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Work Bench

Coenaesthetic Defragmentation: An Artistic Installation Exploring the Relationship Between Sound, Movement, and Self-Awareness

Elena Partesotti

Elena Partesotti NICS---Unicamp University. Email: epartesotti@gmail.com. ORCID: 0000-0002-2878-3524.

Abstract

The artistic installation *Cenesthetic Defragmentation,* showcased at the GAIA Gallery in Brazil, explores the intricate interplay between sound, visuals, movement, and self-awareness with extended digital musical interfaces. The installation provides an interactive platform where participants engage with real-time audiovisual feedback generated by their movements, fostering a heightened sense of self-awareness and a deeper connection with their internal world. Central to the installation is the concept of *coenaesthesia,* the integration of sensory experiences. Rooted in embodied cognition, the installation emphasizes the connection between mind, body, and environment, demonstrating how physical interactions shape cognitive processes. *Cenesthetic Defragmentation* creates an inclusive space and multifaceted exploration of human perception, inviting participants to engage in self-discovery through advanced interactive technologies.

<TX-N>The digital transformationhas reshaped artistic expression, fostering a participatory culture where emerging technologies and new forms of creativity converge [1]. Within this context, digital musical instruments (DMIs) and extended digital musical instruments (EDMIs) have emerged as key tools bridging technology and art [2].

<TX>*Cenesthetic Defragmentation*, exhibited at the GAIA Gallery of the University of Unicamp in Brazil, exemplifies this connection by exploring the interplay between sound, movement, and self-awareness through an EDMI.

Art, for me, is a journey and a creative exchange, one that possesses immense power to provoke contemplation and foster self-discovery. This philosophy is deeply embedded in the installation, which encourages participants to use their movements as a bridge between inner and outer worlds.

The term *cenesthetic* was initially chosen for the installation's title to highlight the unified perception of the body central to its conceptual foundation. However, in this paper, I adopt the term *coenaesthesia* as it more accurately describes the integrated bodily awareness explored in recent philosophical and phenomenological studies [3]. While the theoretical framing has been refined, the original name of the installation, *Cenesthetic Defragmentation,* remains unchanged as a reflection of its artistic and conceptual origins.

This theoretical and conceptual perspective aligns with the paradigm of embodied cognition, which posits that cognitive processes emerge from the dynamic relationship between body and environment [4]. Within this paradigm, the Sensorimotor Contingency Theory [5] highlights how our sensory experiences are shaped by the active engagement of the body with the environment. Sensory modalities operate simultaneously [6], creating a multimodal experience further enriched by the digital environment , as exemplified in the real-time audiovisual feedback of this installation.

By engaging with Cenesthetic Defragmentation, participants explore how their movements generate sound and visuals, fostering a deeper sense of embodiment and promoting self-awareness. This theoretical foundation provides the framework for understanding how these concepts are integrated into the design and experience of this installation.

<1>DMI and EDMI

<TX-N>DMIs and EDMIs are fundamental tools related to the creation and use of digital interfaces for musical production and performance. DMIs are digital musical instruments that employ digital technologies to expand the expressive capabilities of musical artists [7]. These interfaces enable control and manipulation of sound in innovative ways, opening new creative and interpretative perspectives.

<TX>On the other hand, EDMIs represent an evolution of DMIs, going beyond traditional functionalities. They integrate gestural and sonic interaction with other sensory modalities, such as vision and kinesthetic interaction , to create more immersive and engaging musical experiences [8]. While DMIs expand artists' expressive capabilities through digital technologies, EDMIs go further by integrating multiple sensory modalities to create more immersive and engaging musical experiences. In this sense, the fusion of the real and the virtual is essential for establishing any EDMI, where the environment and the user play essential roles. The user's body becomes a technological extension and a digital musical instrument, especially in extended reality environments, where the interaction between digital technologies and physical interfaces provides new possibilities for artistic expression and exploration.

In *Cenesthetic Defragmentation*, the concept of EDMIs is realized through the integration of body tracking via Kinect and the use of TouchDesigner for audiovisual processing. For example, when a participant raises an arm, the system maps the movement to an audiovisual output, creating a multimodal experience that emphasizes the relationship between gesture and sensory feedback. Building on this understanding of EDMIs, the following sections delve into how these principles were applied in the creation of this installation.

<2>EDMI and Creativity

Today, technology has increasingly prominent power and value. Therefore, separating music and technology would not make sense, especially in the light of my study of DMIs and their possible applications for more than a decade. During my research, I decided to expand the concept of DMI by identifying extended DMI. Over time, the concept of DMI has spread to many fields, accompanied by the diffusion of sensors, motion capture systems (MOCAP), and other technologies. The number of artists and researchers engaging with these topics is increasing, along with the exploration of new concepts and applications (e.g., in live electronics, , or music education). In my work, I conceptualize extension as a process occurring through space, through interactivity. This involves the expansion of the body and mind through technological means, with sound serving as a fundamental component. Therefore, sound is not the ultimate goal but the medium through which this goal is achieved.

I designed this interactive installation based on an investigation of an EDMI called BehCreative for research purposes at Interdisciplinary Nucleus for Sound Communication (NICS). The architecture of *Cenesthetic Defragmentation* involves processing data received from the MOCAP (via Kinect 2). Body data is then sent to a software, which transforms it into output, i.e., visual feedback, which will be projected on the screen in front of the user(s). At the same time, this data corresponds to sonification. The software implemented is called TouchDesigner.
Indeed, the notion of EDMI refers both to its schematic and abstract charachter and to its bodily origin, resulting from a constant perceptual operation of movement and manipulation in space. This is because, as Peñalba observes, we can understand music within a technological system through Johnson's Image Schemas and proprioception [9]. From a technical point of view, in this installation, processing occurs through a network including Kinect and body mapping software. Thus, this is a hybrid network that has two functions: processing the input and acting as overall audiovisual output. The user should be immersed in space and interact with it. Special attention was

given to sound feedback; diverse consonant and dissonant musical excerpts were implemented to react according to the user's movement in the environment. Therefore, the variables that are activated through the process between the user and the environment led to creative empowerment [10], which is discussed in the next section. The objective is to carefully listen to the sounds generated by the visitors' movements, combine them, and observe on the screen the colors that these movements produce. The installation allows accessibility, ensuring that individuals with diverse physical abilities can engage with the experience. The mapping of the installation is primarily based on arm and head movements, allowing for real-time audiovisual feedback to be generated solely through these gestures. Indeed, this design choice enables participation even for those who may have limited trunk mobility. By focusing on movements that can be performed without extensive physical exertion, the installation aims to create an inclusive environment where everyone can partake in the transformative experience. This approach underscores the installation's commitment to accessibility, emphasizing the democratization of art by promoting equal participation and engagement for all visitors, regardless of mobility constraints.

<1>Methodology

<TX-N>Since the 1980s, the widespread adoption of interactive digital technologies has expanded across various domains, fostering interdisciplinary collaboration between scientific and humanistic disciplines. This interdisciplinary dialogue has spurred the development of user-friendly systems aimed at facilitating easier interaction. This ongoing interdisciplinary dialogue has facilitated the development of user-friendly systems for interaction and led to the emergence of experimental technologies emphasizing the relationship between action and perception. Drawing from Heidegger's assertion that "the essence of technology is by no means anything technological" [11], we see the emergence of innovative technologies, particularly in the health sector, such as in rehabilitation and music therapy. These advancements enable individuals to engage effectively with musical instruments, regardless of their musical background or physical limitations, thereby fostering proficient, expressive, and creative outcomes.

<TX>As technology evolves, traditional learning paradigms are reshaped by new, subjective stimuli. MOCAP technology, for instance, allows for the sensorless tracking of bodily movements, particularly within EDMI. EDMIs are distinguished by their separate control surfaces and sound generation units, which together extend users' cognitive, sensorimotor, and perceptual capabilities [12]. In this context, the relationship between creative and cognitive dimensions becomes evident.

MOCAP facilitate immersive, performative environments where users forge new connections and pursue goals through movement. Through this process, users develop mastery over technology---a concept referred to as creative empowerment---that enables them to express themselves creatively. Such empowerment arises from mastery sensorimotor contingencies through practice and exploration, resulting in a state of flow conducive to creativity. Inclusive design approaches ensure that individuals with diverse abilities can equally access and benefit from assistive technologies**,** which is essential in artistic installations with a diverse range of users. To address empowerment in the context of Cenesthetic Defragmentation it's useful to situate this work within the broader scope of interactive art and digital musical interfaces, focusing on the concept of creative empowerment [13]. This concept is fostered through EDMIs by providing participants with control over the artistic experience, transforming them from passive spectators into active creators of their perceptual environment. Through real-time feedback generated by movement, users gain a sense of agency as their actions shape the audiovisual landscape, facilitating a connection between personal movement and sensory experience. This relationship echoes findings in studies on interactive art, where technological mediation can enhance participants' perception of self-efficacy and autonomy [14]. In this installation, creative empowerment is encouraged through the design of an intuitive, responsive interface. By minimizing the learning curve and allowing users to generate complex audiovisual outcomes with simple movements, the installation allows participants of varying abilities to experience personal agency within a structured yet open-ended artistic framework.

The installation consists of a performative space with a MOCAP (Kinect). Users can interact with the installation by moving their head laterally, raising a hand upwards, or bending towards the ground. The visitor's movements generate real-time audiovisual feedback (Figs 2 and 3).

Upon approaching the installation, participants encounter a screen with the following description:

<EX>*In 'Cenesthetic Defragmentation' you become an integral part of the installation. Your movements generate real-time audiovisual feedback, interacting with the technological elements of the artwork. By moving your head laterally, you create one soundtrack; by raising a hand, you produce another soundtrack; finally, by bending towards the ground, you generate a third sound element.*

The goal is to carefully listen to the sounds that emerge from your movements, combining them, and observing your actions on a screen in front of you, allowing you to visualize the colours generated by your movements.

This experience invites tuning into the internal world, stimulating self-awareness. It requires patience to listen to each track and combine it with others, noticing how your body moves to produce the sounds.

By providing an opportunity to listen, feel, and recreate unique combinations of movements and sounds, the installation encourages users to explore their own embodied experiences. Users are then free to perform in front of the screen following the instructions (Fig. 2). For a visual overview of the installation, see the accompanying supplementary *video*.

Figure 1. User interacting with the installation, performing the movements suggested by the note: head movement, raising one arm, and bending down

Figure 2: Two users exploring the installation freely.

<2>Coenaesthesia: Embodied Awareness and Sensory Integration in XR Environments

<TX-N>Cenesthesia, as suggested by Sobchack [16], goes beyond the mere sum of somatic perceptions; it represents an embodied awareness of the entire body, which acts as an active perceptive agent. This concept differs from synesthesia, which involves the translation of sensory perceptions between different senses. Coenaesthesia, on the other hand, concerns the complete integration of sensory experiences within a bodily context. Sobchack explores this idea by

emphasizing how the body not only perceives the world but also understands it viscerally, through embodied experience----as described above. In this sense, coenaesthesia is not a passive perception but an active experience where the body becomes both the subject and object of knowledge, merging vision, touch, action, and perception. This multidimensional approach to bodily perception is often reflected in interactive art installations, where the body is called upon to explore its own physical and mental state through interaction with the environment, as seen in works fosthering self-awareness through sound and movement.

Coenaesthesia is a complex phenomenon involving a series of sensory systems, including the vestibular, proprioceptive, and somatosensory systems, which allow us to perceive our body in space. These sensory inputs are integrated by the brain to create a unified representation of the body, essential for immersion in Extended Reality (XR) environments. XR is an umbrella term that encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR), providing users with immersive experiences that blend the physical and digital worlds. XR technologies use various tools, such as headsets, motion sensors, and surround sound, to immerse users in these environments. Within such contexts, the perception of the body in space becomes central to the user's experience, echoing the role of coenaesthesia in creating a deep connection between body, mind, and environment. This integration of sensory modalities and embodied awareness forms the core of the participant's interaction with *Cenesthetic Defragmentation.*

<1>Users' Interaction

The experience of *Cenesthetic Defragmentation* is engaging and meditative. The installation invites users to tune into the internal world, stimulating self-awareness, as they explore each track and discover how their movements create the sounds.

In the artwork, the visitor becomes an integral part of the work itself. Their movements generate real-time audiovisual feedback, interacting with the technological elements of the artwork. Lateral head movements, raised hands, and bending toward the ground each generate a distinct audio track. The objective is to carefully listen to the sounds that emerge from their movements, combining them together, and observing their actions on a screen in front of them, allowing visualization of the colors generated by the movements. This experience invites tuning into the internal world, stimulating self-awareness. It requires an understanding of how bodily movements generate sounds.

The intention is to allow participants to explore their bodily space without distractions, fostering a deeper connection with movement and the sound it generates. Experience this environment as an

opportunity to listen, feel, and recreate a personal combination of movements and sounds while increasing self-awareness [17]. It is open to interpretation, allowing participants to find their own personal meaning. Another possible interpretation of the installation is that it represents a meditation on the connection between sound, movement, and self-awareness. The artwork invites users to connect with the internal world. The small screen was used due to technical limitations of the venue and space constraints in the gallery.

The artwork was designed with accessibility in mind, ensuring that people with diverse physical abilities can effectively interact with the system. The gallery is located on the ground floor of a large university library, which is equipped with facilities for individuals with mobility impairments. From a technical perspective, the environment is highly responsive and configurable, reacting to movements of the arms, torso, and head. This design allows for a broad range of interaction possibilities, enabling participation even for those with limited mobility. Although no wheelchair users participated in this event, the accessibility features were conceived with this demographic in mind, and similar setups have been successfully tested in the past [18]. Moreover, the system can be configured to recognize minimal or restricted movements, making it adaptable to the needs of users.

<2>Inclusivity and Accessibility

Building on inclusive design principles that prioritize accessibility and co-creation (e.g., as explored in projects like the Rhyme[1] project by Cappelen and Andersson [15]), this installation is designed to allow individuals of varying physical abilities to engage meaningfully with the installation. By ensuring responsiveness to minimal gestures---such as head, arm, and torso movements---and situating the installation in a fully accessible gallery, the work embodies a commitment to inclusivity that aligns with contemporary approaches in interactive and assistive technologies. The system's adaptability in detecting constrained movements enables participation for users with reduced mobility, consistent with research advocating for interactive environments that respond to subtle gestural input. However, individuals with physical limitations were not present in this showcase. Future versions will incorporate feedback from participants with mobility impairments, enabling iterative improvements based on real user experience, as seen in co-creative methodologies.

<2> Conceptual Foundation

[1] https://musicalfieldsforever.com/rhyme/indexcdf1.html?page_id=10

In my work, I prefer to approach interaction as a technique, as I have been studying it for a long time [19]. I enjoy observing how different disciplines and techniques blend, producing hybrid tools that remain 'open,' so to speak, not fixed to a single interpretation but adaptable by the user. A concept of democratic art, accessible and reproducible by everyone, as I believe that only through such openness can ideas circulate freely and become valuable tools for society. My research focuses on interdisciplinarity, which in this work takes shape through an interest in multimodality, embodied cognition, and technology, positioning art as a tool for self-awareness and a pathway toward diverse personal goals [20]. Guided by my initial interest in synesthesia, I explored the fundamental relationships between sound and color in search of meaningful connections. Today, I am convinced that audiovisual experience, even when influenced by strong cultural factors—as Heller demonstrates in her book on color significance (2012)—remains inherently subjective. It depends on the moment, the situation, the environment, the relationship with the surroundings, the cultural background, and everything that shapes the experience [21]. In the installation, colors were generated in real time through a Brownian noise algorithm, which produced a dynamic matrix for the red, green, and blue (RGB) channels. This approach enabled a continuous and organic variation in color intensity, in perfect alignment with the interactive nature of the performance. For example, bodily movements triggered subtle shifts between cool and warm tones, reflecting the dynamics of interaction.

Several interpretations of the same artwork are proposed here, offering users various approaches to explore the environment. Specifically, they can choose to:

<BL>Experience body sonification

Engage with visual feedback linked to the body

Foster bodily awareness that generates audiovisual feedback.

Approaching the installation and starting the experience, a track is given to suggest to the public how to explore as stated in section 2.

I hope that each visitor, in becoming an interpreter of the work, will pause, take a deep breath, and use it as a personal instrument—a medium for proprioceptive awareness, sensing how their body transforms into a technological extension, a musical instrument in itself. In my work, concepts such as Gibson's affordances [22] converge and are extended to the immersive interactive domain as Virtual Affordances [23]. In this installation, I propose three Virtual Affordances, expressed through short chords and sequences of notes (Table 1).

<1>On Gesture

The use of musical instruments requires prior knowledge of gesturesto play them effectively. However, these gestures are not always compatible with the performer's preferences. The introduction of DMIs thus stems from a reconsideration of the musician's relationship with their instrument. As suggested by Mulder [24\(2000), Control Intimacy refers to the compatibility between a variety of consciously emitted sounds and the physical and physiological abilities of an experienced performer; in other words, it's the full conscious control of the instrument. With current musical technologies, achieving control intimacy is possible even without prior knowledge of the instrument.

Within the ensemble represented by the term New Interfaces for Musical Expression (NIME), various types of technologies and musical interfaces are found, referred to as DMIs. These DMIs consist of a control surface (or gestural controller) and a sound generation unit, with both units being independent modules related to each other by mapping strategies [25]. DMIs can take the form of traditional instruments or completely different and unusual shapes. For this installation, I have implemented an EDMI in which the user seamlessly transitions into the role of the instrument itself [26]. The mapping of movements to sound parameters in the installation was designed to maintain ease of use. Arm and head movements exceeding specific thresholds, detected via the Kinect, triggered prerecorded audio files corresponding to distinct soundtracks. While this approach ensures accessibility, particularly for participants with limited mobility, it also highlights a balance between responsiveness and expressiveness. The reliance on thresholds may limit fine control over sound dynamics, but it emphasizes the installation’s focus on self-awareness and meditative engagement rather than high technical virtuosity. Future iterations will explore continuous mappings to expand expressiveness while retaining inclusivity.

The study of gestures in interactive musical technologies must be done broadly, considering the physicality of the gesture, where every movement can communicate information [27]. According to Norton [28], a musical gesture includes various types of secondary gestures such as articulations, made by the user in the expressive act. To understand and analyze it, it is necessary to acquire the gesture through DMIs. Gesture acquisition in a DMI environment can occur directly, indirectly, and through physiological signals [29]. Direct gesture acquisition involves the use of MOCAP systems, allowing subjects to move freely in space. According to Wanderley and Depalle [30], gesture refers to the movements made by a skilled instrumentalist during musical performance. Additionally, Norton [31] emphasizes that gesture acquires meaning through a process involving our experience and interaction with the phenomenon we experience and learn about.

Furthermore, the consideration of gesture extends to movements or changes in state that become significant to an agent, as suggested by Delalande and Hatten [32]. Within a DMI, randomized gestures can become meaningful actions.

<1>Conclusion

Coenaesthesia is an important factor to consider in the design of XR experiences. Future research should focus on developing methods to enhance cenesthetic feedback in XR,to create more immersive and engaging experiences. *Cenesthetic Defragmentation* is an interactive artistic installation that explores the relationship between sound, movement, and self-awareness and by doing so it aims to demonstrate that interactions between art, music, and technology can promote societal benefits. The installation is an experience that can be interpreted in many ways, inviting participants to feel their bodies in relation to the environment. It is worth noting that it is designed with accessibility in mind, accommodating individuals in wheelchairs or with limited mobility, ensuring that everyone can engage with the artwork and experience its transformative effects.

In conclusion, *Cenesthetic Defragmentation* demonstrates how multisensory interactions, particularly through EDMIs, can enhance bodily awareness and self-reflection. The integration of sound and movement within the installation facilitates an exploration of the concept of coenaesthesia, allowing participants to actively engage with their physical and mental states. This process highlights the potential of interactive art to foster new ways of experiencing the body and its relation with the environment.

Moving forward, further research could explore how the principles of coenaesthesia applied in this installation could be extended into other fields, such as rehabilitation, educational settings, and XR environments. The potential to deepen embodied cognition and creative engagement through technologies like XR opens new possibilities for immersive and transformative experiences, particularly in contexts where accessibility and inclusivity are prioritized. By emphasizing the role of the body as both subject and object in interactive spaces, the installation offers a glimpse into future explorations of human perception, creativity, and sensory integration.

In the future, it will be important to include specific testing with participants who have mobility impairments to gather empirical data on the system's usability and effectiveness for people with disabilities. This approach will allow to further improve accessibility and ensure that the artwork offers an inclusive and transformative experience for all visitors.

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<BIO>Elena Partesotti is a postdoctoral researcher between the NICS and the BRAINN at Unicamp, focusing on embodied cognition in music technology for therapeutic purposes.

Table 1: Forms of interaction in the artistic installation Cenesthetic Defragmentation

Type of Interaction	Movement Intensity	Feedback
Sonification	High	Excerpt of a piano composition
Visual elements	Medium	Images

Position	High	Changes in the virtual environment
Body area	Varying	Audiovisual feedback