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ORIGINAL ARTICLE

Performing the Immersive: Electroacoustic Music at the Threshold of Technology

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Resumo: Investiga-se como a convergência entre tecnologias imersivas e música eletroacústica molda as propriedades emergentes da performance contemporânea. A transição da obra musical de suporte fixo (tape) para ambientes interativos e exploráveis redefine as fronteiras da autoria e os papéis de compositor e de intérprete. Nesse cenário, o público deixa a passividade e assume o papel de participante ativo, moldando a experiência sonora em tempo real. A performance torna-se um processo emergente, resultante da interação entre a ação humana e os sistemas generativos. Os resultados imprevisíveis abrem portas para novas formas de fluidez estética. O foco passa da noção de produto final ou obra acabada para o desenvolvimento dinâmico do processo criativo. Cada obra adquire suas características por meio das possibilidades criativas que oferece, do seu design interativo e da qualidade da experiência resultante. Neste modelo, o papel principal do artista é projetar um mundo para a performance musical colaborativa.

Palavras-chave: Design de Sistemas Interativos, Cocriação Humano-IA, Interação Corporificada, Ecossistemas Interpretativos, Agência do Público.

Abstract: This discussion examines the emerging characteristics of immersive performance within the context of electroacoustic music, resulting from the integration of immersive technologies. The transformation of fixed-media (tape) compositions into interactive, explorable, and performable environments redefines creative roles and the notion of authorship between composer and performer. In this framework, the audience becomes an active participant, shaping the musical work in real time. Performance becomes an emergent process arising from the interaction between human agency and generative systems. These unpredictable outcomes open doors to new forms of aesthetic engagement. The focus shifts from the concept of a final product or finished work toward the dynamic development of the creative process itself. Each piece acquires its character through the creative possibilities it offers, its interactive design, and the quality of the experience it delivers. In this model, the artist's primary role is to design a world for collaborative musical performance.

Keywords: Interactive Systems Design, Human-AI Co-creation, Embodied Interaction, Interpretive Ecosystems, Audience Agency.

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The impact of technological advancement on musical aesthetics, to the extent that it fosters new genres, is a recurring phenomenon in music history (Dixon, 2015; Manning, 2013; Théberge, 1997). Instrumental developments, for instance, have frequently altered compositional and performance practices, in some cases leading to the definitive emergence of new musical genres and styles. A clear historical example is the evolution of the pianoforte from the harpsichord in the early 18th century (Fielden, 1938); the piano's new ability to control dynamics (playing both soft and loud) was a technological breakthrough that directly altered compositional approaches, paving the way for the expressive range of Classical and Romantic keyboard music. Similarly, the invention and amplification of the electric guitar in the 20th century were not merely about volume; they enabled new performance techniques such as string bending, feedback, and distortion, which became the foundational sonic elements of the emergence of blues-rock, hard rock, and heavy metal. The electroacoustic genre itself also provides a primary example, as its reliance on recorded sound is intrinsically tied to the evolution of signal-processing technology. Here, the genre and the technology are inextricably linked.

The evolution of electroacoustic music is intrinsically linked to the use of sonic technology to continuously explore and expand acoustic space. From initial experiments with stereophony to the development of sophisticated multichannel diffusion systems and loudspeaker orchestras, composers have endeavored to structure sound within the physical domain, thereby establishing the listening environment as a primary compositional parameter. This inherent focus on sensory engagement exhibits a clear conceptual parallel to the objectives of immersive technologies, which use technological means to elicit a broad range of sensory perceptions. The aim of these technologies is to facilitate immersion, producing a sensation of presence in which the participant feels situated within a new virtual environment (Lombard and Ditton, 1997; Slater, 2009). Immersive technologies have exerted a significant influence upon numerous fields, led predominantly by visual applications such as virtual reality devices, yet they encompass a wider spectrum of applications, with spatial audio being of principal importance.

These immersive sound practices, when applied to electroacoustic music, however, have largely maintained a fundamental separation between the sonic object and the space in which it is perceived, with the music projected into the space for a largely stationary audience (Chion, 2019;

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Emmerson, 2017). A more recent yet established tradition challenges this passive listening paradigm by leveraging emergent immersive technologies. Tools such as virtual reality equipment, omnidirectional projections, real-time multimodal rendering, wearable apparatuses, haptic interfaces, and generative artificial intelligence have been progressively integrated into artistic practice. The adoption of these innovations has significantly broadened the compositional palette, expanded performance modalities, and diversified the channels of musical dissemination.

This paper argues that the integration of these technologies has led to the emergence of a new modality of electroacoustic music, one that collapses the distinctions between composition, performance, and audience. We propose the term Performative Immersive Electroacoustic Music (PIEM) to describe this modality. Within this framework, the musical work is not a fixed object placed within a space; it becomes a navigable, interactive, and performable environment. This progression builds upon the twentieth-century emancipation of sound and noise as musical phenomena (Kahn, 1999), a dialectic that necessitated new discursive solutions beyond traditional frameworks. However, the recent surge of accessible immersive technology has initiated a distinct wave of change. Innovations from sensors to displays have produced a noticeable transformation in creative processes, and, as we propose here, in prevailing aesthetic patterns. This convergence of practice now enables the identification of the aesthetic clusters that define Performative Immersive Electroacoustic Music.

The primary impact of this shift is that the musical experience is now conceived as an intrinsically connected, multisensory event. This sensory immersion creates new modalities for artistic delivery and fundamentally alters how the audience experiences the work. Consequently, the scope of the compositional process expands: feedback loops between the audience and the performance become viable, compelling the composer to consider dynamic interactions rather than static stimulus production. This condition establishes a new paradigm, representing a definitive shift away from the composer as an architect of fixed sonic forms and toward the composer as a world builder, a designer of dynamic, responsive ecosystems that invite interpretation and co-creation (Manovich, 2002; Murray, 1998).

This paper provides an exposition of the aesthetic foundations defining Performative Immersive Electroacoustic Music. The inquiry begins by establishing a conceptual groundwork

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through a constituent analysis of the genre's title. This is followed by an examination of the technological apparatus, detailing the integrated ecosystem of tools essential for its realization. Theoretical and technical explorations are grounded in contemporary practice, utilizing the work of key artists to illustrate the genre. These observations are synthesized into a set of aesthetic tenets that formalize the modality's defining characteristics. Finally, the paper evaluates the field's future trajectory, examining its potential evolution and the significant challenges that accompany its development.

1. Performance, Immersion, and Electroacoustics

The formalization of PIEM as a distinct musical modality was conducted through a multi-stage qualitative research design rooted in Thematic Analysis and Research-through-Design (RtD) (Frayling, 1993). The methodology employed a comparative case study analysis where a personal qualitative investigation and a series of structured discussions among the authors were used to identify and categorize illustrative examples of contemporary practice. The authors, acting as specialists in the intersection of music and technology, utilized a Thematic Synthesis technique to extract recurring technical and aesthetic parameters from the selected works (Thomas & Harden, 2008). By mapping these commonalities, the authors established the core aesthetic tenets that serve as the fundamental standards for defining the genre. This systematic approach ensures that the definition of the new style is grounded in a rigorous analysis of the reciprocal relationship between human agency and immersive technological systems.

To establish the conceptual foundations of Performative Immersive Electroacoustic Music (PIEM), it is necessary to first analyze the three constituent terms that form the genre's title: Performance, Immersion, and Electroacoustic Music. Each of these concepts carries its own significant historical and theoretical legacy. However, within the PIEM framework, they are synthesized and re-examined in a unique way that moves beyond their traditional definitions. The following analysis will explore each term individually to build a robust conceptual groundwork for understanding this emergent artistic practice, beginning with a redefinition of performance itself.

Musical performance, traditionally conceptualized as the translation of static structures into dynamic acoustic realizations (Palmer, 1997), relies on systematic expressive deviations to convey emotional and structural meaning (Juslin, 2001; Seashore, 1938). However, the PIEM framework challenges this paradigm by redefining performance as an emergent, co-creative event within a technologically mediated ecosystem. By collapsing the traditional dichotomy between active creator and passive recipient, this modality empowers performers and audiences as "inter-actors." Consequently, the artistic object shifts from a finished product to an ongoing process, in which the "performance" becomes a real-time actualization of possibilities, and the act of experiencing the work is rendered synonymous with its execution.

The work of Canadian artist Janet Cardiff exemplifies this principle. In her renowned installation The Forty Part Motet (2001) (Storolli, 2016), a reinterpretation of Thomas Tallis's 16th-century choral piece "Spem in alium nunquam habui", the voices of 40 individual singers are played through 40 separate speakers arranged in an oval. The audience is invited to walk among the speakers, effectively creating their own personal mix of the piece based on their physical position and movement. The act of listening becomes a performative exploration; by choosing to stand near a single soprano or in the center of a full choir, the participant actively "performs" their own experience of the composition. Similarly, Cardiff's "audio walks" guide participants through physical environments using headphones, layering a fictional narrative over the real world. The act of walking and listening becomes the performance itself, a unique synthesis of the real and the mediated. This principle of audience-as-performer is also evident in works that directly incorporate participant technology, such as compositions for ensembles and mobile devices, in which audience members' phones become individual nodes in a 360-degree sound system, making them integral components of the overall musical texture (Taylor, 2017; Xambó and Roma, 2020). Such works establish compelling "feedback loops" between the artistic system and its participants, compelling the composer to design for dynamic interaction rather than static production.

Furthermore, in PIEM, the very concept of a musical instrument expands from a discrete object manipulated by a performer to encompass the entire immersive environment. While earlier forms of live, interactive electronic media positioned the computer as a real-time extension of the performer, PIEM posits the environment itself as the instrument, played by the performer and by

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participants' presence and actions. The sound sculptures of Swiss artist Zimoun exemplify this concept (Salimi; Pasquier, 2021) [https://www.zimoun.net/]. He constructs large-scale, architecturally minded platforms from simple industrial materials such as cardboard boxes, DC motors, and welding wire. Once activated by electricity, these systems become self-performing ecosystems. The performance is the emergent sonic behavior of the materials as they interact, constituting a phenomenon Zimoun terms' primitive complexity,' in which a complex, chaotic, and evolving soundscape arises from a simple, ordered set of initial conditions. The artwork is simultaneously the instrument, the score (its physical construction), and the performer.

This paradigm shift has profound implications for the role of the composer, recasting them from an architect of fixed sonic forms to a world builder or a designer of interpretive ecosystems. The compositional act becomes less about dictating specific notes and rhythms and more about establishing the rules, constraints, and generative possibilities of a dynamic system. This approach is powerfully augmented by the integration of generative artificial intelligence (AI). AI tools, trained on vast musical datasets, can function as creative partners, generating novel melodic, harmonic, rhythmic, or textural material based on parameters set by the artist. This methodology does not replace human creativity but rather reframes it as a collaborative and co-creative process of working with the machine, feeding ideas and refining the output together. In a live musical context, AI can facilitate interactive experiences in which the music evolves in real time based on audience movement, biometric data, or other environmental inputs, creating a truly responsive, co-created performance. The work of composer Mariam Gviniashvili, who uses AI-generated sounds, including inherent glitches and distortions, as raw material for her 3D sound compositions, demonstrates this approach (Gviniashvili, 2022). She allows the sonic properties of the AI's output to guide the compositional form, embracing a co-creative process with the machine itself.

Ultimately, this necessitates an evolution in aesthetic judgment. If the final sonic output of a PIEM work is emergent, unpredictable, and unique to each iteration, then traditional aesthetic criteria focused on fixed compositional structure are insufficient. The critical focus must shift from the artistic product to the creative process. The success of the work is measured by the richness of the possibility space it creates, the elegance of its interactive design, and the coherence of the emergent experience it facilitates. This redefines authorship itself, moving from the romantic ideal of the sole

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creator to a model of the artist as a systems architect who designs the world in which a distributed, co-creative performance can unfold.

Immersion, in the context of PIEM, refers to the construction of a cohesive, multisensory, and navigable artistic environment. It moves beyond the passive envelopment of traditional surround sound, leveraging technologies like spatial audio and virtual reality to induce a state of 'presence.' In this state, the participant is not merely an observer but an embodied agent within a dynamic ecosystem, collapsing the distance between them and the artwork. This approach shifts the aesthetic focus: rather than projecting sound into a space, the space itself becomes the work, inviting exploration and interaction.

The concept of immersion can be understood through a taxonomy of its core components, including proximity (the perceived distance of sound sources), envelopment (the sensation of being surrounded by sound), and advanced sound processing that ensures sonic clarity and accurate localization. The synergistic application of these techniques aims to induce a psychological state of presence, the compelling sensation of “being there” in a mediated or virtual environment. This pursuit of presence has been the primary driver behind more than a century of audio technology development, a journey from a single point of sound to fully realized virtual worlds. An example can be found in the evolution and uses of microphones and immersive audio diffusers, increasingly used in real-time electroacoustic music.

The technological trajectory toward this goal reveals a clear and accelerating progression. The evolution began with the move from monophonic sound, a single point source, to stereophonic sound in the 1930s, which introduced a horizontal soundstage and the illusion of width. Early forays into true surround sound were often tied to cinema, such as Walt Disney's experimental Fantasound system for the 1940 film Fantasia, which used multiple channels and dozens of speakers to create the illusion of sounds moving around the theater (Garity; Hawkins, 1941). While the music industry experimented with formats such as quadraphonic LPs in the 1970s and 5.1 surround SACDs in the 2000s, these channel-based systems failed to achieve widespread adoption in music, largely due to the cost and complexity of the required consumer hardware (Gronow; Saunio, 1999; Théberge, 2004). These formats, while creating a sense of envelopment, were primarily limited to the horizontal plane.

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The critical technological leap was the addition of the vertical dimension, giving rise to what is now commonly known as spatial audio or 3D audio. Object-based audio formats like Dolby Atmos and DTS:X moved beyond a fixed channel layout, allowing sound designers to place and move individual sonic objects in a three-dimensional field, including overhead (Pfanzagl-Cardone, 2023; Sergi, 2013). This development, coupled with rendering techniques like Ambisonics for full-sphere sound capture and binaural audio for realistic headphone reproduction, provided the technical toolkit for creating truly three-dimensional soundscapes. The culmination of this trajectory is found in Virtual Reality (VR) and Augmented Reality (AR). VR creates a complete, computer-generated environment that a user can inhabit, while AR overlays digital information onto the real world. Platforms such as Wave and VRChat now enable the creation of entire virtual concert venues, transforming the listening experience from a sound field into a fully navigable, interactive world (Onderdijk et al., 2023).

This technological evolution enables a fundamental aesthetic shift that is central to Performative Immersive Electroacoustic Music. Traditional electroacoustic spatialization, even with sophisticated multichannel arrays, largely adhered to a paradigm of projection: the sonic object was projected into a listening space for a relatively stationary audience, who remained observers of a sonic architecture. In Performative Immersive Electroacoustic Music, this separation collapses. The musical work becomes the environment. The installations of Japanese artist Ryoji Ikeda are exemplary (Lakatos, 2020), with works such as data.tron that use floor-to-ceiling projections and overwhelming sound to immerse participants in a torrent of visualized data, creating a sensory experience of being swept away by a digital river. The audience must physically navigate the space to negotiate their relationship with the work. Similarly, composer SiHyun Uhm's String Quartet No. 2, for AFC System, utilizes an immersive audio system not merely for playback but as an active compositional parameter, altering the perceived acoustics of the performance hall in real-time to evoke different landscapes, making the space itself a mutable element of the piece (Ohgi et al., 2023).

While the technological development of immersive audio is often framed as a quest for greater realism, to recreate sound as we naturally perceive it, many of the most compelling works of Performative Immersive Electroacoustic Music subvert this goal. They leverage simulation tools to create profoundly abstract and surreal experiences. VR concerts can transport audiences to

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fantastical settings impossible to achieve in a physical venue. Ryoji Ikeda's work does not aim to simulate a real space but to immerse the audience in the pure, abstract mathematics of data. Mariam Gviniashvili's compositions explore a strange cosmic ballet of the audiovisual, while Vilbjørg Broch's work is algorithmically generated from the structure of four-dimensional quasicrystals (Broch, 2024). The aesthetic power of immersion in PIE, therefore, lies not primarily in its capacity for simulation but in its capacity for worlding, creating entirely new, self-contained, and cohesive perceptual realities. The technology of realism is repurposed for the aesthetics of abstraction, making the environment itself the primary medium of expression.

Electroacoustics is a mode of musical composition and practice defined by its intrinsic reliance on technology for recording, generating, and manipulating sound. Historically rooted in a dialectic between the organization of recorded real-world sounds (musique concrète) and the creation of synthetic electronic sounds (elektronische Musik), its evolution is characterized by a continuous expansion of the sonic palette and a profound preoccupation with the spatialization of sound as a primary compositional parameter. Within the context of Performative Immersive Electroacoustic Music, electroacoustics serves as the foundational methodology, providing not only sonic materials but also the technological framework for creating dynamic, responsive, and spatially aware musical environments.

The genre's origins can be traced to the post-war European avant-garde and two seminal, initially oppositional, schools of thought. In 1940s Paris, Pierre Schaeffer pioneered musique concrète, a method using recorded real-world sounds as primary compositional material. His Etude aux chemins de fer (Schaeffer, 1948), composed from recordings of trains, established the radical principle of taking sounds from the world and reorganizing them via tape manipulation into a fixed musical work, thereby representing an aesthetic of re-contextualization. In contrast, the Cologne-based studio of the Westdeutscher Rundfunk, led by figures such as Herbert Eimert and Karlheinz Stockhausen, developed elektronische Musik (Iverson, 2017). This school rejected recorded sounds in favor of creating music from purely electronically generated sources, such as sine-wave oscillators. Works such as Stockhausen's Studie II (1954) embodied an aesthetic of synthesis and absolute control, building sound from its fundamental electronic components, often without human performers. By the late 1950s, these two streams began to merge, with composers such as

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Stockhausen himself integrating recorded and synthetic sounds in landmark pieces such as Gesang der Jünglinge (1956), thereby setting the stage for the hybrid nature of contemporary electroacoustic practice.

The aesthetic possibilities of electroacoustics are inextricably linked to the available technology, creating a history defined by a technological imperative. The era of magnetic tape established the paradigm of fixed media, or acousmatic music, in which the electronic component of a work is a static, unchangeable recording played back through loudspeakers. Compositions such as Mario Davidovsky's Synchronism No. 6 (1970) for piano and tape exemplify this model, seeking to embed acoustic and electronic sounds within a single, coherent aesthetic space. A fundamental shift occurred with the advent of real-time computer processing and the development of graphical programming environments like Max/MSP and SuperCollider (Wang, 2017). These tools enabled live, interactive electronics, transforming the computer from a playback device into a responsive musical partner. Philippe Manoury's Pluton (1988), for piano and live electronics, was a watershed moment, using real-time analysis of the piano's MIDI and audio signals to trigger and manipulate electronic responses. This marked the critical evolution from a static electronic part to a dynamic, performative one, fulfilling the emancipation of sound and noise envisioned by early modernists by liberating pitch, timbre, and rhythm from the constraints of traditional instruments and notation.

From its inception, electroacoustic music has been defined by a deep preoccupation with the physical space of listening, providing a direct conceptual lineage for the immersive aspect of Performative Immersive Electroacoustic Music. The invention of stereophony, which creates the illusion of a spatial soundstage, was only the first step. Composers quickly sought to organize sound throughout the entire performance venue. Early examples include Henry Brant's Millennium II (1954), which strategically placed musicians around the auditorium, and Stockhausen's five-channel works, which created a three-dimensional acoustic space by surrounding the audience with loudspeakers. This practice was formalized with the development of High-Density Loudspeaker Arrays (HDLAs) and loudspeaker orchestras such as the Acousmonium, in which a performer or diffusionist actively plays the space by routing sounds to different speakers, treating the acoustic environment as a primary compositional dimension (Ridout, 2025). However, these practices largely

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maintained a fundamental separation: the music was an object projected into the space for a stationary audience. This established paradigm is precisely what the PIEM came to collapse.

A deeper analysis of the history of electroacoustics reveals a cyclical relationship with materiality. The practice begins with the hyper-materiality of musique concrète, in which the specific sonic signature of a concrete object (a train, a pot, a pan) serves as the musical atom (Schaeffer, 2017). This was followed by the deliberate dematerialization of Elektronische Musik, which sought a pure, acousmatic sound divorced from any recognizable physical source. Contemporary practices within PIEM, however, demonstrate a sophisticated return to materiality, using advanced technology not to abstract the world but to animate it. For example, Zimoun's work is not a recording of cardboard; it is the real-time, physical sound of hundreds of pieces of cardboard agitated by motors. The interspecies music of David Rothenberg is not a composition that merely incorporates whale songs; it is a live, material, and improvisational interaction with a living whale (Rothenberg, 2008). This suggests that Performative Immersive Electroacoustic Music represents a synthesis in which technology serves as a bridge back to the physical world, used to explore and amplify the sonic properties of materials and living systems in direct, performative ways. The electroacoustic foundation of PIEM, therefore, must be understood not only as a history of sound manipulation and spatialization but also as an evolving inquiry into the very nature of sonic materiality.

2. The Technologies of Performative Immersive Electroacoustic Music

The technological apparatus that enables PIEM is not a discrete collection of tools but a deeply integrated ecosystem. This technological framework is fundamentally inseparable from the genre's core aesthetic tenets, facilitating the paradigm shift from a fixed sonic object projected into a space to a dynamic, navigable, and co-created environment. The analysis of this apparatus is structured to reflect the process of creating and interacting with such an environment. It moves from the macro-level construction of the virtual world itself to the architecture of its sonic properties, the modalities of embodied interaction, and, finally, the computational systems that generate and process the experience in real time. TABLE 1 provides a concise summary of the core technological categories and their principal functions within the PIEM framework, serving as an organizational map for the

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detailed analysis that follows.

Technologies of Environmental Construction

Foundational technologies in PIEM facilitate the construction of interpretive ecosystems that serve as the primary navigable reality for a performance. This environmental synthesis is achieved through distinct immersive modalities, primarily Virtual Reality (VR) and Augmented Reality (AR). VR utilizes head-mounted near-eye displays and pose tracking to simulate physical presence within a computer-generated environment, effectively replacing the user's sensory surroundings. Conversely, AR overlays digital information and virtual objects onto the physical world, blending tangible and synthetic elements. As core emergent technologies, both VR and AR apparatuses are increasingly integrated into artistic practice to establish the immersive spatial frameworks essential for contemporary PIEM works.

TABLE 1 – Technologies of Performative Immersive Electroacoustic Music

Technological Category	**Core Principle**	**Key Technologies**	**Role in Performative**
Environmental Construction	Worlding & Presence	Virtual Reality (VR), Augmented Reality (AR), Omnidirectional Projection	Establishes the work's fundamental perceptual reality, creating a navigable, multisensory environment that participants inhabit and explore.
Sonic Architecture	Spatialization & Auralization	Object-Based Audio (OBA), Scene-Based Audio (SBA), Binaural Audio	Decouples sound from fixed speaker channels, creating a three-dimensional, dynamic soundscape that can be rendered from the participant's perspective.
Embodied Interaction	Agency & Feedback	Wearable Sensors, Haptic Interfaces, Biometric Sensors, Brain Computer Interfaces (BCIs)	Translates physical gesture and physiological state into musical control, creating a reciprocal feedback loop between the participant and the artistic system.
Generation & Processing	Emergence & Integration	Generative Artificial Intelligence (AI), Graphical Programming Environments	Provides autonomous creative agents and the computational nexus to integrate all other technologies into a single, responsive, real-time system.

Source: Authors

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In this context, VR and AR transcend visual display to function as the primary apparatus for worlding, establishing the perceptual reality that replaces or enriches the physical environment. By constructing a self-contained, navigable reality, these technologies collapse the distinction between the artwork and the space in which it is perceived. Platforms like Wave and VRChat demonstrate this shift by transforming the listening experience into active exploration of an interactive venue, where the work becomes a world to inhabit rather than an object of observation. This evolution enhances the navigation score, in which the virtual environment operates as a volumetric, explorable composition. Consequently, the aesthetic integrity of the work depends on technical parameters such as display resolution, image latency, refresh frequency, and field of view, all of which are critical for maintaining presence and preventing the fracture of immersion caused by simulator sickness.

Collective immersion offers an alternative to individualized displays through omnidirectional projection systems, such as full-dome environments and Cave Automatic Virtual Environments (CAVE). These systems facilitate shared immersive experiences without requiring head-mounted hardware. By employing high-resolution multi-projector arrays, they generate seamless 360-degree visual fields that envelop a group of participants, effectively bridging the gap between physical and virtual spaces. This technology supports diverse applications, ranging from large-scale public art installations and concerts to scientific data visualization and advanced training simulations.

Omnidirectional projection systems address the social dimension of performance by facilitating communal immersion as an alternative to the isolation inherent in VR headsets. This technological approach directly influences the tenet of cocreation, shifting the interactive paradigm from networked individuals to a physically copresent group. By enabling both verbal and nonverbal communication among participants, these systems integrate social rituals into the immersive environment as an additional layer of interaction. Consequently, the selection between individualized VR and collective projection is a fundamental compositional decision that defines the social topology of the work, determining whether cocreation occurs as a distributed networked activity or a shared, physically present experience.

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Technologies of Sonic Architecture

Advanced audio technologies enable the sonic dimension by constructing three-dimensional, navigable soundscapes, shifting the paradigm from sound projection for stationary audiences to the creation of the space itself. The evolution of spatial audio is central to this transition. Traditional Channel-Based Audio relies on fixed loudspeaker configurations, such as 5.1 or 7.1 surround sound (Sun, 2021), which optimizes perception for a static sweet spot and reinforces passive listening. More flexible models include Object-Based Audio and Scene-Based Audio. Object-Based Audio uses discrete audio objects with metadata that define their 3D spatial coordinates, allowing a renderer to adapt the sound to any playback system. Conversely, Scene-Based Audio, primarily through Higher Order Ambisonics, represents the entire sound field independently of speaker configurations. This progression decouples compositional data from physical hardware, providing the technical prerequisite for a navigable environment. By allowing the listener to function as an interactor, these technologies facilitate personal, position-dependent sonic experiences, as in the work of Janet Cardiff

Object-Based Audio formats treat sound as independent entities rather than channel-assigned signals, utilizing metadata such as Cartesian coordinates and amplitude. This enables the precise positioning and trajectory of individual sonic elements within a three-dimensional field, including the vertical dimension. Commercial formats like Dolby Atmos and DTS:X are significant not for their channel counts, but for the granular control they provide, essential for world-building. By decoupling compositional data from physical playback hardware, these formats allow sounds to function as discrete entities with specific behaviors within a virtual ecosystem, independent of the listener's loudspeaker configuration. This methodology aligns with the object-oriented logic of game engines and virtual environments, facilitating the seamless integration of sonic, visual, and interactive elements.

Ambisonics facilitates scene-based audio rendering by capturing a holistic, speaker-independent representation of a sound field. This technique utilizes the multichannel B-format, derived from a spherical-harmonic decomposition of the soundscape. The first-order B-format comprises a W channel for omnidirectional pressure and X-, Y-, and Z-channels for pressure gradients along the three spatial axes. Higher-Order Ambisonics (HOA) incorporates additional

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components to enhance spatial resolution and reconstruction accuracy. Because the B-format represents the complete sound field, it can be mathematically rotated in real time to synchronize with a listener's head movements and decoded for any loudspeaker configuration or binaural headphone output. While object-based formats excel at localizing discrete sources, scene-based audio is optimal for rendering the cohesive acoustic identity, reverberation, and ambiance of an environment. In this context, Ambisonics is critical for establishing an intrinsic sonic character, which is essential for inducing a state of presence within the virtual world.

Binaural audio serves as the perceptual translation layer for individualized experiences, facilitating 3D auditory externalization via headphones. This technique simulates the acoustic filtering of the listener's head, torso, and pinnae by convolving a monophonic sound source with Head-Related Impulse Responses (HRIRs). For comprehensive environmental simulation, Binaural Room Impulse Responses (BRIRs) are utilized to include spatial reflections and reverberation. When synchronized with real-time motion-tracking data, head-tracked binaural auralization ensures that sound sources remain spatially fixed as the listener moves. This process is essential for externalization—the sensation that sounds originate from the external environment rather than within the head. By bridging abstract spatial data from object-based or scene-based formats with the human neurophysiological hearing system, binaural rendering establishes the perceptual plausibility required for a navigable virtual world.

Technologies of Embodied Interaction and Performance

The performative aspect of PIEM is actualized through technologies that facilitate active, embodied participation. These systems create compelling feedback loops between the participant's actions and the behavior of the artistic environment, collapsing the distinction between audience and performer.

Wearable sensor technologies facilitate gestural and somatic control within PIEM by capturing human movement for real-time musical modulation. These apparatuses typically employ three-axis accelerometers and nine-axis inertial measurement units to track linear acceleration and spatial orientation with high fidelity. The resulting data streams are converted into protocols such as MIDI

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or OSC to modulate audio synthesis parameters, thereby actualizing the Gestural Embodied Instrument. This paradigm shifts the interface from discrete external objects to the performer's body, as demonstrated by the Mi.Mu Gloves. Consequently, musical virtuosity is redefined, transitioning from the localized motor dexterity of traditional instrumentation toward the expressive articulation of the entire body in space.

Haptic interfaces address the tactile dimension of digital interaction by utilizing sensors to detect user input and actuators to provide physical feedback. This feedback primarily manifests as vibrotactile stimulation to simulate texture, force feedback to emulate resistance and weight, or mid-air ultrasonic feedback via modulated air pressure. Within PIEM, these interfaces are critical for establishing a multisensory perception-action loop, providing the direct physical stimuli necessary for reciprocal interaction. By returning physical sensations to the body in response to digital actions, haptics transforms virtual elements into tangible entities. This integration significantly enhances the performer's sense of embodiment and presence, ensuring that interactions within the virtual environment carry a level of consequentiality comparable to the physical world.

Physiological feedback technologies extend performance into subconscious and involuntary processes by utilizing biometric sensors to capture real-time data. This includes heart rate via photoplethysmography, muscle tension via electromyography, and neural activity via electroencephalography. These signals establish a direct feedback loop where the system's sonic or visual behavior reflects the participant's internal affective state. Brain-Computer Music Interfaces (BCMIs) further this integration by translating neural patterns, such as alpha and beta rhythms, into specific musical control commands or compositional parameters. Jônatas Manzolli's Multimodal Brain Orchestra exemplifies this approach (Groux et al., 2010), where the system functions as an interpretive ecosystem. By mirroring and modulating biological rhythms, these technologies transform the performance into a reflexive artistic experience that responds empathetically to the participant's internal state.

Technologies of Generation and Real-Time Processing

A powerful computational core drives the dynamic and unpredictable nature of these works, providing the generative and integrative framework required for live, multimodal interaction. The primary generative component is Generative Artificial Intelligence, which functions as an autonomous agent. Powered by machine learning models like neural networks, these systems analyze complex musical patterns to generate novel material. Within this ecosystem, AI acts as a creative partner, evolving melodic or textural content in real time based on participant movement, biometric data, or environmental inputs. This integration shifts the compositional role from dictating fixed forms to designing the rules and behaviors of a system containing non-human agents. Consequently, the artist functions as a world builder rather than a traditional architect. This introduces a fundamental element of unpredictability, ensuring the artistic output is not a repeatable object but a unique result of the improvisational dialogue between human participants and AI co-performers.

Graphical programming environments, such as Max/MSP and SuperCollider, function as the interactive nexus and central nervous system of the performance. These platforms enable the creation of custom software instruments and real-time processing networks by modularly connecting functional objects. This environment provides the essential connective tissue for the technological apparatus, acting as a hub that integrates disparate data streams. Tracking data from VR/AR, MIDI/OSC from wearables, and biometric signals are received, scaled, and mapped here to control spatial audio renderers, visual engines, haptic actuators, and generative AI models. The visual and real-time nature of these platforms is uniquely suited for managing the immense complexity of multimodal mapping. By lowering the barrier to complex systems integration, these environments serve as the foundational technology that enables the practical implementation of such sophisticated works.

3. Contemporary Practice of Performative Immersive Electroacoustic Music

From academic research laboratories to mainstream popular music, artists are increasingly leveraging immersive technologies to forge new relationships between sound, space, and the body.

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This section provides an analytical cartography of this field, mapping the work of key artists to demonstrate the breadth and relevance of the PIEM genre. We do not aim to provide a comprehensive survey of all PIEM initiatives, but rather to present illustrative examples. The analysis is structured to explore a broader spectrum of immersive aesthetics in both avant-garde and popular contexts.

The compositional and theoretical work of Brazilian composer and researcher Jônatas Manzolli is a representative example of recurring aesthetic patterns that appear to define the character of Performative Immersive Electroacoustic Music. Manzolli's work provides a fundamental rethinking of composition, technology, and performance. His research, articulated at the intersection of musical creation, computer technology, psychoacoustics, and cognitive sciences, positions the composer closer to the role of a system designer whose objective is not to provide a production tool but to open a gateway to interpretation. This concept dissolves the traditional hierarchy of composer, performer, and instrument, recasting the musical work as an interactive dialogue between a human agent and a technological partner.

This paradigm is predicated on a broad notion of the musical instrument, where the boundary between the instrument and its environment dissolves. The entire interactive space is conceived as a single, integrated musical instrument. Manzolli describes this as the ability to "program the computer and put together a sort of sound installation, or go up on the stage and interact with the machine in real time as a musical instrument". The system itself becomes a cognitive partner with which the performer engages in an "embodied dialogue," a tightly coupled perception-action loop where the system's affordances shape the performer's output, and the performer's actions redefine the system's expressive potential.

Two of Manzolli's works serve as prime examples of this theory in practice. The mixed reality installation MovieScape allows visitors to use hand gestures to manipulate and remix an "audiovisual-scape" derived from the poetics of silent film. In this work, the visitor perfectly embodies the role of the conductor who interprets the environment in real time, creating a unique artistic output through their interaction with the system. The installation is not a tool but a world that responds to performance, perfectly realizing the goal of opening a door for interpretation. An even more radical exploration of these concepts is found in the Multimodal Brain Orchestra, a project in which

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performers use brain-computer interface (BCI) technology to play virtual instruments directly from their brain states. While technologically complex, its conceptual core is profoundly relevant to the PIEM genre, as it explores the direct source of creative intent and poses fundamental questions about embodiment and agency when the "instrument" is itself an extension of neural activity.

This approach fundamentally alters the concept of artistic agency. In traditional music, the roles of composer, performer, instrument maker, and conductor are often distinct. In a sophisticated PIEM environment, a single user can embody all of these roles simultaneously or in rapid succession. They might begin by building a virtual instrument (as in the application PatchXR), then perform on it to generate material, structure that material, and finally conduct the playback of the entire immersive scene. This hybrid creative agency, born from the Manzolli's perspective, is a defining characteristic of the PIEM genre, signifying not just a change in technology but a redefinition of the artistic act itself.

The theoretical principles articulated by Jônatas Manzolli have directly influenced a generation of composers and researchers exploring the intersection of performance and technology. This lineage is evident in the work of his students and in the broader academic community dedicated to developing new forms of musical expression. A direct case study of this lineage can be found in the work of the Brazilian percussion duo Paticumpá, formed by Cleber Campos and Cesar Traldi. The duo's academic history is explicitly linked to Manzolli, under whose supervision they completed their master's and doctoral research at Unicamp, focusing on the performer's interaction with technological means and real-time electronic devices. The duo's work, such as the piece Paticumpatá, exemplifies the application of PIEM principles to an acoustic electronic medium. Their research and performance practice explore new interpretive postures, multimodality, and improvisation, in which the performers engage in a dynamic dialogue with technology, augmenting their percussion setup with sensors and real-time processing to expand their expressive palette. Their work embodies the PIEM tenets of the Gestural-Embodied Instrument and the Performer as World-Conductor within a live, non-VR context, demonstrating the portability of these core principles.

The broader academic context for PIEM is the vibrant international community centered around the New Interfaces for Musical Expression (NIME) conference. For over two decades, this annual gathering has been the premier venue for research on the design of new musical controllers,

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gestural interaction, and their artistic application. The NIME proceedings are a rich repository of projects that align with the PIEM framework. For example, a recent paper titled MagneTip Reintroducing a Physical Interaction Loop for 3D Musical Drawing in eXtended Reality explores novel hardware for gestural control within immersive environments, directly addressing the tenet of the Gestural-Embodied Instrument. Similarly, projects including You're An Instrument! Creating active music-making experiences through worldbuilding and storytelling investigates how narrative and audience participation can engage users with new digital instruments, echoing the principles of the Navigable Score and the Performer as World-Conductor.

This academic exploration is not new. The work of Tod Machover at the MIT Media Lab stands as a crucial precursor and parallel development. Since the 1980s, Machover has pioneered the development of "Hyperinstruments," which use smart computers to augment musical expression and creativity. His audience interactive works, most notably the Brain Opera (1996), invited the public to contribute to and interact with a large-scale musical work, predating many contemporary PIEM concepts by decades. Machover's career has been dedicated to expanding music's potential for everyone, from virtuosos to amateurs, a goal that resonates deeply with Manzolli's paradigm of creating open, interpretive environments.

Beyond the academy, the principles of PIEM are manifest in the work of a wide range of influential artists who use immersive technologies to achieve distinct aesthetic goals. Their work demonstrates that PIEM is not a monolithic style but a flexible modality that can be adapted to serve artistic intentions ranging from intimate personal narrative to mass public spectacle.

At one end of this spectrum lies the work of Icelandic artist Björk. Her project Vulnicura VR translates the raw emotional narrative of her album about heartbreak into a series of immersive virtual reality experiences. Björk leverages the "isolating" nature of VR to create a hyper-intimate connection with the listener, transporting them to an Icelandic landscape to witness the songs unfold. The experience is not entirely passive; in one scene, the user can use their hands to "stitch" together Björk's broken heart, a direct, if simple, form of embodied interaction with the musical narrative. Here, the PIEM framework is used to foster empathy and place the audience member in the role of a sympathetic witness within a deeply personal story.

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Occupying a different point on the spectrum is the work of British musician Imogen Heap, whose development of the Mi.Mu Gloves is a landmark in the history of the Gestural-Embodied Instrument. The gloves are a sophisticated wearable controller, equipped with sensors that translate nuanced hand and arm gestures into MIDI signals, allowing Heap to control her voice, synthesizers, and effects wirelessly on stage. Her goal was to break free from the static configuration of keyboards and computers, enabling a more physically expressive and intuitive performance style. Heap's work is a masterclass in gestural virtuosity, where the direct, one-to-one mapping of body to sound places the performer in complete control of the sonic environment.

American avant-garde icon Laurie Anderson, in collaboration with artist Hsin-Chien Huang, uses VR to explore themes of narrative, freedom, and disembodiment. Her works Chalkroom and To the Moon are dreamlike virtual environments that the user can navigate and explore. Chalkroom is an enormous, labyrinthine structure made of words and drawings that the user "flies" through, while Anderson's voice provides a poetic, narrative guide. For Anderson, VR is a medium that synthesizes all her artistic practices, such as music, language, and movement, and offers the potential to achieve a sense of “disembodiment,” freeing the imagination and allowing the user to “disappear into something”. Her work exemplifies the Navigable Score, in which the composition is an explorable world, and the Performer as World-Conductor, in which the user's journey constructs their unique experience of the piece.

At the opposite end of the spectrum from Björk's intimacy is the public spectacle created by French electronic music pioneer Jean-Michel Jarre. His New Year's Eve concert, Welcome to the Other Side, was a mixed reality event set in a virtual reconstruction of the Notre-Dame Cathedral in Paris. While Jarre performed live in a studio, his avatar performed simultaneously inside the virtual cathedral. The concert was broadcast globally across a wide range of platforms, from VR headsets to traditional television and social media, reaching an audience of 75 million. In this case, VR is not used to create a personal, interactive journey, but to stage a massive, shared cultural event, blending the real and the virtual to create a new form of global, distributed liveness.

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4. The Aesthetics of Performative Immersive Electroacoustic Music

To formalize PIEM as a unified practice, it is necessary to translate its underlying design principles into a coherent set of aesthetic tenets. By reframing the general principles of immersive technologies through the lens of musicology and performance theory, a robust vocabulary can be established for the analysis and creation of PIEM works. Following the Thematic Synthesis method, and based on the curated data previously identified through a Research-through-Design approach, we conducted a cross-case analysis of contemporary practices to induce the fundamental parameters of the genre. This systematic mapping allows the identification of the aesthetic clusters that define the character of PIEM.

The initial aesthetic dimension, Media Generation, involves PIEM's significant overlap with standard electroacoustic music, positioning the genre as a derivation. The essential commonality concerns the methodologies for sound generation, encompassing technologies for sound synthesis, tape techniques, and sound spatialization. What distinguishes PIEM, however, is its expansion beyond the auditory domain. It defines media generation as an integrated process where the produced sound shares a unified context with other media modalities, such as projected images, video, dynamic illumination, and embodied performance. This symbiotic relationship between music and performance is prevalent throughout musical history and remains crucial in many genres. A clear illustration is opera, where the musical score and the dramatic staging are inextricably linked, with neither element fully comprehensible without the other. Similarly, classical ballet relies on this fusion, as the choreography is fundamentally structured by and expressive of the musical composition.

A second principle is the Gestural Embodied Instrument, which establishes a new form of virtuosity founded on gestural, full-body interaction. This approach redirects focus from replicating physical instruments in virtual space or using traditional instruments on stage to creating novel performance modalities native to the immersive medium. The creative act is consequently redefined, transcending discrete inputs like a key press or a mouse click to encompass broader physical motions such as a sweep of the arm, a rotation of the wrist, or a forward step. This principle is manifested in the development of new Virtual Reality Musical Instruments and wearable controllers. As seen in

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Imogen Heap's practice (discussed above), performance thereby becomes a profoundly embodied activity that completes the perception-action feedback cycle through rich, multimodal feedback, positioning the artist's body as the primary interface for musical expression.

A third principle, the Navigation Score, posits that the musical score is no longer a static, two-dimensional document but a navigable, volumetric architecture. The virtual world itself functions as the score. Musical parameters such as pitch, timbre, and rhythm are mapped onto spatial and visual dimensions, transforming abstract sonic ideas into a directly manipulable environment. For instance, frequency can be mapped vertically and the stereo field horizontally, allowing the performer to physically move around and position sounds in three-dimensional space. This concept extends historical precedents in graphic and indeterminate notation by adding the dimensions of embodiment, real-time interaction, and spatial exploration. The composition is experienced not by reading a set of instructions, but by moving through and interacting with a sonic world.

The fourth aesthetic tenet, Native Interaction, articulates the synthesis of performance and composition into a unified, dynamic methodology. This principle shares conceptual territory with improvisation but is characterized by the establishment of explicit channels for audience participation, thereby facilitating their role in the collaborative creation of artistic expression. This process effectively blurs the traditional distinctions between artist and audience, transforming the participant from a passive spectator into an active agent with some control over their experience. Consequently, this modality establishes compelling feedback loops between the artistic system and its participants, compelling the composer to design for dynamic interplay rather than static stimulus production. This deep interconnectedness ensures that performance and sound production become inseparable, where one cannot be fully understood without the other. The centrality of this concept is underscored by the fact that interaction is a fundamental constituent of the classical definition of immersion, rendering it an essential and defining aspect of the entire PIEM framework.

A fifth tenet is Generative Constraints, which addresses the need for a structured framework to prevent chaotic nonsense from arising when expanded gestural instruments and dynamic interactions are used. This tenet analyzes how the rules or physics of the virtual world function as generative constraints that catalyze creativity. Absolute freedom can be paralyzing; well-designed constraints provide a scaffold that channels expression, much like the rules of harmony or the formal

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structure of a sonata guide a composer's choices. In a PIEM work, these constraints might manifest as a rhythmic grid for quantizing actions, a harmonic palette that limits melodic choices, or an algorithmic system that responds to input according to a predefined logic. This principle is powerfully demonstrated in the work of Tod Machover, whose “Hyperinstruments” use smart computation to augment and structure a performer's gestures, creating a collaborative balance between human intent and systemic guidance.

Lastly, the final pillar is The Performer as World Conductor. This principle synthesizes the previous tenets and draws directly from Manzolli's paradigm of The Composer as World Builder, defining the artist's role as an interpreter or conductor of the virtual environment. The performance is not the execution of a fixed work but a cocreative dialogue with a responsive, emergent system. The artist navigates the navigation score, plays the Gestural Embodied Instrument, and explores the creative possibilities offered by the generative constraints, thereby "conducting" the sonic ecosystem in real time. This is evident in Laurie Anderson's desire to create immersive works that are "composed and completed by the listener and viewer, who walks into it and experiences it viscerally, emotionally and intellectually". The final musical output emerges uniquely from this interaction, making each performance an unrepeatable event.

From these tenets, it is also important to define what PIEM is not. There is a whole field of sound installations with a strong relation to the electroacoustics tradition. We understand that PIEM's performance aspect requires a performant, which is not necessarily an interpreter, though in most cases it would be. This performance is, in great part, emergent from the dynamics of interference or even the execution of predefined, constrained steps. One important point is that performance will extend the sound itself, which might involve emergent behavior and gesture in a sound installation. Sound installations that maintain a passive role would not fit this definition of PIEM, but those in which generation involves audience interaction certainly would. In many of the works, we see a fit to PIEM; however, the interaction might be constrained to the performer or musician engaging with the technology and the world built by the composer.

While the six aesthetic tenets provide a theoretical framework, their practical application requires a formal protocol to differentiate PIEM from related modalities like traditional surround sound or passive installations. To verify if a work constitutes PIEM, it must meet a Triple-Constraint

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operational threshold: Environmental Reciprocity, Embodied Agency, and Dynamic Emergence. Under this protocol, a work is identified as PIEM if it utilizes an integrated technological ecosystem to move beyond mere sound projection, creating a navigable world where the participant's physical presence or gestures directly modulate the sonic architecture in real-time. If the interaction is static or does not involve a perception-action feedback loop that alters the musical outcome, the work remains categorized as a traditional sound installation.

To standardize this identification, researchers can verify the presence of specific operational markers that define the genre's technical and interactional boundaries. A work qualifies as PIEM when it implements Volumetric Scoring, mapping musical parameters like pitch and timbre onto a 3D navigable space rather than a 2D timeline , and utilizes Sensor-Mediated Virtuosity, where the primary interface is an embodied system—such as wearables, BCIs, or tracking—that translates full-body motion into musical control. Furthermore, the work must exhibit Systemic Autonomy by employing generative constraints or AI agents to ensure that each iteration remains unique and unrepeatable. Still, there should be no hard boundaries for the proposed genre; rather, identifying artistic expressions within this framework is relevant to allow for a better use of analytical thinking, thereby facilitating a more effective interplay between practitioners and those interested in the field.

Systematic Evaluation of Case Studies via the PIEM Matrix

To move beyond illustrative descriptions, it is essential to apply the PIEM aesthetic pillars and the Triple-Constraint operational threshold (Environmental Reciprocity, Embodied Agency, and Dynamic Emergence) to established contemporary practices. This systematic mapping allows for a rigorous classification of how diverse artists inhabit the PIEM modality.

Building upon the foundational pillars and the operational threshold previously established, these theoretical concepts find empirical resonance in the systematic mapping of contemporary practices. As detailed in Table 2, Janet Cardiff's *The Forty Part Motet* serves as a primary example of Environmental Reciprocity through the lens of a Navigation Score. By deconstructing a polyphonic choral work into 40 discrete sound sources, Cardiff transforms a fixed musical object into a navigable environment where the listener's physical trajectory dictates the acoustic mix. This shifts the

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performance from the stage to the participant's body in space, meeting the PIEM criteria for Native Interaction where the audience becomes an inter-actor responsible for the real-time actualization of the work's sonic possibilities.

TABLE 2 – PIEM Systematic Analytical Matrix

Aesthetic Pillar	**Case Studies**		
	Janet Cardiff (e.g., Forty Part Motet)	**Zimoun (Sound Sculptures)**	**Jônatas Manzolli (e.g., Brain Orchestra)**
Media Generation	Spatial re-contextualization of 360° choral audio.	Material and primitive sound from industrial objects.	Multimodal integration of sound, image, and biometric data.
Gestural Instrument	Physical movement of the audience serves as the performative gesture.	The self-performing mechanical system acts as the instrument.	Body-centric control via BCIs and motion sensors.
Navigation Score	The physical arrangement of speakers defines the spatial score.	The architectural layout and motor constraints set the score.	The virtual world functions as a volumetric, navigable architecture.
Native Interaction	Audience agency in real-time spatial mixing via movement.	Systemic interaction based on emergent material behavior.	Direct feedback loop between interactor state and the ecosystem.
Generative Constraints	Fixed recordings and speaker positions limit content variation.	Laws of physics and mechanical simplicity catalyze complexity.	Algorithms and AI agents structure creative freedom.
World Conductor	The listener conducts their own unique auditory perspective.	The artist designs an autonomous, self-contained ecosystem.	The user unifies the roles of composer, conductor, and performer.

Source: Authors

In a similar vein, the sound sculptures of Zimoun exemplify the pillar of Generative Constraints and the concept of Dynamic Emergence. In his work, the instrument is not a tool played by a human but an entire architecturally minded platform where simple industrial materials and DC motors create a self-performing ecosystem. This illustrates a shift toward the composer as a systems architect who establishes initial conditions, a phenomenon Zimoun calls primitive complexity, allowing for a chaotic and evolving soundscape that is simultaneously the score and the performer.

Furthermore, Jônatas Manzolli's work, particularly the *Multimodal Brain Orchestra*, represents the highest degree of Embodied Agency within the PIEM framework as highlighted in the comparative analysis. By utilizing Brain-Computer Interfaces to translate neural patterns into musical control, Manzolli collapses the distinction between internal creative intent and external sonic

production. This approach fulfills the paradigm of the Gestural Embodied Instrument where the musical work is conceived as an interactive dialogue and a tightly coupled perception-action loop between the human agent and a responsive technological cognitive partner. These established practices demonstrate the current maturity of the field while providing the essential conceptual groundwork for exploring the increasingly autonomous and networked future frontiers of the genre.

5. The Future Frontiers of Performative Immersive Electroacoustic Music

The integration of Generative Artificial Intelligence into PIEM marks the next logical, yet most profound, step in the genre's evolution. The current paradigm, as established throughout this paper, frames AI as a powerful creative partner, a sophisticated instrument capable of generating novel sonic material and facilitating real-time interactive experiences based on participant data. This model aligns with contemporary practices in human AI cocreation, where the technology serves as an amplification force for human creativity, operating within an iterative, human-in-the-loop workflow of generation, curation, and refinement. In this capacity, AI extends the composer's palette and fulfills the paradigm of the system as a cognitive partner, but the locus of creative agency remains firmly with the human artist.

The future frontier, however, points toward a fundamental ontological shift: the evolution of AI from a responsive tool to an autonomous agent within the PIEM ecosystem. This trajectory moves beyond a purely cybernetic model of control and feedback into a truly ecological one. The foundational definition of PIEM as an interpretive ecosystem where agency is distributed among participants provides the conceptual groundwork for this shift. While current human-AI partnerships represent a classic cybernetic feedback system, emerging research into Large Language Model (LLM) based autonomous agents reveals systems capable of independent planning, adaptation to environmental feedback, and complex problem-solving without direct human intervention. Projects such as AI Nüshu, in which AI agents develop a unique language system through environmental observation, demonstrate a capacity for emergent behavior that transcends predefined rules. Consequently, the PIEM composer's role as world builder expands from designing an environment for human interpretation to architecting a digital ecology populated by both human

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and non-human agents. The compositional act becomes a form of speculative sociology, defining the initial conditions and interaction protocols for a hybrid society.

In this advanced paradigm, the AI becomes a genuine co-performer, not merely reacting to stimuli but actively contributing to the work's emergent narrative. This vision is powerfully articulated by media artist Refik Anadol's practice of teaching an AI to “dream intentionally,” using vast datasets to generate novel aesthetic outputs that are not mere recombinations but unique, machine-native imaginings. An AI agent within a PIEM work could be designed to "dream" in response to the unfolding performance, introducing unpredictable sonic, visual, or structural elements that actively shape the collective experience. This fully realizes the PIEM principle of creating emergent, unrepeatable events, in which the AI's contributions become a primary source of aesthetic novelty. The PIEM environment evolves into a hybrid stage for a shared, improvisational dialogue between human participants and autonomous AI performers.

This evolution necessitates a radical re-evaluation of authorship and aesthetic judgment. The romantic ideal of the sole creator, already challenged by PIEM's emphasis on audience participation, is fully dissolved in a model of distributed creativity that encompasses the world builder, human participants, and autonomous AI agents. This technological shift acts as an ontological wrecking ball, forcing a reconsideration of what it means to create and what constitutes an artistic work. The critical focus must irrevocably shift from the ephemeral artistic product to the enduring artistic system itself. The success of a work is no longer measured by its fixed form, but by the quality of human-AI interactions it fosters and the richness of the collaborative ecosystem it sustains.

This ultimate vision for PIEM extends to scaling from intimate, localized installations to massively multiuser, networked worlds that connect a global audience in a shared act of creation. While existing platforms like VRChat and Second Life have demonstrated the technical feasibility of virtual copresence for large numbers of users, PIEM demands a far more sophisticated form of interaction. The goal is not merely to occupy the same virtual space, but to engage in genuine cocreation, where the collective actions of a distributed ensemble meaningfully and coherently shape a single, emergent artistic outcome. The conceptual challenge, therefore, is to move beyond the architecture of a virtual gallery and design a dynamic system that can foster collaborative performance on a massive scale.

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In such a massively multiuser environment, the sheer volume of participant input presents a significant risk of devolving into chaotic, incoherent noise. This is where a sophisticated AI agent can assume a new and crucial role as the algorithmic conductor. This AI would not function as a traditional, top-down director but as a mediator and interpreter of the collective will. By analyzing the streams of interaction data from thousands of participants in real time, the algorithmic conductor could identify emergent patterns, group related gestures, and subtly guide the overall texture toward harmonic or rhythmic coherence. It would act as a homeostatic force, balancing individual creative agency with collective artistic expression, thereby realizing the PIEM tenet of generative constraints on a massive scale.

However, this vision of a boundless, globally distributed ensemble inevitably collides with the intractable physical laws of network communication—a sharp conflict between digital imagination and physical reality. While distributed liveness (as seen in Jean-Michel Jarre's work) enables massive broadcasting, true real-time interaction is limited by the speed of light, making synchronous rhythmic performance across continents a practical impossibility. Consequently, the genre must pivot toward what might be termed an asynchronous aesthetic. Rather than viewing latency as a technical defect, this approach accepts the delay as a foundational material property of the medium. This aesthetic reframes the network's technical limitations as creative features. The impossibility of maintaining a global, unified beat necessitates a fundamental shift in musical values away from rhythmically driven structures and toward textural, ambient, and layered forms of composition that are resilient to network delay. This approach finds precedent in post-digital aesthetics that embrace the inherent fragility and material properties of the network itself as part of the artistic medium. In this model, performance would be built on accumulating soundscapes, asynchronous call-and-response patterns, and evolving drones, where the precise timing of a contribution is less important than its presence within the collective whole. The AI algorithmic conductor would be essential in this context, weaving disparate, time-shifted inputs into a cohesive, continually unfolding sonic tapestry.

This visionary future for PIEM is predicated on overcoming a series of formidable, interconnected barriers. These challenges, spanning the physical limits of networks, the computational demands of virtual worlds, the fragmented state of hardware, and profound ethical

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quandaries, are not trivial obstacles but fundamental constraints that will shape the genre's development. The single greatest obstacle to real-time, distributed musical performance is network latency. For interactive music to feel natural and allow for rhythmic synchronization, the end-to-end audio delay must remain below a perceptual threshold of approximately 30 milliseconds. Empirical studies confirm that collaborative synchronization consistently fails when delays exceed 40 ms. This is not a software issue that can be optimized away, but a hard physical constraint imposed by the speed of light in fiber-optic cables; it is a limitation that, for global-scale interactions, will never disappear. This physical reality fundamentally disrupts the tightly coupled perception-action feedback loop essential to embodied musical performance, fragmenting the sense of a shared, co-creative event and rendering synchronous ensemble playing across large distances impossible.

Furthermore, the creation of a cohesive, navigable, and multisensory PIEM environment, the act of "worlding", imposes an immense computational load. A believable virtual world requires significant processing power to render high-fidelity graphics, spatialized audio, and potentially haptic feedback in real time. When the dynamic processes of generative AI are layered on top of this, to create content, animate autonomous agents, and conduct the ensemble, the computational demand increases exponentially. Scaling this experience to hundreds or thousands of simultaneous users presents a monumental technical challenge. The processing required to render the environment, track every participant's state, and execute complex AI routines in real time far exceeds the capacity of current consumer-grade hardware and would strain even the most powerful cloud-based server architectures. This computational ceiling directly limits the aesthetic complexity of the world, the number of participants it can support, and the system's responsiveness, which is critical for maintaining a state of presence.

This computational burden is compounded by the contemporary VR and AR landscape, which is not a unified platform but a fractured collection of proprietary, incompatible hardware and software ecosystems. This lack of standardization creates "walled gardens" that severely limit audience reach, inflate development costs, and prevent users from customizing their setups with hardware that best suits their needs or physical abilities. This fragmentation is compounded by significant barriers to access. The high cost of capable hardware remains prohibitive for many, while poor ergonomic design, leading to issues of weight, heat, and physical discomfort, can make

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prolonged engagement untenable. Furthermore, the industry has largely failed to prioritize accessibility for users with physical, visual, or hearing disabilities, threatening to relegate PIEM to a niche genre for the technologically and financially privileged.

Alongside these practical barriers are critical ethical quandaries. The generative AI models at the heart of future PIEM works are trained on vast datasets of existing human culture, creating a significant risk that they will reproduce and amplify the societal biases embedded in those datasets. The very nature of a PIEM experience, which tracks and responds to user interactions, makes the collection of sensitive behavioral and even biometric data possible, raising profound questions of privacy and consent. Finally, the deeply entangled nature of human-AI cocreation fundamentally complicates established legal and philosophical frameworks for copyright, ownership, and artistic identity, creating an ambiguous future for intellectual property in the age of autonomous creative agents.

The future trajectory of PIEM is defined by a profound tension between its boundless creative potential and the formidable constraints of the physical and digital worlds. The grand vision of a globally interconnected, cocreative performance environment is perpetually challenged by the hard realities of physics, computation, economics, and ethics. Yet, it is precisely within the negotiation of these constraints that the true, mature aesthetic of PIEM will be forged. The genre's evolution will not be measured by its capacity to perfectly simulate reality or to erase the technological seams of its construction. Rather, its success will be found in the design of elegant, expressive, and resilient systems for cocreation. This reinforces the central argument of this paper: the critical focus must irrevocably shift from the artistic product, an ephemeral, unique, and unrepeatable output, to the artistic system itself. The aesthetic merit of a future PIEM work will be judged on the richness of the possibility space it offers its participants, the coherence of the emergent experiences it facilitates, the inclusivity of its design, and the ethical integrity of its architecture. The composer as world builder thus becomes a true systems architect, designing not a finite piece of music, but a universe of creative potential for a distributed, hybrid ensemble of human and artificial performers to explore together.

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6. Conclusion

This paper formalizes Performative Immersive Electroacoustic Music (PIEM) as a distinct modality arising from the integration of immersive technologies with electroacoustic practice. This synthesis instigates an ontological transformation in which the musical work evolves from a static sonic object into a navigable, interactive environment. Consequently, creative roles are redefined: the composer functions as a designer of interpretive ecosystems, and the audience transitions from passive recipients to active participants whose agency is essential to the artistic outcome.

Within this paradigm, performance is an emergent event realized through the interplay of human action and generative processes. Future trajectories suggest the evolution of artificial intelligence from a creative tool into an autonomous co-performer within these digital ecologies. This shift necessitates a corresponding evolution in aesthetic judgment; traditional criteria based on fixed structures are replaced by an evaluation of the artistic system itself. A work's value is determined by the richness of its possibility space, the elegance of its interactive architecture, and the coherence of the resulting experience.

Ultimately, the artist acts as a systems architect, designing worlds that facilitate distributed, collaborative performance. This programmatic vision, however, requires a transition from theoretical synthesis to empirical validation. While this essay establishes the conceptual pillars of PIEM through discursive argumentation, the absence of a systematic review and quantitative metrics remains a limitation. However, recent efforts have begun to bridge this gap by translating these musical paradigms into a formal design framework for immersive creativity (Rennó-Costa et al., 2026), organizing the approach around visualization, embodied interfaces, and structured freedom. Future research must, therefore, adopt systematic analytical procedures and case studies to evaluate the impact of these immersive environments on performance and reception. By developing precise criteria to quantify audience agency and the effectiveness of generative systems, the field can move beyond a theoretical model toward a fully mature, empirically grounded analytical framework.

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x	Investigation	x	Visualization
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RESEARCH DATA AVAILABILITY

No research data generated or used.

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