisms. In the Feedback Cello, designed by Eldridge and Kiefer (2019), the vibration generated by the performer is captured and sent back into the instrument's body through embedded loudspeakers and transducers. This configuration creates a loop of physical and sonic feedback that actively influences musical execution, shaping subsequent gestures and making the instrument itself a dynamic co-agent in performance. The tactile resonance transforms the cello's surface into a space sensitive to friction and contact, challenging the traditional separation between cause and effect. In a distinct yet conceptually aligned approach, the ResoFlute by Lupone et al. (2020) integrates internal microphones and an acoustic feedback system controlled by gesture and proximity. The captured sound is processed in real time and returned to the instrument through a resonant chamber and loudspeaker, generating a tangible acoustic field that responds to the performer's position and pressure. This architecture allows the flutist to continuously modulate the sound without altering traditional gestures, fostering a performance experience in which the instrument's physical response becomes an extension of the performer's own gesture.

4.8.4. *Co-authorship, mutuality and system as agent*

In this review, a distinction is made between co-authorship and system agency (co-agency). While co-authorship concerns the attribution of creative responsibility among human and non-human contributors, co-agency refers to the distribution of operative decision-making during performance. Although these concepts are analytically distinct, they may partially overlap in practice: sustained or recurrent system-driven decisions can significantly shape a work's identity without necessarily implying authorial status. A system may therefore exhibit co-agency - by influencing timing, timbre, structure, or gesture - without being considered an authorial entity. This distinction is particularly relevant in technologically expanded instruments, where feedback, adaptive processing, or autonomous behaviours shape musical outcomes in real time. Within the analysed corpus, explicit forms of co-authorship are relatively rare and primarily occur in contexts of human–human collaboration mediated by computational systems, such as game-based improvisation or live coding performance. By contrast, system co-agency is more prevalent and does not, in itself, imply authorial status.

The works of Davis (2017) and Panariello and Percivati (2023) exemplify the paradigm of mutuality and system agency, destabilising traditional performer–instrument hierarchies. Davis's *Feral Cello* introduces a system that actively challenges the notion of instrumental mastery by embedding gesture recognition and autonomous decision-making within a Max/MSP patch. As the cello's acoustic output is processed and reintroduced via actuators, it alters its own response, prompting the performer to adapt in real time. This mutual responsiveness results in an improvisational ecology where agency is distributed between human and machine—not as fixed entities but as co-emergent collaborators. Similarly, Panariello et al.'s *WYPYM* for feedback-augmented bass clarinet creates a closed loop of acoustic and electronic response. A dynamic feedback system - built in SuperCollider - transforms the clarinet's sonic behaviour in real time, requiring the performer to renegotiate technique and control continuously. Both projects blur the lines between instrument, performer and system, presenting musical creation as a process of reciprocal influence, where the computational system is no longer a passive tool but an autonomous, expressive partner.

4.8.5. Spatiality / movement / choreography

Both Leung (2022) and Michalakos (2021) explore spatiality and choreographic embodiment as central vectors of interaction in augmented performance systems. Leung (2022) presents the *Mubone* – a trombone augmented with a Joy-Con sensor and Max/MSP integration – as a choreo-musical interface. The system captures performer movement in 3D space to control granular synthesis and audiovisual responses, where gesture precedes sound in compositional design. Collaborating with a choreographer, the piece prioritises movement and autobiography, constructing a narrative that unfolds through spatial memory and performative orientation. Likewise, Michalakos (2021) introduces a ludic framework in which performers engage with audiovisual game rules projected in the performance space. Here, conventional instruments remain physically unchanged, but the musicians respond to spatially distributed prompts, decisions and constraints. In both cases, spatial interaction is not merely gestural; it constitutes a performative domain where sound, body and system co-evolve within dynamic environments that expand traditional performance boundaries.

4.8.6. Inclusion / accessibility / installation

The Sverm–Resonans project, developed by Sanchez et al. (2018), exemplifies the convergence of accessibility, sensory exploration and performative installation. The system is based on a collection of digitally augmented acoustic guitars equipped with infrared sensors and embedded actuators, controlled by Bela microcomputers and programmed in Pure Data. Suspended within the exhibition space, the guitars are activated by the participant's bodily stillness – a paradigm of inverse control that encourages attention to minimal gesture and somatic perception. The installation is conceived as a meditative environment, accessible to anyone regardless of musical background, promoting a tactile and auditory experience through the direct vibration of the instruments. Its passive interface logic, which responds to the absence of movement, constitutes an innovative form of inclusion, fostering contemplation and a sensory relationship with sound and the body. Another example is the project described by Hamilton et al. (2025), centred on the creation of an augmented replica of a historical harpsichord specifically designed for museum display at the Museo San Colombano (Bologna), with the dual aims of accessibility and musical heritage preservation. This replica maintains the tactile and aesthetic fidelity of the original instruments but integrates optical sensors concealed beneath the keys that convert mechanical gestures into MIDI messages, linked to a sound library of historical instruments. The interface is accessible to the general public, including blind or low-vision visitors and was developed as part of a programme to remove physical and cognitive barriers funded by the NextGenerationEU initiative. The system offers an inclusive and interactive experience, allowing the public to explore historical sounds and gestures without risking damage to the original instruments, combining museological reconstruction, sensory accessibility and digital mediation of cultural heritage.

4.8.7. Learning / pedagogy / didactic support

In her doctoral dissertation, Pardue (2016) proposes a comprehensive model for the use of augmentation technologies in violin education. The research focuses on the concept of complexity management, whereby the system supports the learner in technically demanding tasks – such as accurate intonation, bow control, or gestural coordination – by reducing frustration during early learning stages. The work describes various experimental approaches to augmented interaction, including sensors for bow and pitch tracking, auditory and visual feedback algorithms and intuitive interfaces designed for beginners. This theoretical proposal is grounded in a user-centred pedagogical perspective and was validated through pilot studies involving violinists at different levels. The emphasis is placed on motivation and learning effectiveness, highlighting the role of technology as a mediator of technical and expressive development. Pardue et al. (2019) presents the practical materialisation of many of the concepts developed in Pardue (2016) through the instrument Svampolin: a hybrid system that physically separates the performative gesture from the sound source. Combining an acoustic resonator body with a digital interface (a 'stick' electric violin), the system enables real-time manipulation of the performer's sound using pitch correction (AutoTalent) and intonation analysis (Yin algorithm), returning the transformed sound to the acoustic body via physical feedback. The article explores the applicability of this technology in educational contexts, providing beginner students with positive auditory reinforcement and a more rewarding performance experience. The research included tests with both novice and advanced violinists and reflected on the motivational and pedagogical potential of a system that offers stable sonic results even with technically limited execution. Svampolin thus represents a pedagogically oriented approach to instrumental augmentation, focused on accessibility and the progressive development of musical skills.

4.8.8. Transcription / symbolic representation

The article by Freire et al. (2021) fits clearly within this category through its presentation of GuiaRT, an interactive musical setup based on a nylon-string guitar equipped with hexaphonic piezo pickups. The system allows real-time symbolic transcription of musical excerpts played live; interactive transformation of symbolic data for compositional, performative and pedagogical purposes; representation of musical data based on low-level descriptors (onsets, pitch, amplitude, spectral centroids), organised in a symbolic format and manipulable in real time; and the generation of performative variations, instrumental technique analysis and use in educational contexts. This work stands out for integrating a complex chain of extraction, transcription and symbolic transformation without altering the traditional technique of the instrument, making it particularly relevant for research into the symbolic representation of instrumental performance in real time.

5. Discussion

The 40 publications included in this systematic review were analysed across multiple parameters. Regarding the technological dimension, the sonic augmentation of traditional acoustic instruments in the last decade has predominantly been achieved through the integration of sensors (e.g. inertial, tactile, optical), actuators, audio feedback circuits, sound capture (microphones and pickups), microcontrollers and, less frequently, augmented reality and spatialisation systems. These augmentative strategies are enabled by digital technologies designed to enhance the instrument's expressive, interactive, or spatial affordances. In terms of interaction design, most systems prioritise performer-centred control. However, the spectrum of approaches is diverse, encompassing audience-mediated interaction, autonomous computational behaviours, human–computer co-creativity and feedback loops where the instrument acts as a resonator or transducer. Several systems also explore human–human computer-mediated performance, in which two performers engage via technological intermediaries.

From a software standpoint, while a variety of environments such as Pure Data and SuperCollider are represented, Max/MSP emerges as the dominant platform across the corpus, confirming its widespread adoption in creative coding for real-time sound processing and interactive system design. Two key research questions guided the performative analysis: (1) whether formal evaluation methods are employed to assess the systems; and (2) whether these systems influence instrumental practice. On the first point, although a range of evaluative practices was identified - ranging from controlled laboratory studies to live performance documentation - there is no common methodological framework that allows for meta-analytical synthesis. The absence of standardised protocols for assessing usability, expressiveness, or performative impact remains a critical limitation in the field. On the second question, most studies report a positive transformation of performance practice. These include timbral diversification, enhanced technical control, greater expressive latitude and the emergence of new performative models that challenge traditional boundaries between instrument, body and system.

While many of the thematic concerns identified in this review - such as expanded control, system agency, movement and pedagogy - have long histories within digital musical instrument research, their articulation within augmented acoustic instruments presents distinct characteristics. In the reviewed corpus, the term *expanded instrument* is not used merely to denote timbral augmentation of an acoustic source, but increasingly to describe systems in which computational processes actively participate in shaping performance outcomes. In these systems, algorithms may introduce autonomous behaviour, generate feedback structures, or mediate interaction between multiple human performers. However, unlike many purely digital musical instruments (DMI), the acoustic instrument remains central to sound production and embodied technique. This continued acoustic grounding differentiates augmented acoustic instruments from more general DMI paradigms, anchoring technological experimentation within established instrumental practices and performance traditions. Rather than representing a complete ideological rupture, the last decade of research suggests a reconfiguration and intensification of existing DMI concerns, shaped by the constraints, affordances and cultural weight of acoustic instruments. This has resulted in highly individualised and practice-driven forms of experimentation, where artistic intention increasingly frames technological development, counterbalancing earlier emphases on technological novelty alone.

5.1. Towards best practices for evaluating technologically expanded instruments

Based on the reviewed literature, effective evaluation of technologically expanded acoustic instruments tends to emerge from sustained experimentation in real performance contexts, rather than from isolated demonstrations or short-term testing. This observation aligns with practice-based research methodologies, in which knowledge is generated through iterative artistic engagement and reflective documentation. Across the analysed corpus, evaluation practices prove most robust when they address multiple dimensions of the expanded instrument, including performative effectiveness, aesthetic outcomes, ergonomic integration and technical reliability. Rather than relying on standardised metrics, successful evaluations adapt their methods to the intended context of use – such as concert performance, installation, or pedagogy - while maintaining consistency in documentation and critical reflection. An additional insight concerns the diversity of software environments, hardware configurations and interaction modalities identified across the corpus. This heterogeneity suggests that no single technical solution or evaluative protocol can be universally applied. Instead, effective evaluation frameworks must remain flexible and context-sensitive, aligning assessment criteria with the artistic intentions and performative conditions of each system. Taken together, these findings suggest that best practices in the evaluation of expanded instruments are characterised by longitudinal engagement, performer-centred feedback and adaptive evaluation criteria that reflect the hybrid artistic and technological nature of the instrument.

Rather than advocating for a universal or standardised epistemology, this review argues for a structured yet situated epistemic framework, in which evaluation criteria emerge from shared analytical dimensions - such as those outlined in Table 1 - while remaining grounded in specific artistic and performative conditions. In this sense, structure refers not to uniform metrics, but to comparable analytical lenses that enable dialogue across heterogeneous practices. A further observation emerging from the corpus concerns the relative emphasis placed on technological capability over articulated artistic intent. While many studies provide detailed accounts of system design and technical affordances, fewer explicitly frame their contributions in terms of aesthetic objectives, artistic processes, or performative meaning. This imbalance highlights an opportunity for future research to more explicitly integrate artistic perspectives into the documentation and evaluation of expanded acoustic instruments.

6. Conclusion

This systematic literature review reveals that, despite the diversity of artistic and technological approaches, many of the works analysed share common objectives and strategies. Notably, a significant methodological gap is identified – one that emerges not through what is present, but through what is consistently absent. While many contributions adopt practice-based research frameworks, the diversity of approaches and the absence of shared criteria currently limit opportunities for systematic comparison or meta-analysis. Furthermore, the review effectively addresses the research questions initially proposed, particularly concerning the types of technological augmentation, modes of interaction, software environments and evaluation strategies. As such, this article offers a structured contribution to the mapping of this field and provides a foundation for future investigations – whether theoretical, empirical, or practice-based.

By clarifying recurring patterns and exposing conceptual and methodological gaps, it contributes to the consolidation of a rapidly evolving research domain situated at the intersection of acoustic performance, technological design and artistic experimentation. For designers and artist-researchers, the proposed framework can serve as a reflective tool to situate new instruments within existing technological and performative paradigms. For instrumentalists, it offers a lens through which expanded instruments may be understood in terms of agency, interaction and embodied practice. For researchers, the categorisation and evaluation heuristics outlined here contribute to the development of a more coherent epistemic basis for comparative analysis in this evolving domain. Collectively, these contributions support the consolidation of technologically expanded acoustic performance as a research field at the intersection of acoustic practice, technological design and artistic experimentation. In sum, while this review argues for greater methodological structure, it does not assume that unified standards are universally desirable. The proposed framework should be understood as a situated analytical tool – potentially also a creative resource for practitioners in the field – compatible with perspectives that emphasise partiality, contingency and the co-production of knowledge in practice-based research.

7. Limitations

This systematic review deliberately focuses on peer-reviewed academic publications in order to ensure methodological transparency and comparability. Consequently, a substantial body of practice-based work developed outside academic publishing – including commercial instruments, patents, online platforms and undocumented performance practices (e.g. music tracks from conferences such as NIME) – is excluded. These omissions are not random and may bias the analysis toward academic design narratives and evaluation practices.

An additional limitation arises from the heterogeneous terminology used in this field. Terms such as 'hyper', 'actuated', or 'smart' instruments are often employed to describe overlapping practices. Exploratory searches using alternative terminology indicated substantial overlap with the existing corpus; nevertheless, additional searches could further expand it. This review therefore prioritised conceptual coherence and reproducibility over terminological exhaustiveness. The findings should be interpreted as representative of research discourse rather than of the full spectrum of contemporary instrumental practice.

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References

Arslan, C., Berthaut, F., Beuchey, A., Cambourian, P., & Paté, A. (2022). Vibrating shapes: Design and evolution of a spatial augmented reality interface for actuated instruments. *International Conference New Interfaces Musical Expression • NIME, 2022*, 1–25. https://doi.org/10.21428/92fbeb44.c28dd323

Baethge, C., Goldbeck-Wood, S., & Mertens, S. (2019). SANRA-a scale for the quality assessment of narrative review articles. *Research Integrity and Peer Review*, *4*, Article 5. https://doi.org/10.1186/s41073-019-0064-8

Bardin, M. (2023). Cyberinet: Integrated semi-modular sensors for the computer-augmented clarinet [PhD, Louisiana State University]. https://repository.lsu.edu/gradschool_dissertations.

Battier, M. (2022). The emergence of interactive music: The vision and presence of Joel Chadabe. *Leonardo*, *55*(1), 107–111. https://doi.org/10.1162/leon_a_02180

Booth, A., Sutton, A., & Papaioannou, D. (2016). *Systematic approaches to a successful literature review*. SAGE Publications.

Braidotti, R. (2006). Posthuman, all too human. *Theory, Culture & Society*, *23*(7-8), 197–208. https://doi.org/10.1177/0263276406069232

Conforti, S., & Güsewell, A. (2015). PRIME gesture recognition: New paradigms for the interaction between Paetzold recorder players and machines in live electronic music. *Dissonance/Dissonanz*, *132*. www.primeresearch.ch

Dahlstedt, P. (2015). Mapping strategies and sound engine design for an augmented hybrid piano. Proc. Int. Conf. New Interfaces Music. Expr., 271–276.

Davis, T. (2017). The feral cello: A philosophically informed approach to an actuated instrument. Proc. Int. Conf. New Interfaces Music. Expr., 279–282.

de Cecco, A. (2025). A gesture-centered real-time composition ecosystem for augmented musical instruments. Proc. 32th Journées d'Informatique Music. GRAME.

Ek, R. (2024). Playing with resistance. NIME 2024 Proc. Int. Conf. New Interfaces Music. Expr. https://doi.org/10.5281/zenodo.13904814

Eldridge, A., & Kiefer, C. (2019). The self-resonating feedback cello: Interfacing gestural and generative processes in improvised performance. Proceeding New Interfaces Music. Expr., 25–29.

Evaristo Gonzalez Sanchez, V., Zelechowska, A., Martin, C. P., Johnson, V., Vadstensvik, K. A., Independent, B., & Jensenius, A. R. (2018). Bela-based augmented acoustic guitars for inverse sonic microinteraction. Int. Conf. New Interfaces Music. Expr. https://doi.org/10.5281/zenodo.1215947

Ferrando, F. (2014). Posthumanism. *Tidsskrift for kjønnsforskning*, *38*(2), 168–172. https://doi.org/10.18261/ISSN1891-1781-2014-02-05

Freire, S., Armondes, A., & Silva, R. (2021). Real-time symbolic transcription and interactive transformation using a hexaphonic nylon-string guitar. *Computer Music Journal*, *45*(4), 20–39. https://doi.org/10.1162/comj_a_00625

Gonzalez Sanchez, V. E., Martin, C. P., Zelechowska, A., Bjerkestrand, K. A. V., Johnson, V., & Jensenius, A. R. (2018). Bela–based augmented acoustic guitars for sonic microinteraction. *Proceedings of the International Conference on New*

Interfaces for Musical Expression, 324–327. https://doi.org/10.5281/zenodo.1302599
Granieri, N. (2020). Augmenting the experience of playing the piano: Controlling audio processing through ancillary gestures [PhD Thesis]. Birmigham City University (Birmingham).
Hamilton, M., Ducceschi, M., Livi, R., Vicens, C., & Mcpherson, A. (2025). Augmentation of a historical harpsichord keyboard replica for haptic-enabled interaction in museum exhibitions. Proc. Int. Conf. New Interfaces Music. Expression (Canberra, Aust).
Haraway, D. (1985). A cyborg manifesto: science, technology, and socialist-feminism in the late twentieth century. *Socialist Review*, *80*, 65–108.
Jenkins, H. (2016). Cultura da Convergência (S. Alexandria, Trad.). ALEPH.
Kallionpaa, M. (2016). Performing the super instrument: reaching beyond technical and expressive capabilities. Electron. Vis. Arts, 28–33. https://doi.org/10.14236/ewic/EVA2016.7
Ko, C., & Oehlberg, L. (2020). Construction and performance applications of an augmented violin: TRAVIS II. *Computer Music Journal*, *44*(2-3), 55–68. https://doi.org/10.1162/comj_a_00563
Leung, K. (2022). Garcia (2021) for Mubone. Int. Conf. New Interfaces Music. Expr. NIME 2022. https://doi.org/10.21428/92fbeb44.e048e4b7
Lupone, M., Bianchini, L., Lanzalone, S., & Gabriele, A. (2019). Augmented instruments at CRM – Centro Ricerche Musicali of Rome: Feed-Drum, SkinAct, WindBack and ResoFlute. ICMC Int. Comput. Music Conf.
Lupone, M., Bianchini, L., Lanzalone, S., & Gabriele, A. (2020). Research at Rome's Centro Ricerche Musicali on interactive and adaptive installations and on augmented instruments. *Computer Music Journal*, *44*(2-3), 133–158. https://doi.org/10.1162/comj_a_00570
Machover, T. (1992). Hyperinstruments: A progress report, 1987-1991. MIT Media Laboratory.
Magnusson, T. (2017). Musical organics: A heterarchical approach to digital organology. *Journal of New Music Research*, *46*(3), 286–303. https://doi.org/10.1080/09298215.2017.1353636
Magnusson, T. (2019). *Sonic writing: Technologies of material, symbolic, and signal inscriptions*. Bloomsbury Academic. https://doi.org/10.5040/9781501313899
Manovich, L. (2001). *The language of the new media*. The MIT Press.
Manovich, L. (2013). *Software takes command. Em Softw. Tak. Command*. Bloomsbury Academic. https://doi.org/10.5040/9781472544988
Martelloni, A., McPherson, A., & Barthet, M. (2021). Guitar augmentation for percussive fingerstyle: Combining self-reflexive practice and user-centred design. Proc. Int. Conf. New Interfaces Music. Expr., 1–13. https://doi.org/10.21428/92fbeb44.2f6db6e6.
McLuhan, M. (1964). Os Meios De Comunicaçao Como Extensões Do Homem (Cultrix, Ed.; D. Pignatari, Trad.). www.pensamento-cultrix.com.br.
McPherson, A. (2015). Buttons, handles, and keys: Advances in continuous-control keyboard instruments. *Computer Music Journal*, *39*(2), 28–46. https://doi.org/10.1162/COMJ_a_00297
Michalakos, C. (2021). Designing musical games for electroacoustic improvisation. *Organised Sound*, *26*(1), 78–88. https://doi.org/10.1017/S1355771821000078
Neill, B. (2016). The Mutantrumpet. NIME, 489–490.
Normark, C. J., Parnes, P., Ek, R., & Andersson, H. (2016). The extended clarinet. Int. Conf. new interfaces Music. Expr., 162–167. http://www.nime.org/proceedings/2016/nime2016_paper0034.pdf.
Panariello, C., & Percivati, C. (2023). 'WYPYM': A study for feedback-augmented bass clarinet. Proc. Int. Conf. New Interfaces Music. Expr., 151–155. https://doi.org/10.5281/zenodo.11189146.
Pardue, L. S. (2016). Violin augmentation techniques for learning assistance [PhD, Queen Mary University of London]. https://qmro.qmul.ac.uk/xmlui/handle/123456789/25934.
Pardue, L. S., Buys, K., Edinger, M., Overholt, D., & McPherson, A. P. (2019). Separating sound from source: Sonic transformation of the violin through electrodynamic pickups and acoustic actuation. Proc. Int. Conf. New Interfaces Music. Expr., 278–283.
Portovedo, H., Lopes, P. F., & Mendes, R. (2017). Saxophone augmentation. *Proc. Artech*, *2017*, 157–160. https://doi.org/10.1145/3106548.3106611
Reed, C. N., & McPherson, A. P. (2020). Surface electromyography for direct vocal control. Proc. Int. Conf. New Interfaces Music. Expr., 458–463.
Reid, S., Gaston, R., Honigman, C., & Kapur, A. (2016). Minimally invasive gesture sensing interface (MIGSI) for trumpet. Int. Conf. New Interfaces Music. Expr., 419–424.
Reid, S., Gaston, R., & Kapur, A. (2019). Perspectives on time: Performance practice, mapping strategies, & composition with MIGSI. Proc. Int. Conf. New Interfaces Music. Expr., 234–239.
Rimoldi, G., & Manzolli, J. (2017). Dynamic mapping strategies using content-based classification: A proposed method for an augmented instrument. Lect. Notes Comput. Sci., 347–356. https://doi.org/10.1007/978-3-319-67738-5_21
Rossitto, C., Tholander, J., Barkhuus, L., Rostami, A., McMillan, D., Fischione, C., & Turchet, L. (2018). Musicians' initial encounters with a smart guitar. ACM Int. Conf. Proceeding Ser., 13–24. https://doi.org/10.1145/3240167.3240223
Savery, A. (2023). Enhancing violin performance through real-time interaction: Design and evaluation of a wireless audio-visual interface. *Chroma*, *39*(2), 1–12.
Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039
Souchal, N., & Schwarz, D. (2025). Acoustic augmentation of the trumpet – navigating control and unpredictability in a long-term research-creation collaboration. Journées d'Informatique Music., 5102295. https://ircam-ismm.github.io/max-msp/catart.html.
Stifjell, E. (2023). A flexible musical instrument augmentation that is programmable, integrated in a box (FLAPIBox). Int. Conf. New Interfaces Music. Expr. https://www.raspberrypi.com.
Sullivan, J., Tibbitts, A., Gatinet, B., & Wanderley, M. M. (2018). Gestural control of augmented instrumental performance: A case study of the concert harp. ACM Int. Conf. Proceeding Ser. https://doi.org/10.1145/3212721.3212814

Thorn, S. D. (2021). Flows of inhomogeneous matter: Improvising an augmented violin. *Organised Sound*, *26*(1), 65–77. https://doi.org/10.1017/S1355771821000066

Travasso, R. (2022). MAD Clarinet 2.1.: Sound travels. Proc. - 3rd Int. Conf. Digit. Creat. Arts, Media Technol. Emerg. Ext. Realities, ARTeFACTo 2022, 1–4. https://doi.org/10.1109/ARTeFACTo57448.2022.10061246

Travasso, R., & Marques, L. (2024). MAD Clarinet 3. 0: Dialogues with my computer. Rotura - Rev. Comun. Cult. e Artes, 4(1), 212–219. https://doi.org/10.34623/bh3w-w556

Turchet, L. (2018). Some reflections on the relation between augmented and smart musical instruments. ACM Int. Conf. Proceeding Ser. https://doi.org/10.1145/3243274.3243281

Ulfarsson, H., & Melbye, A. P. (2020). Sculpting the behaviour of the feedback-actuated augmented bass: Design strategies for subtle manipulations of string feedback using simple adaptive algorithms. Proc. Int. Conf. New Interfaces Music. Expr., 221–226.

Wessel, D., Wright, M., & Schott, J. (2002). Intimate musical control of computers with a variety of controllers and gesture mapping metaphors. Proc. Int. Conf. New Interfaces Music. Expr., NIME02-01-NIME02-03.

Wolstanholme, L., Shier, J., Constanzo, R., Mcpherson, A., Wolstanholme, L., Shier, J., & Mcpherson, A. (2015). Drum modal feedback: Concept design of an augmented percussion instrument. Proc. Int. Conf. New Interfaces Music. Expr., 108–115.