Cultural Inertia and Technical Concretisation: A Systematic Review of Keyboard Interfaces at NIME

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Abstract

Keyboard interfaces occupy a dual position in music technology as both a historical standard and a site for experimental augmentation. Although the NIME community is reflexive, no systematic review has yet investigated how the keyboard interface has evolved within this research context. We address this issue with an inductive thematic analysis of 104 publications from 2001 to 2025. Grounding our findings in Simondon's concept of concretisation and postphenomenology, we identify a strong cultural inertia associated with Western music theory. Results show that innovation is predominantly concentrated on key-based continuous control, focusing on the micro-gestures of the fingertip. This review reveals that despite the community's increasing global diversity, keyboard design philosophies based on non-Western music theories remain largely overlooked. To address this, we suggest leveraging interface multistability to support non-Western musical frameworks. Furthermore, we encourage the invention of novel keyboard interfaces grounded in non-Western music theories.

Keywords

Keyboard interfaces, Systematic review, Philosophy of technology, Cultural analysis, Interaction modalities

1 Introduction

Coeckelbergh describes music as a complex interplay of performance, improvisation, and conducting, characterising it as an embodied, social, cultural, and technological practice involving sound and business [20]. Within this ecology, Magnusson describes the musical instrument not merely as a tool for sound production, but as "containers of music, demonstrators of natural laws, an embodiment of theory, ideology, and often aesthetics" [84]. As industrialisation transformed European craft traditions [123], Western musical culture became particularly notable for its historical conjunction of music, religion, and the mechanical principle, with keyboard instruments occupying a central position within this nexus [4, 57].

The history and organology of keyboard instruments have been extensively documented in various literatures [42, 65, 110, 120, 125, 139]. Defined as "a set of levers (keys) actuating the mechanism of a musical instrument" [97], the keyboard traces its origins back to the Greek hydraulis. The layout evolved with the rise of polyphony, culminating in the 15th-century chromatic arrangement that remains standard today [97, 125]. The subsequent transition from harpsichord to piano was a century-long process driven by the demands of composers like Scarlatti, who sought greater expressive potential in dynamics and novel timbres, playing a pivotal role in the development of the earliest fortepiano [120, 139]. This invention, later scaled by industrialisation [123], allowed the piano to achieve what Gilbert Simondon termed a *transindividual* state [84]: it became a medium connecting diverse social groups and a ubiquitous domestic object, particularly for the rising middle class [18, 42], and spread to other continents through colonisation and musical practices [146]. This morphological convergence also influenced bowed keyboards designed for continuous control, whose layouts evolved from the early organistrum to harpsichord-like designs such as the piano-viole [40, 79, 135].

The keyboard's influence persisted through technological shifts, becoming one of the default interfaces for electronic instruments, from the Telharmonium to modern MIDI controllers and synthesisers [29, 109]. This transition included further explorations of continuous control using the new technology with this established interface, as seen with the *ondes Martenot* [110]. The trend became especially prominent during the 1980s, which saw a standardisation of digital instrument interfaces within the pre-NIME computer music community [154]; concurrently, more radical approaches using textile-based keyboards, such as Haken's *Continuum Fingerboard*, also emerged [1, 14]. Within the NIME community, the survey by Morreale and colleagues reveals that the vast majority (91%) of NIME performers possess a background in traditional instruments, with the piano ranking as one of the most ubiquitous foundational skills (42%) alongside guitars (45%) [108], indicating that the influence of the piano may also be prominent in the NIME community regarding keyboard instruments.

However, past dominance does not guarantee present relevance. Moreover, longitudinal analyses of 20 years of NIME (2001–2020) by Fasciani indicate a gradual diversification of the community's practices and demographics over time [36]. Although the layout of an instrument may embody ideology and influence music composition [84, 98], as of 2025, the NIME community has not conducted an investigation into keyboard instrument interfaces to assess whether their layouts have become more diverse, despite their continued popularity. This raises the question: *How are keyboard interfaces situated within the NIME literature, specifically regarding their morphology and the interaction modalities they afford?*

This study addresses this research question through a systematic review of NIME publications related to keyboard instruments. We collected papers spanning from 2001 to 2025 and identified 104 relevant publications (Section 2). We then structured our analysis into three subsections, examining the papers across three dimensions: contributions of the papers, the layout of the keyboard interface, and additional interaction modalities added to the keyboard (Section 3). Based on these findings, this study discusses the results through two main lenses: Simondon's philosophy regarding the process of the *transindividual* [134] (existing

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NIME papers have discussed *plurifunctionality* [38] and *transduction* [62]) and Don Ihde's Postphenomenology, which analyses mediational relations with instruments [19] (applied to the Magpick regarding *relations* [95, 105]). We found a degree of diversity in keyboard interfaces within the NIME community, although these instruments are predominantly designed around Western music theory. This suggests an underexplored potential for designing keyboard interfaces grounded in non-Western musical paradigms. Furthermore, although continuous control via the fingertip is the most explored additional interaction modality on keyboards within the NIME community, there remains room to explore its cross-cultural *multistability* in musical applications (Section 4).

2 Methodology

Over the past decade, the NIME community has seen a growing body of meta-analyses employing both quantitative and qualitative methods to examine its own output. For instance, Fasciani presented a comprehensive bibliometric analysis of the proceedings from 2001 to 2023 [35] and, in a separate study, audited the carbon footprint associated with twenty years of NIME travel, advocating for the retention of online conference formats post-COVID to ensure environmental sustainability [36].

Other studies have focused on specific artefacts and technologies. Masu and colleagues conducted systematic reviews to examine how the concept of the "score" has been used within NIME [87], as well as an investigation into longevity and the ideology of "newness" within the community [88]. Furthermore, Jourdan and Caramiaux performed a systematic review of the use of Machine Learning for musical expression between 2012 and 2022 [69]. Following PRISMA guidelines, they analysed 69 contributions to categorise how ML is applied and examined the degree of user control over these systems. Finally, Saitis and colleagues undertook a corpus-assisted discourse analysis combined with a detailed review to examine the concept of "timbre" in NIME research [128].

To the best of our knowledge, no systematic review has been specifically dedicated to investigating keyboard instruments at NIME. To address the research question, the reporting of this review adheres to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) 2020 statement [118]. The synthesis of the selected literature was conducted using thematic analysis with an inductive approach [10].

2.1 Screening Process

We implemented a data mining and screening pipeline comprising corpus construction, keyword-based filtration, and a final manual selection based on whether the paper presents a contribution related to keyboard instruments. The initial dataset was compiled using data from three distinct sources to ensure maximum coverage and accuracy:

(1) Custom web crawlers targeting the official NIME proceedings (2001–2025).[1]
(2) Data generated by the NIME Proceedings Analyzer [36].[2]
(3) The community-maintained NIME bibliography repository.[3]

Cross-referencing these sources and excluding attachments as well as retracted papers resulted in a total corpus of 2,298 papers. Where possible, all files were synchronised with metadata from the official NIME community repository to facilitate subsequent processing[4].

2.2 Keyword Filtration and Text Processing

To identify potentially relevant contributions, we selected keywords according to literature providing overviews of keyboard instruments [97, 110]. We then cross-referenced NIME papers that contained these keywords and iteratively refined the keywords to adequately cover papers related to keyboard instruments. Consequently, we established a dictionary of keywords: *Organ*, *Keyboard*, *Piano*, *Clavichord*, *Harpsichord*, *Accordion*, *Interface*, and *Layout*. Note that generic terms like *Interface* and *Layout* were only considered valid when co-occurring with instrument-related terms to reduce noise.

We then performed full-text extraction on the corpus, followed by a data cleaning process. To mitigate false positives, the algorithm automatically truncated content appearing after the "References" or "Citations" sections, ensuring that papers were not selected merely due to citations of keyboard-related work. This automated filtering process reduced the corpus to 1,082 candidate papers[5].

2.3 Manual Selection

Certain keywords, such as *organ* and *keyboard*, possess polysemous meanings unrelated to musical instruments. To facilitate manual review of the 1,082 candidates, we developed a heuristic scoring model based on TF-IDF (Term Frequency-Inverse Document Frequency) [55]. This model ranked papers by calculating the density of instrument-specific terms while penalising contexts associated with non-musical text entry (e.g., *QWERTY*, *typing*).

The final selection was conducted through a manual review of the full texts of these ranked candidates. The inclusion criteria were strictly defined based on the authors' intent regarding the instrumental nature of the keyboard:

- **Inclusion:** Papers were retained if the authors explicitly framed their work as related to, utilising, or contributing to the future development of keyboard instruments, regardless of the interface's physical morphology (hardware or software).
- **Exclusion:** Papers were excluded if the keyboard was treated merely as a generic controller for non-musical tasks, or if it was mentioned solely as a baseline for comparison (e.g., as an interface to be transcended) without being the primary subject of the contribution.

This process resulted in a final set of 104 papers, which constitutes the core dataset for this systematic review[6].

3 Results and Analysis

Figure 1 illustrates the annual distribution of keyboard-related papers published at NIME between 2001 and 2025, categorised by the nature of their contribution. A detailed classification of the referenced papers is provided in Table 1. For the purpose of

[1] https://github.com/superbowyiming/NIME-2001-25-Keyboard-Interface-Review
[2] https://github.com/jacksongoode/NIME-proceedings-analyzer
[3] https://nime-conference.github.io/NIME-bibliography/

[4] The resulting CSV file is named `nime_aligned.csv` in the attachments and https://github.com/superbowyiming/NIME-2001-25-Keyboard-Interface-Review
[5] The full list of papers resulting from this filtering step is provided in the `filter_results.csv` file in the supplementary material.
[6] The complete list of screened candidates and their inclusion status is provided in the `kwic_context_screening.csv` file in the supplementary material.

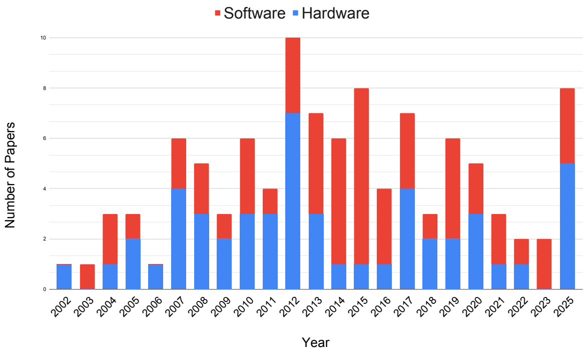

Figure 1: Yearly Distribution of Contributions in Keyboard-Related Papers.

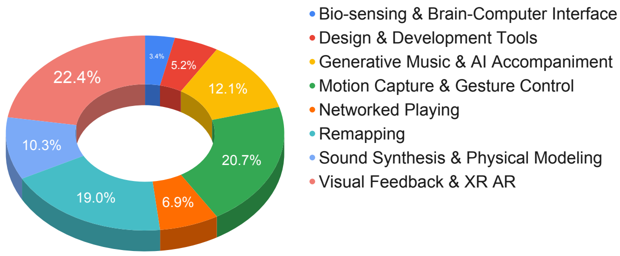

Figure 2: Distribution of surveyed literature by software contribution

this analysis, *Software* refers to original contributions focused exclusively on software implementation, whereas *Hardware* refers to contributions that involve the development or modification of physical components.

Table 1: Categorisation of Selected Papers by Contribution Type (Hardware vs. Software)

Category	Papers
Hardware	[7, 9, 15–17, 21, 31, 33, 38, 43, 45–47, 49, 52, 56, 61, 68, 71, 73, 75, 77, 78, 81, 86, 90–93, 101, 104, 111, 113, 115–117, 121, 126, 130–132, 137, 138, 140, 141, 145, 150, 157–160]
Software	[2, 3, 5, 6, 8, 11, 23–28, 30, 32, 34, 37, 41, 44, 50, 51, 53, 54, 59, 66, 70, 72, 74, 82, 83, 85, 96, 100, 114, 119, 124, 127, 129, 133, 142, 143, 148, 152, 153, 156, 161, 164–171]

3.1 Taxonomy of Contributions

The taxonomy was developed through an inductive thematic analysis. The categories emerged directly from the corpus based on the primary technical innovation or functional role described by the authors.

3.1.1 Software instruments. With respect to *software* instruments, contributions are taxonomically grouped based on their functional role within the musical ecosystem. The specific definitions for each software category are as follows:

Bio-sensing & brain-computer interface: Systems that utilise physiological data acquired from the performer's body (e.g., brainwaves or electrodermal activity) to modulate or influence keyboard performance parameters.

Design & development tools: Software frameworks or toolkits specifically designed to facilitate the creation or customisation of virtual keyboard interfaces or synthesis environments.

Generative music & AI accompaniment: Algorithmic systems that can exhibit agency, providing real-time generative musical content, or intelligent accompaniment that responds dynamically to the musician's input.

Motion capture & gesture control: Applications employing existing camera-based or sensor-based tracking of the performer's body and hand movements, utilised either to gather performer's data or as an additional layer of expressive control over the sound.

Networked playing: Systems designed to facilitate remote control, enabling the playing of geographically distributed keyboard instruments via network protocols, whether synchronously or asynchronously.

Remapping: Software that remaps the function of the keyboard device's keys or controllers. This category includes features such as chord mappings, pitch correction, or stochastic modulation processes.

Sound synthesis & physical modelling: Contributions focused on sound design, particularly physical modelling or novel synthesis techniques driven specifically by keyboard input.

Visual feedback & extended reality: Interfaces that augment the performance environment with visual information via displays, projection mapping, or extended reality (XR/AR/VR) technologies to support pedagogy, performance cues, or aesthetic enhancement.

Table 2 details the classification, while Figure 2 illustrates the distribution. Notably, *Visual feedback & extended reality*, *Motion capture & gesture control*, and *Remapping* emerge as the most presented categories, collectively accounting for 62% of the surveyed literature. This concentration suggests that keyboard-related software research in NIME is primarily driven by multimodal feedback and the management of mapping complexity.

Table 2: Software Papers Interface Taxonomy Summary

Software Contribution	Papers
Bio-sensing & brain-computer interface	[74, 170]
Design & development tools	[32, 148, 156]
Generative music & AI accompaniment	[8, 23, 34, 70, 142, 161, 164]
Motion capture & gesture control	[2, 6, 11, 27, 44, 50, 51, 53, 96, 168, 171]
Networked playing	[5, 54, 85, 161]
Remapping	[28, 30, 59, 66, 72, 100, 114, 119, 153, 156, 167]
Sound synthesis & physical modelling	[24–27, 124, 127]
Visual feedback & extended reality	[3, 37, 41, 59, 82, 83, 129, 133, 143, 152, 165, 166, 169]

3.1.2 Hardware instruments. In *hardware* papers, we first classified papers into five categories. Table 3 establishes this framework, while Figure 3 shows the category distribution.

The specific definitions for each hardware category are as follows:

Augmented acoustic keyboard instruments: Projects involving the integration of sensor technologies, actuators, or digital processing systems into traditional acoustic instruments (e.g., pianos, harpsichords, harmoniums) to extend their sonic or expressive capabilities while retaining their acoustic core.

Augmented electronic & electromechanical keyboard instruments: Contributions that keep the full function of the original instrument/device, then modify the existing electronic, digital, or electromechanical keyboards by embedding additional sensors or features to expand their native control parameters.

Components & circuits: Research focusing on specific hardware elements, such as novel force-sensing circuits or electromagnetic actuation mechanisms, that are developed independently rather than as complete, standalone instruments.

New keyboard instruments: Refers to the design and construction of novel keyboard instruments. Unlike augmented instruments, these are built from the ground up or based on a certain device but break the original function rather than augmenting an existing instrument.

Reimagined keyboard instruments: Refers to the replication, re-implementation, or revision of historical/classical keyboard instrument concepts using modern technologies.

The results show that the *New keyboard instruments* category is dominant, representing 41.2% of the literature, though the combined total of *Augmented acoustic keyboard* and *Augmented electronic keyboard* instruments would surpass it slightly. A notable case is the *Dimi-O*: although its creator, Erkki Kurenniemi, was a pioneer in breaking traditional interface paradigms, the *Dimi-O* is included in this study as a rare example in his oeuvre that incorporates a piano-style keyboard, even though strictly as an auxiliary interface [117]. Another example to mention is the *Haptic Carillon* [56]: although it utilises stick-like levers for carillon control and can be played with fists, it retains a piano-derived spatial arrangement and is classified as a keyboard according to the paper.

Table 3: Hardware Papers Interface Taxonomy Summary

Hardware Category	Papers
Augmented acoustic keyboard instruments	[45, 46, 71, 75, 78, 92, 93, 101, 113, 130, 145, 157]
Augmented electronic & electromechanical keyboard instruments	[9, 15, 43, 49, 77, 91, 104, 111, 131, 132]
Components & circuits	[33, 81, 90]
New keyboard instruments	[7, 16, 17, 21, 31, 47, 61, 68, 73, 86, 115, 116, 121, 137, 138, 140, 141, 150, 158–160]
Reimagined keyboard instruments	[38, 52, 56, 117, 126]

We also conducted an analysis of the hardware's technical implementation. Table 4 summarises the surveyed literature according to thirteen distinct functional modalities, while Figure 4 illustrates their thematic distribution. The specific definitions for each hardware functional modality are as follows:

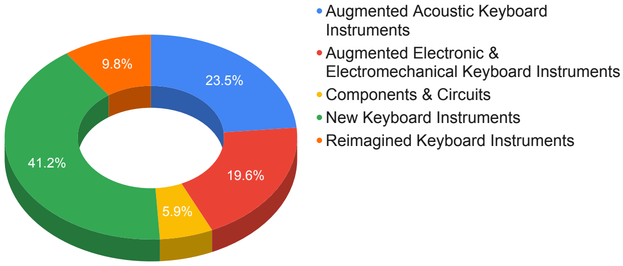

Figure 3: Distribution of Surveyed Papers by Hardware Category

Actuation & sound augmentation: Systems employing active mechanical means, such as electromagnetic actuation, to physically vibrate strings (in stringed keyboards) or metal tines (a component in certain electronic keyboards), thereby sustaining or augmenting the sound played from the instrument.

Breath & pneumatic controllers: Interfaces incorporating breath sensors, mouthpieces, or pneumatic mechanisms to allow the performer to control sound parameters via air pressure or flow.

Embedded platforms & driver circuits: Development of embedded systems or circuit boards integrated into the keyboard chassis to handle local signal processing or sensing.

External gesture capture: Systems utilising auxiliary sensors (e.g., cameras or proximity sensors) to track body movements occurring outside the direct key-contact zone.

Haptic & thermal feedback: Interfaces providing physical feedback to the performer's fingers, including force feedback, vibrotactile stimulation, or thermal cues.

Heritage & retro instruments: This category shares similarities with the *Reimagined keyboard instruments* category in table 3, but specifically refers to projects aiming to restore hardware devices or instruments that may face obsolescence. Authors contribute to the preservation of historical or culturally significant instruments/devices (e.g., typewriters, bandoneons).

Keyboard-keybed sensing hardware: Novel sensing technologies installed directly within the key mechanism or keybed to capture nuanced data (e.g., continuous key position or velocity) beyond standard MIDI note-on/off.

Materials & textile controllers: Papers that focus on materials. Specifically, keyboards constructed from non-traditional materials, such as e-textiles or smart fabrics, allowing for deformable or flexible interfaces.

Modular & configurable architecture: Designs featuring re-arrangeable units that allow the performer to physically customise the instrument's topology or layout.

Pedal sensing hardware: Hardware innovations focused specifically on augmenting or monitoring the movement and control of foot pedals.

Robotic & mechanical automation & AI driven: Instruments incorporating autonomous agents, robotic arms, or AI-driven mechanical systems that physically interact with the keyboard, generate sound without human interaction, or accompany human interaction.

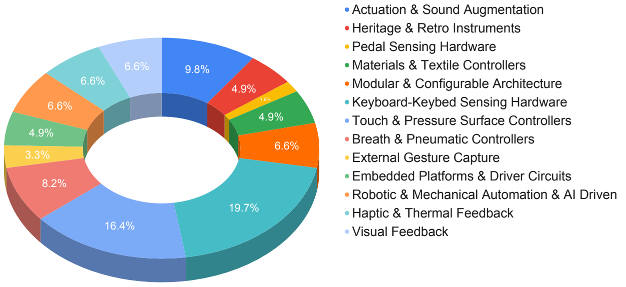

Figure 4: Thematic distribution of the 51 surveyed hardware papers across thirteen functional modalities.

Touch & pressure surface controllers: Interfaces utilising continuous touch-sensitive planar surfaces (e.g., force-sensing resistor arrays or capacitive touchpads).

Visual feedback: Hardware integrations of visual displays (e.g., embedded LEDs, screens) designed to provide real-time feedback directly on the instrument.

The results reveal that *Keyboard-keybed sensing* and *Touch & pressure surfaces* remain the most explored technical areas. In addition, specialised domains such as pedal sensing and novel materials have been underexplored.

Table 4: Detailed Taxonomy of Hardware Functional Modalities

Functional Modality	Papers
Actuation & sound augmentation	[93, 113, 130–132, 145]
Breath & pneumatic controllers	[17, 21, 71, 126, 160]
Embedded platforms & driver circuits	[47, 90, 104]
External gesture capture	[49, 160]
Haptic & thermal feedback	[52, 56, 101, 116]
Heritage & retro instruments	[77, 117, 126]
Keyboard-keybed sensing hardware	[9, 31, 52, 61, 68, 91–93, 104, 111, 157, 160]
Materials & textile controllers	[38, 158, 159]
Modular & configurable architecture	[86, 115, 140, 141]
Pedal sensing hardware	[78]
Robotic & mechanical automation & AI driven	[16, 71, 75, 81]
Touch & pressure surface controllers	[33, 38, 45, 46, 73, 137, 138, 150, 158, 159]
Visual feedback	[7, 15, 43, 121]

3.2 Analysis of Keyboard Interface Design

We then aimed to identify the specific design rationales behind layout selection. Within the corpus of *software* literature, a relatively small subset, comprising only six papers (approximately 11%), explicitly articulates the rationale for leveraging or repurposing off-the-shelf hardware as a musical interface. Table 5 portrays a taxonomy of these software-based interfaces, categorising the literature in three primary dimensions: key layout, medium of interaction, and design motivation.

Three studies illustrate contrasting approaches to physical constraints. Hirai and colleagues [59] utilise a standard QWERTY keyboard as a tactile substrate, employing XR to implement reconfigurable layouts, including 12-tone piano and microtonal systems. This maintains physical haptic feedback while providing digital flexibility. In contrast, Han and Kim [53] explore *Air-Keys*, a touchless interface requiring navigation of an imaginary piano layout. While the complete absence of haptic feedback hindered the application of traditional techniques, the *AirPiano* [27] achieved comparatively greater efficacy by reducing the number of emulated keys and incorporating a tablet or a transparent PVC sheet, thereby mitigating the spatial navigation challenges inherent in mid-air interaction.

Table 5: Taxonomy of Interface Design in Software-Centric Papers

Dimension	Category	Papers
Key Layout	Isomorphic	[100, 156, 161]
	QWERTY Keyboard	[59, 96, 156]
	Piano	[27, 53]
	Adaptive/Reconfigurable	[27, 59]
Interaction Medium	Computer Keyboard Repurposing	[59, 96, 156]
	Touchscreen	[100, 161]
	XR/Augmented Reality	[59]
	Air Gesture	[27, 53]
Design Rationale	Accessibility	[96, 156, 161]
	Microtonality	[59, 100]
	Ergonomics	[100, 156]
	Tactile Feedback	[59]
	Aesthetic Mimicry	[96]
	Touchless Interaction	[27, 53]

Within the *hardware* literature, we specifically focused our analysis on the *New keyboard instruments* category. We prioritised this category because it represents the primary domain within *hardware* research that demonstrates both the intent and the capacity to explore novel alternative keyboard interfaces. Notably, this category constitutes a significantly larger corpus compared to its *software* counterpart. Table 6 summarises these instruments across three dimensions: key layout, medium of interaction, and design rationale.

The distribution of layouts (shown in Figure 5) confirms the continued dominance of the traditional piano-style configuration. Two studies categorised as *Others* due to their unconventional topologies are Bender's [7], which utilises a static arrangement mapped to harmonic functions, and Nunes's [115], which employs a camera-tracked modular interface. Within the *Piano-style* subset, three designs introduce adaptive or reconfigurable mechanisms [140, 158, 159], allowing performers to physically manipulate the layout during performance.

In the interaction medium (distribution shown in Figure 6), we observe that *Lever-actuated keys* play the most significant role. This is expected, as the *Piano-style* category constitutes a large proportion of the dataset. Here, *Push-button* keys refer to keys that resemble buttons rather than the lever-actuated mechanism found in pianos. It is worth noting that both Park and colleagues [121] and Bender and colleagues [7] developed virtual versions of their keyboards for touchscreen devices; consequently, these have been included in the *Static capacitive surface* category as well.

The analysis of design rationales (distribution shown in Figure 7) reveals a more diverse distribution. Regarding the distinction between the two piano-related reasons: *Accessibility & familiarity of piano layout* indicates that the authors aim to leverage the accumulated years of piano playing experience and technique, whereas *Simulate piano experience* suggests the choice of layout was driven by a desire to replicate the haptic feedback or tactile experience of piano performance. *Ergonomics or to increase performance speed* implies the authors selected the interface based on ergonomic considerations or to facilitate virtuosic performance. The *Not explicitly stated* category includes papers where the authors explained the development process but did not explicitly justify their choice of layout. Interestingly, in the category *To play microtonal*, both papers utilise the *Isomorphic* layout, which appears to be the default keyboard interface considered for microtonality within the NIME community.

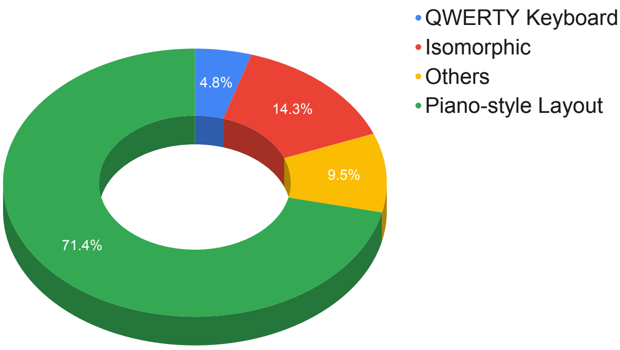

Figure 5: Distribution of keyboard layouts in hardware papers.

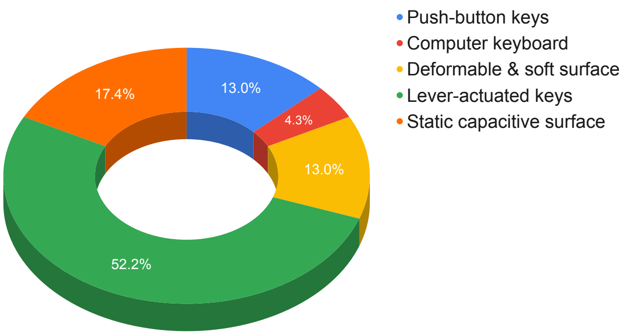

Figure 6: Distribution of interaction media for hardware interfaces.

3.3 Analysis of Extended Interaction Modalities

This section synthesises the corpus of 46 papers, spanning both hardware and software contributions, categorised by the novel

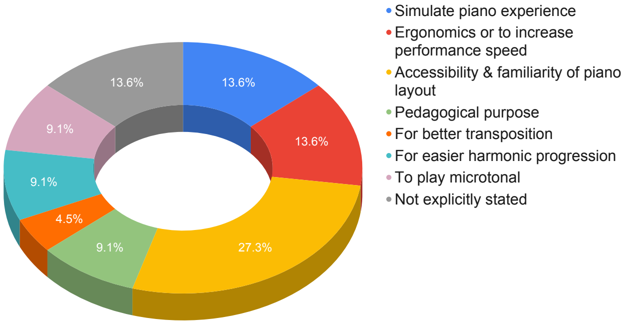

Figure 7: Distribution of design rationales behind layout selection.

interaction paradigms they introduce. The scope is specifically restricted to interaction modalities that allow the player to influence expressive control during the act of performance, extending beyond discrete note-on/off events.

Table 7 details the taxonomy developed for this analysis:

Extended instrumental techniques: Interactions that leverage the physical body of the instrument in non-standard ways, such as percussive strikes on the chassis or plucking virtual strings, mirroring practices in acoustic instrument playing [149].

Human-agent interaction: Systems where the instrument exhibits agency, acting as a co-creative partner through algorithmic improvisation or intelligent accompaniment.

Key-based continuous control: Continuous control applied by the fingers after the key press, such as pressure (aftertouch) or finger position, enabling per-note expression beyond the basic note trigger.

Non-key-based continuous control: Continuous modulation derived from other parts of the instrument (e.g., faders, ribbons, or manipulation of the instrument body) distinct from the keys.

Spatial gestures: Interaction occurring in the three-dimensional space immediately above the keyboard surface[7], where mid-air gestures influence sound parameters.

Figure 8 illustrates the distribution of these interaction categories. The data shows that *Key-based continuous control* remains the primary focus within the NIME community for keyboard instruments. Although key pressure sensitivity (aftertouch) has existed since the 20th century [12], its continued prevalence suggests a strong reliance on established piano technique. Notably, the influence of the *TouchKeys* [91] project is significant, with 18 of the 24 identified papers either authored by the original researchers or citing their work. Beyond tactile control, the community shows a clear interest in *Spatial gestures*, exploring the space above the keyboard as a complementary medium for sound modulation.

4 Discussion

The quantitative analysis presented in Section 3 reveals that the influence of the piano remains significant in keyboard instrument design within the NIME community over the past 25 years. In this section, we discuss the results through the lens of Postphenomenology [63] and Simondon's concept of the *transindividual* [134]. We first briefly outline these concepts.

[7]Restricted to the instrument's proximity to maintain the scope of this review.

Table 6: Taxonomy of New and Reimagined Keyboards: Interface and Design Dimensions

Dimension	Category	Papers
Key Layout	QWERTY Keyboard	[47]
	Isomorphic	[121, 137, 150]
	Piano-style	[16, 17, 21, 31, 61, 68, 73, 86, 116, 138, 140, 141, 158–160]
	Others	[7, 115]
Interaction Medium	Push-button keys	[7, 121, 150]
	Computer keyboard	[47]
	Deformable & soft surface	[73, 158, 159]
	Lever-actuated keys	[16, 17, 21, 31, 61, 68, 86, 115, 116, 140, 141, 160]
	Static capacitive surface	[7, 121, 137, 138]
Design Rationale	Simulate piano experience	[61, 68, 116]
	Ergonomics or to increase performance speed	[21, 47, 138]
	Accessibility & familiarity of piano layout	[17, 31, 73, 86, 158, 159]
	Pedagogical purpose	[115, 121]
	For better transposition	[140]
	For easier harmonic progression	[7, 150]
	To play microtonal	[121, 137]
	Not explicitly stated	[16, 141, 160]

Table 7: Taxonomy of Interaction Beyond Key-On/Off in Keyboard Instruments

Interaction Paradigm	Papers
Extended instrumental techniques	[24–26, 28, 113]
Human-agent interaction	[8, 16, 23–26, 70, 170]
Key-based continuous control	[9, 24–26, 31, 73, 91–93, 104, 111, 119, 124, 130–132, 137, 138, 145, 150, 157–160]
Non-key-based continuous control	[9, 17, 21, 86, 96, 119, 126, 127, 158]
Spatial gestures	[11, 27, 44, 49, 113, 129, 133, 158, 159, 168, 169, 171]

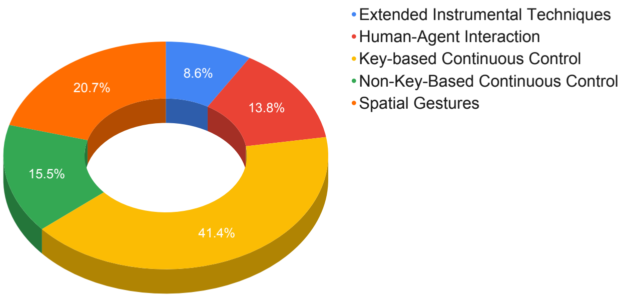

Figure 8: Distribution of interaction modalities beyond standard key-on/off events.

4.1 Overview of Postphenomenology and the Process of the Transindividual

4.1.1 Postphenomenology in Music. Postphenomenology, primarily proposed by Don Ihde, analyses how technologies mediate human experience. It posits that human subjectivity and the objective world are co-constituted through technological mediation [151].

Ihde articulates four primary human-technology-world relations (Table 8). In music, these relations describe how an instrument transforms from an external object into an embodied extension, or alters the perception of sound itself [95]. Another critical concept is *multistability*, where a single technology affords multiple uses depending on context [63, 64]. This phenomenon is observed in NIME, where Morreale and colleagues found that unexpected user adaptations sometimes redirect an instrument's evolutionary path [107].

Relation Type	Mediation Schema
Embodiment	(Human – Technology) → World
Hermeneutic	Human → (Technology – World)
Alterity	Human → Technology (– World)
Background	Human (– Technology / World)

Table 8: Postphenomenological Relations [151].

4.1.2 From Concretisation to the Transindividual. While Postphenomenology analyses the *relations* formed with instruments, the philosophy of Gilbert Simondon provides a genetic perspective on their evolution. Simondon defines the technical object by its ontogenesis rather than its static utility [48, 172][8].

Simondon's theory examines human-technology relations in an alienating industrial era, rejecting the dichotomy of humans as either slaves to machines or their masters [134]. Central to this is the process of *concretisation*: the evolution from an "abstract" assembly of isolated components to a "concrete" state where

[8]"Simondon argues that philosophy should be concerned...with the processes of individuation that create these individuals." [172]

parts become pluri-functional and internally resonant (*individualisation*) [134]. Within music, this parallels the integration of isolated parts into a cohesive instrument. Crucially, a concretised object retains a "margin of indeterminacy" that enables interaction with the outside world [134]. Simondon posits that machines require a human mediator to interpret their variability of forms, a meaningful variation he defines as *information* [134]. Using a musical analogy, Simondon likens the human mediator to a conductor synchronising a collective of objects, just as different conductors uniquely interpret the same score [134]. He aligns this openness with art, suggesting that art preserves a "pre-individual reality", a potential source that enables communication within a collective of individuals from diverse specialisations, driven by the intention to appreciate its artistic outcomes [134]. When this exchange of *information* accumulates substantially, the *transindividual* relationship emerges. The technical object acts as a material carrier of this pre-individual reality, connecting inventors, makers, and users across time and space [134]. The instrument, therefore, functions as a medium for a collective relationship, binding individuals through the shared technical reality of the object itself.

4.2 The Transindividualised Interface

Our review suggests a degree of interpretative diversity in NIME keyboard design. Generally, authors of *software* papers are naturally less likely to dictate physical layout choices compared to those of *hardware* papers; however, when they do, they are more likely to explore alternatives to the traditional piano layout, as shown in Table 5 and discussed in Section 3.2. In terms of the hardware corpus, the recurring presence of the piano-style layout remains significant. As shown in Figure 5 and discussed in Section 3.2, the piano layout often acts as the implicit default, even when the materiality of the interface does not dictate it. This is evident in devices utilising planar touch surfaces or textile-based fabric keyboards [158, 159], where the physical constraints of mechanical keys are absent, yet the traditional topography is voluntarily replicated.

From a Simondonian perspective, the piano may be viewed as a highly *concretised* technical object, one that achieved a stable synergy between its internal mechanism and the human body by the late 19th century [125, 134]. Its ease of sound production, functional versatility [99], vast repertoire [58], and its global dissemination through colonialism as a symbol of modernity [146], have all contributed to its dominance. Furthermore, in the electronic age, it remained one of the pioneer interfaces adapted for synthesis [97, 154]. These factors have accumulated a substantial amount of *information* over centuries, effectively establishing the piano as a highly *transindividualised* interface. Historically, various alternative interfaces were proposed for the piano but failed due to the resistance of the 7-plus-5 arrangement based on the C major scale, as the majority of keyboard repertoire and teaching material are firmly anchored to this layout standard [97].

In our data, this inertia is reflected in the design rationales summarised in Figure 7 and Table 6. Notably, the two explicitly piano-centric motivations (*Simulate piano experience* and *Accessibility & familiarity of piano layout*) collectively constitute the largest proportion of stated rationales in authors' user consideration. This finding aligns with the interaction patterns observed in Section 3.3, where *Key-based continuous control* represents the most prominent category among papers exploring novel interactions. The prevalence of such designs suggests that they persist because they avoid disrupting existing playing habits, allowing performers to leverage years of accumulated practice and embodied experience.

Qualitative accounts within the NIME community illustrate this reliance on established forms. For instance, the designer of the *TouchKeys* explicitly noted the value of retaining familiar playing techniques during a survey [107]. In contrast, establishing entirely novel interfaces faces significant challenges. Research on performer identity indicates that the lack of a cultural foundation, such as a shared repertoire and community, hinders the development of virtuosity [108]. Consequently, using the piano layout is a practical strategy. It enables designers to benefit from existing teaching materials and musicians' physical skills, effectively treating the interface as a *background relation* that requires relatively minimal mental effort [4]. Thus, the fact that the piano layout constitutes the majority suggests that Simondon's *transindividual* reality [134] also exists within the NIME community. This collective behaviour establishes a shared connection between makers and players through the exchange of *information*. However, exceptions such as the entirely non-piano *Song Kernel* [7] and *Sibilim* [115] still demonstrate a "margin of indeterminacy" [134]. Yet, the small proportion of these papers may imply that alternative interfaces require further exchanges of *information*, such as sustained musical practices, to become more *concretised*.

Furthermore, even among the reviewed alternative interfaces, such as isomorphic layouts, the design logic remains firmly anchored in Western harmony or equal-tempered microtonality [39, 162]. Notably, no keyboard layouts based on non-Western temperament systems, such as those from the Middle East [144], were found in our corpus. Structurally, these isomorphic layouts exhibit little evolution beyond earlier models [89, 100, 110, 121], typically offering only minor ergonomic refinements or increased customisability. Ultimately, in terms of morphological diversity, the isomorphic keyboard layouts developed within the NIME community do not appear to surpass the breadth of historical experiments from earlier eras, as documented by Moseley [109].

In addition, as illustrated in Tables 5 and 6, the taxonomy of interaction mediums exhibits a diversity that equals, if not marginally exceeds, that of key layouts. Furthermore, this exploration of keyboard interaction has revealed an unexpected cultural dimension within keyboard-based interfaces, which has previously been underexplored.

4.3 Multistability and Cultural Orientation

As discussed in Section 4.1.1, instruments possess the characteristic of *multistability*. Reviewed literature demonstrates this capacity. For instance, Lepri and colleagues repurposed a typewriter into a musical instrument [77], while Dahlstedt and colleagues utilised a digital keyboard to model extended techniques typically performed on piano strings [25]. Existing research, such as that by Morreale and colleagues [106] and McPherson and colleagues [94], argues that musical tools are not neutral and may actively shape the user's musical ideation. Notably, two recent contributions demonstrate the application of cross-cultural *multistability* to existing keyboard hardware and software. West and colleagues [157] reconfigured the traditional harmonium keyboard to enable continuous pitch bending and vibrato, subverting its discrete nature to support the continuous pitch requirements of Hindustani music. Similarly, Hirai and colleagues [59] noted a "growing interest in de-Westernized musical practices" and utilised XR to decouple the tactile surface from the visual layout, allowing a standard QWERTY keyboard to adapt to various modal preferences.

Such cross-cultural applications may reframe previous evaluations of keyboard technologies. Morreale and colleagues previously noted that the *TouchKeys* faced greater barriers to "artistic uptake" compared to the Magnetic Resonator Piano (MRP) because it lacked a "signature sound," leaving it too tethered to the functional role of a standard MIDI controller [107]. Yet, the aforementioned work by West and colleagues [157] employed the same capacitive sensing technology found in the *TouchKeys* within the context of the Hindustani harmonium. By facilitating microtonal expression in an Indian ethnomusicological setting, this application suggests that when viewed outside the Western canon, seemingly exhausted fingertip sensing technologies reveal new musical potential. This cross-cultural *multistability* [64] extends beyond the NIME community; musicians such as Allami document how local practitioners in Egypt integrate digital tools to preserve their musical heritage. As such repurposing only recently emerged in our reviewed corpus around 2025 and remains scarce, expanding these efforts within NIME could offer significant support to these practitioners.

While the instances of cross-cultural *multistability* demonstrate the value of repurposing existing instrument interfaces at the hardware and software levels, a complementary path remains unexplored. While Morreale and colleagues previously found that non-Western musical genres remain underexplored within the NIME community [108], Fasciani highlights an increasingly diverse and global community [36]. Indeed, recent years have seen a noticeable increase in NIME research emerging from non-Western contexts, including China [60, 163], Korea [102, 103], India [67, 122], Brazil [147], and the Andean region [13, 112]. Despite this diversification, a significant opportunity remains absent from the reviewed papers: NIME designers could draw foundational inspiration from non-Western music theories to develop novel keyboard interfaces.

5 Limitations

Our search strategy relied on explicit terminology associated with keyboard organology, informed by foundational literature [97, 110], as well as authorial self-identification within the reviewed papers. Consequently, interfaces that physically resemble keyboards but omit these specific terms may have been excluded during the initial keyword filtering. For example, percussion instruments like the xylophone and non-Western instruments like the Taishōgoto [80, 136] feature keyboard-like layouts but are rarely described using such terminology.

Secondly, the taxonomy and thematic analysis presented in this paper are qualitative and inductive. While we employed a rigorous coding process, the categorisation of contribution types and interaction modalities inherently involves a degree of subjective interpretation. Future studies might employ different frameworks that could yield alternative classifications.

Thirdly, this review analyses research publications rather than the instruments themselves. Our assessment of the interfaces is based on the authors' textual descriptions and claims regarding functionality and expressivity. Without physical access to the instruments, we cannot verify the actual tactile quality of the haptic feedback or the long-term viability of the proposed interaction modalities. Future studies might focus on surveying developers directly regarding their rationale for selecting specific keyboard interfaces. Furthermore, the perspectives of developers designing for non-Western musical traditions warrant deeper discussion. As evidenced by existing non-Western NIME instruments grounded in traditional instruments [13, 60], these paradigms are often inherently distinct from keyboard architectures, suggesting that the keyboard interface may not be an optimal choice for such musical contexts.

Finally, the discussion in this paper relies on two specific philosophical perspectives: postphenomenology and Simondon's technical *transindividual* process. Applying alternative theoretical lenses could yield distinct insights, such as Weber's *rationalisation* of the keyboard interface [155] or Leman's *embodied music cognition* regarding instrument interactions [22, 76].

6 Conclusion

Our review of 104 publications reveals that the definition of a keyboard within the NIME community has expanded beyond traditional lever-based mechanisms to encompass buttons and even spatial gestures. Drawing on Simondon's concepts of *concretisation* and the *transindividual*, we discussed the cultural inertia underlying the absolute dominance of Western music theory in current NIME keyboard designs. Future research could benefit from surveying developers directly to understand this persistence. Furthermore, we identified the recent emergence of cross-cultural *multistability* in NIME keyboard applications, encouraging further exploration in this area. Finally, we propose that inventing novel keyboard interfaces based on unexplored non-Western music theories remains a significant opportunity.

7 Ethical Standards

This research constitutes a systematic review of existing public literature. As such, it did not involve any human participants or animals, and no informed consent or ethical approval was required. The authors declare that there are no conflicts of interest regarding the publication of this paper. No specific funding was received for this work.

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