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Beyond the Bellows: A Critical Review of Free Reed Instrument Research, Gaps, and Future Innovations

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ABSTRACT

This paper presents a structured and technical review of free reed instrument research, focusing on four critical aspects: sound production mechanisms, structural analysis, material characterization, and vibration analysis. Through a detailed classification of over 100 studies, we identify prevailing trends, methodological approaches, and underexplored areas. A significant portion of the literature focuses on Western instruments like the accordion and harmonica, while traditional Asian instruments such as the sheng and khaen remain critically under-researched. Methodologically, the field is dominated by experimental studies and finite element modeling (FEM), with limited integration of computational advancements such as machine learning or artificial intelligence (AI). Furthermore, structural and material research often overlooks eco-friendly or sustainable alternatives, suggesting a gap in environmentally conscious design. This review advocates for a more interdisciplinary approach, combining acoustics, structural dynamics, and material science with global perspectives on lesser-known instruments. Emerging trends, such as digital augmentation and AI-driven sound optimization, present promising avenues for future exploration. Additionally, the review underscores the need for sustainable design in instrument construction, as the field remains focused on traditional materials. By identifying key gaps and proposing future directions, this review provides a roadmap for advancing research in free reed instruments through innovation, sustainability, and a more inclusive global outlook.

INTRODUCTION

Free reed instruments are a unique class of musical instruments where sound is produced by the vibration of a reed, driven by an airstream. Instruments such as the accordion, harmonica, and sheng have long held a cultural and musical significance across the globe. However, despite their diverse applications and rich history, research into their acoustic and structural properties remains highly fragmented and focused on a limited subset of instruments, predominantly those from the Western world.

The objective of this paper is to provide a structured review of existing literature on free reed instruments, with the aim of identifying key trends, gaps, and future directions in research. By organizing the literature according to research focus, instrument type, research methodology, and application area, we highlight both the depth and limitations of current studies. Furthermore, this review emphasizes the need for a more inclusive approach, drawing attention to underrepresented instruments and methodologies.

This review also incorporates four major themes that will guide the analysis: Interdisciplinary Innovation, Global Perspective, Future of Instrument Design, and Sustainability and Cultural Preservation. These themes serve to widen the lens through which free reed instrument research is currently viewed, encouraging new approaches that integrate technological advancements, cultural considerations, and eco-friendly design.

We will explore the following research questions: How balanced is current research across different instrument types, particularly between Western and non-Western instruments? What methodologies dominate the field, and are innovative approaches such as AI and machine learning underutilized? How can future research expand beyond traditional acoustic studies to embrace broader interdisciplinary and global perspectives? By addressing these questions, this paper aims to provide a roadmap for advancing the study of free reed instruments into a more comprehensive and innovative future.

MATERIALS AND METHODS

This section outlines the systematic approach used to identify, categorize, and analyze the literature on free reed instruments. The goal of this methodology is to ensure a comprehensive review that highlights key trends, gaps, and future directions in the research field.

A broad literature search was conducted using several academic databases, including Google Scholar, Research Rabbit, ResearchGate, Scopus, Zenodo, Research Square, IEEE Xplore, ScienceDirect, and PubMed. The search focused on research related to free reed instruments, with the aim of capturing a wide range of studies across acoustics, structural analysis, material science, and performance optimization. Keywords such as "free reed instruments", "accordion acoustics," "FEM modeling of free reeds," and "harmonica sound production" were used to ensure coverage of both Western and non-Western instruments.

The search was limited to peer-reviewed journal articles, conference papers, and book chapters published within

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the past three decades to ensure relevance and modern applicability. Studies focusing solely on the historical, cultural, or musical analysis without a technical or scientific component were excluded. After removing duplicates and irrelevant entries, a final dataset of 119 papers was compiled for review.

A classification framework was developed based on four key categories: research focus, instrument type, research methodology, and application area to systematically analyze the literature. Each study was reviewed and categorized according to its primary scientific or technical goals, allowing for a structured analysis that reveals trends and underexplored areas.

Research Focus

This category refers to the main scientific objective of each study (e.g., sound production mechanisms, structural analysis, etc.).

Instrument Type

Studies were categorized based on whether they focused on Western instruments (accordion, harmonica, concertina, bandoneon, …), Asian instruments (sheng, khaen, sho, …), or hybrid/modern instruments.

Research Methodology

Papers were classified based on the methods employed, such as experimental, theoretical, or computational studies.

Application Area

This refers to the practical use or goal of the research (e.g., musical performance, instrument design, pedagogy). The papers were analyzed using both qualitative and quantitative methods to identify trends and gaps. Qualitative thematic analysis was applied to organize papers based on recurring topics and themes, while quantitative analysis was used to count the distribution of studies across the four categories. This allowed for the identification of dominant trends (e.g., focus on Western instruments) and the uncovering of significant gaps (e.g., underrepresentation of interdisciplinary approaches).

The final classification and data analysis aim to provide insights into both the current state of research and opportunities for future studies, particularly in areas like interdisciplinary innovation, sustainability, and the global representation of non-Western instruments.

LITERATURE REVIEW

Literature Classification and Analysis

This section presents the classification of the 119 studies reviewed, following the methodology outlined before. The studies are grouped into four main categories: research focus, instrument type, research methodology, and application area. This structured classification allows for a clear and systematic examination of the body of research, facilitating the identification of trends, gaps, and opportunities for future work.

The literature on free reed instruments can be divided into five primary research focuses, representing the key scientific and technical goals of the studies:

- Sound Production Mechanisms
  - Studies that investigate the fundamental processes by which free reed instruments produce sound, focusing on aspects such as airflow, reed vibration, and reed-resonator interaction.
  - This research often examines how modifications to the reed or airflow affect the instrument's acoustic output, which is crucial for tuning and optimizing instrument design.
- Structural Analysis
  - Research focusing on the mechanical integrity and structural dynamics of free reed instruments. This includes studies on how materials and design affect the durability and performance of the instrument under playing conditions.
  - Key concerns include the fatigue of reeds, stress on instrument bodies, and how structural factors contribute to acoustic performance over time.
- Material Characterization
  - This category includes studies that analyze the materials used in free reed instruments, such as metal reeds, wood, plastics, and more recently, eco-friendly materials. The aim is to understand how different materials affect sound production, durability, and environmental sustainability.
  - Recent interest in sustainable and innovative materials is growing but remains underrepresented in the overall literature.
- Vibration Analysis
  - Studies that explore the vibrational behavior of reeds and their interaction with the instrument's body and resonator. These studies typically use modal analysis or vibrational modeling to understand how different frequencies and modes affect sound quality and playability.
  - Vibration analysis is crucial for improving the tonal accuracy and dynamic control of free reed instruments.
- Thermal Effects
  - A less commonly studied area, thermal effects research examines how environmental conditions such as temperature and humidity impact the performance and longevity of free reed instruments.
  - These studies are vital for understanding how instruments behave in different climates, particularly for performers who travel or play in varying conditions.
- Other

The studies reviewed are grouped based on the type of free reed instrument they focus on. This allows for an understanding of which instruments have received the most research attention and which remain underexplored.

- Western Instruments
  - This group includes instruments such as the accordion, harmonica, concertina, bandoneon and reed organ. Western instruments dominate the literature, with the accordion and harmonica receiving the most attention in terms of both acoustic and structural studies.

• Asian Instruments

○ Asian free reed instruments, such as the sheng, khaen, and sho, are significantly less represented in the literature compared to their Western counterparts. These instruments have unique construction and acoustic properties that are underexplored, particularly in terms of sound production and material characterization.

• Hybrid or Other Instruments

○ This category includes modern or experimental instruments that blend traditional free reed mechanisms with electronic augmentation or other innovations. Hybrid instruments represent an emerging area of research, particularly in terms of digital sound production and electronic control mechanisms.

• Other

The research methodology employed in the reviewed studies is a key classification that highlights how the instruments are studied. We categorize the methodologies into three primary types:

• Experimental Studies

○ Studies based on empirical data collection, where the behavior of the instruments is measured under controlled conditions. This includes physical measurements of sound, airflow, and vibration using various tools such as laser vibrometers, acoustic chambers, and wind tunnels.

○ Experimental studies are vital for validating theoretical models and providing concrete data on instrument performance.

• Theoretical Studies

○ These studies develop and apply mathematical or physical models to predict the behavior of free reed instruments. Theoretical studies often involve modeling the interaction between the reed and the airflow or resonator without experimental verification, though they provide crucial insights into the physical principles that govern instrument operation.

• Computational Studies

○ Computational methods, such as finite element modeling (FEM) and computational fluid dynamics (CFD), are used to simulate the behavior of free reed instruments. These studies offer detailed predictions of how instruments will perform under different conditions and are often used to optimize instrument design before physical prototypes are built.

○ Although growing in popularity, computational studies are still underutilized in areas like AI-driven sound optimization, presenting opportunities for future research.

• Other

This classification focuses on the practical applications of the research, identifying the intended outcomes or uses of the studies:

• Musical Performance

○ Research that focuses on how free reed instruments perform in real-world musical contexts, including studies on tuning, dynamics, sound control, and how various design factors affect the experience of both performers and listeners.

○ Studies often examine how modifications to the instrument (e.g., changes in reed design or resonator shape) improve the control over tonal quality and volume during live performances.

• Instrument Design

○ This sub-area covers research aimed at improving the physical construction of free reed instruments, focusing on factors like durability, ease of manufacturing, and optimizing acoustic performance. Many of these studies investigate new materials or design techniques to enhance sound production or structural integrity.

○ Sustainable instrument design is an emerging trend, with researchers exploring eco-friendly materials and methods to reduce the environmental impact of instrument manufacturing.

• Education and Pedagogy

○ Studies that explore the role of free reed instruments in music education, focusing on teaching methodologies, curriculum development, and the cultural transmission of musical knowledge.

○ While relatively underexplored, particularly in non-Western contexts, this area presents opportunities for future research to better integrate free reed instruments into formal music education.

• Other

Detailed Literature Classification Table

This part of the paper provides a comprehensive overview of the 119 reviewed studies, classified according to the established categories: Research Focus, Instrument Type, Research Methodology, and Application Area. The purpose of this table is to offer readers a quick reference guide to see how each paper fits within the broader landscape of free reed instrument research, and to support the identified key trends.

The table is structured as follow:

• Reference: This column lists each reviewed paper in standard APA format, providing clear references for readers to locate the original work.

• Year of Publication: This column provides the year in which the paper was published. Clearly, this represents a later point in time respect to when the research has been effectively carried out

• Research Focus: each paper is categorized based on its primary scientific or technical objective, following the five research focuses before defined: Sound Production Mechanisms, Structural Analysis, Material Characterization, Vibration Analysis, and Thermal Effects.

• Instrument Type: This column identifies which type of instrument the study focuses on. Instruments are categorized into three groups: Western Instruments (e.g., accordion, harmonica), Asian Instruments (e.g., sheng, khaen, sho), and Hybrid or Other Instruments (e.g., modern instruments incorporating digital elements).

• Research Methodology: This column classifies the research methodology employed in each study, distinguishing between Experimental, Theoretical, and Computational approaches.

• Application Area: Finally, the application area specifies the practical outcomes or focus of the research, such as Musical Performance, Instrument Design, or Education and Pedagogy.

Table 1: Categorization of Research Papers Based on Research Focus, Instrument Type, Research Methodology, and Application Area

Number	Reference	Year of publication	Research Focus	Instrument Type	Research Methodology	Application Area
1	(Asiedu *et al.*, 2024)	2024	Other	Other	Other	Other
2	(Bader *et al.*, 2019)	2019	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
3	(Behrens *et al.*, 2009)	2009	Vibration Analysis	Western Instruments	Computational Studies	Musical Performance
4	(Biernat *et al.*, 2013)	2013	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
5	(Bivanti *et al.*, 2020)	2020	Material Characterization	Other	Theoretical Studies	Other
6	(Brock *et al.*, 2011)	2011	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
7	(Busha & Cottingham, 1999)	1999	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
8	(Busha *et al.*, 2002)	2002	Vibration Analysis	Hybrid or Other Instruments	Experimental Studies	Instrument Design
9	(Calleri *et al.*, 2019)	2019	Material Characterization	Other	Experimental Studies	Other
10	(Carini *et al.*, 2023)	2023	Structural Analysis	Western Instruments	Other	Instrument Design
11	(Causse *et al.*, 1999)	1999	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
12	(Chiaia *et al.*, 2013)	2013	Material Characterization	Other	Theoretical Studies	Other
13	(Chiovarelli, 2021)	2021	Sound Production Mechanisms	Western Instruments	Other	Instrument Design
14	(Cottingham, 1993)	1993	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
15	(Cottingham, 1994)	1994	Sound Production Mechanisms	Western Instruments	Experimental Studies	Musical Performance
16	(Cottingham, 1996a)	1996	Structural Analysis	Western Instruments	Experimental Studies	Instrument Design
17	(Cottingham, 1996b)	1996	Structural Analysis	Western Instruments	Experimental Studies	Instrument Design
18	(Cottingham, 1997)	1997	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
19	(Cottingham *et al.*, 1998)	1998	Sound Production Mechanisms	Western Instruments	Theoretical Studies	Instrument Design

20	(Cottingham *et al.*, 1999)	1999	Structural Analysis	Western Instruments	Experimental Studies	Instrument Design
21	(Cottingham, 2000a)	2000	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
22	(Cottingham *et al.*, 2000b)	2000	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
23	(Cottingham, 2002a)	2002	Other	Western Instruments	Other	Other
24	(Cottingham, 2002b)	2002	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
25	(Cottingham, 2003)	2003	Other	Western Instruments	Other	Other
26	(Cottingham, 2004a)	2004	Structural Analysis	Western Instruments	Experimental Studies	Instrument Design
27	(Cottingham, 2004b)	2004	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
28	(Cottingham, 2005)	2005	Vibration Analysis	Western Instruments	Theoretical Studies	Instrument Design
29	(Cottingham, 2006)	2006	Sound Production Mechanisms	Hybrid or Other Instruments	Experimental Studies	Instrument Design
30	(Cottingham, 2008)	2008	Other	Asian Instruments	Other	Other
31	(Cottingham, 2009)	2009	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
32	(Cottingham, 2010a)	2010	Other	Asian Instruments	Other	Other
33	(Cottingham, 2010b)	2010	Structural Analysis	Asian Instruments	Experimental Studies	Instrument Design
34	(Cottingham, 2010c)	2010	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
35	(Cottingham, 2011a)	2011	Material Characterization	Asian Instruments	Experimental Studies	Instrument Design
36	(Cottingham, 2011b)	2011	Sound Production Mechanisms	Hybrid or Other Instruments	Theoretical Studies	Instrument Design
37	(Cottingham, 2012a)	2012	Sound Production Mechanisms	Western Instruments	Experimental Studies	Musical Performance
38	(Cottingham, 2012b)	2012	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
39	(Cottingham, 2012c)	2012	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
40	(Cottingham, 2013)	2013	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
41	(Cottingham, 2014a)	2014	Material Characterization	Asian Instruments	Experimental Studies	Instrument Design

42	(Cottingham, 2014b)	2014	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
43	(Cottingham, 2014c)	2014	Other	Western Instruments	Theoretical Studies	Other
44	(Cottingham, 2015a)	2015	Other	Western Instruments	Theoretical Studies	Other
45	(Cottingham, 2015b)	2015	Other	Asian Instruments	Theoretical Studies	Musical Performance
46	(Cottingham, 2016)	2016	Sound Production Mechanisms	Hybrid or Other Instruments	Theoretical Studies	Other
47	(Cottingham, 2017a)	2017	Other	Western Instruments	Theoretical Studies	Education and Pedagogy
48	(Cottingham, 2017b)	2017	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
49	(Cottingham, 2018)	2018	Other	Other	Other	Other
50	(Cottingham, 2019a)	2019	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
51	(Cottingham, 2019b)	2019	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
52	(Cottingham *et al.*, 1995)	1995	Sound Production Mechanisms	Western Instruments	Experimental Studies	Musical Performance
53	(Cottingham *et al.*, 2008)	2008	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
54	(Cottingham *et al.*, 1997)	1997	Vibration Analysis	Western Instruments	Theoretical Studies	Instrument Design
55	(Cottingham *et al.*, 1992)	1992	Sound Production Mechanisms	Western Instruments	Experimental Studies	Other
56	(Cottingham *et al.*, 1999a)	1999	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
57	(Cottingham *et al.*, 1999b)	1999	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
58	(Cottingham *et al.*, 1991)	1991	Sound Production Mechanisms	Western Instruments	Theoretical Studies	Other
59	(Cottingham *et al.*, 2007)	2007	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
60	(Cottingham *et al.*, 2010)	2010	Vibration Analysis	Asian Instruments	Experimental Studies	Instrument Design
61	(Coyle *et al.*, 2009)	2009	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
62	(Dena *et al.*, 2023)	2023	Other	Other	Other	Other
63	(Dieckman *et al.*, 2006a)	2006	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design

64	(Dieckman *et al.*, 2006b)	2006	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
65	(Dirksen *et al.*, 2002)	2002	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
66	(Drown *et al.*, 2018)	2018	Sound Production Mechanisms	Western Instruments	Experimental Studies	Musical Performance
67	(Dunkel, 1999)	1999	Other	Western Instruments	Other	Other
68	(Faaborg *et al.*, 2011)	2011	Vibration Analysis	Asian Instruments	Experimental Studies	Instrument Design
69	(Fetzer *et al.*, 1999)	1999	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
70	(Fetzer *et al.*, 1997)	1997	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
71	(Franta *et al.*, 2006)	2006	Structural Analysis	Western Instruments	Experimental Studies	Instrument Design
72	(Gaylord, 1989)	1989	Vibration Analysis	Western Instruments	Other	Other
73	(Goetzman *et al.*, 2004)	2004	Sound Production Mechanisms	Hybrid or Other Instruments	Experimental Studies	Instrument Design
74	(Goodweiler *et al.*, 2009)	2009	Sound Production Mechanisms	Other	Experimental Studies	Instrument Design
75	(Gorino *et al.*, 2016)	2016	Material Characterization	Other	Experimental Studies	Other
76	(Gorino *et al.*, 2018)	2018	Material Characterization	Other	Experimental Studies	Other
77	(Hassard *et al.*, 2020)	2020	Vibration Analysis	Asian Instruments	Computational Studies	Instrument Design
78	(Henessee *et al.*, 2014)	2014	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
79	(Hershey *et al.*, 2011)	2011	Material Characterization	Asian Instruments	Experimental Studies	Instrument Design
80	(Hoover *et al.*, 2001)	2001	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
81	(Huber *et al.*, 2003)	2003	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
82	(Jensen *et al.*, 2003)	2003	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
83	(Kaufinger *et al.*, 2021)	2021	Vibration Analysis	Western Instruments	Computational Studies	Instrument Design
84	(Kirk *et al.*, 2016)	2016	Vibration Analysis	Asian Instruments	Experimental Studies	Instrument Design
85	(Koopman *et al.*, 1996a)	1996	Material Characterization	Western Instruments	Experimental Studies	Instrument Design

86	(Koopman *et al.*, 1996b)	1996	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
87	(Kottke *et al.*, 1994)	1994	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
88	(Krishnamurthy *et al.*, 2007)	2007	Sound Production Mechanisms	Other	Experimental Studies	Other
89	(Krishnamurthy *et al.*, 2008)	2008	Other	Other	Experimental Studies	Other
90	(LeDuc *et al.*, 2015)	2015	Sound Production Mechanisms	Asian Instruments	Experimental Studies	Instrument Design
91	(Llanos-Vazquez *et al.*, 2008)	2008	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
92	(Llanos-Vazquez *et al.*, 2014)	2014	Sound Production Mechanisms	Western Instruments	Experimental Studies	Musical Performance
93	(Manfredi, 2022)	2022	Other	Western Instruments	Computational Studies	Instrument Design
94	(Marano, 2020)	2020	Other	Western Instruments	Other	Instrument Design
95	(Martin *et al.*, 2019a)	2019	Vibration Analysis	Asian Instruments	Computational Studies	Instrument Design
96	(Martin *et al.*, 2019b)	2019	Vibration Analysis	Asian Instruments	Experimental Studies	Instrument Design
97	(Miklós *et al.*, 2003)	2003	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
98	(Millot *et al.*, 2007)	2007	Sound Production Mechanisms	Hybrid or Other Instruments	Theoretical Studies	Instrument Design
99	(Misdariis *et al.*, 2000)	2000	Sound Production Mechanisms	Western Instruments	Theoretical Studies	Instrument Design
100	(Munoz *et al.*, 2022)	2022	Other	Western Instruments	Other	Instrument Design
101	(Paquette *et al.*, 2003)	2003	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
102	(Plitnik *et al.*, 2009)	2009	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
103	(Puranik *et al.*, 2022)	2022	Sound Production Mechanisms	Western Instruments	Computational Studies	Instrument Design
104	(Ricot *et al.*, 2005)	2005	Sound Production Mechanisms	Western Instruments	Theoretical Studies	Instrument Design
105	(Rossing *et al.*, 2010)	2010	Other	Western Instruments	Other	Other
106	(Scott *et al.*, 2014)	2014	Other	Western Instruments	Experimental Studies	Musical Performance
107	(Shaw *et al.*, 2019)	2019	Sound Production Mechanisms	Hybrid or Other Instruments	Experimental Studies	Instrument Design

108	(Shtrepi *et al.*, 2020)	2020	Material Characterization	Other	Experimental Studies	Other
109	(Shtrepi *et al.*, 2021)	2021	Material Characterization	Other	Experimental Studies	Other
110	(Signorini, 2006)	2006	Other	Western Instruments	Other	Education and Pedagogy
111	(Silva, 2008)	2008	Sound Production Mechanisms	Other	Computational Studies	Other
112	(St.hilaire *et al.*, 1971)	1971	Sound Production Mechanisms	Western Instruments	Theoretical Studies	Instrument Design
113	(Toussaint *et al.*, 2007)	2007	Vibration Analysis	Western Instruments	Experimental Studies	Instrument Design
114	(Vines *et al.*, 2003)	2003	Sound Production Mechanisms	Western Instruments	Experimental Studies	Instrument Design
115	(Volpatti, 2025)	2025	Material Characterization	Western Instruments	Theoretical Studies	Instrument Design
116	(Wenzel *et al.*, 2006)	2006	Other	Western Instruments	Other	Education and Pedagogy
117	(Wheeler, 2009)	2009	Other	Western Instruments	Other	Education and Pedagogy
118	(Wilson *et al.*, 2009)	2009	Material Characterization	Western Instruments	Experimental Studies	Instrument Design
119	(Wolff *et al.*, 2014)	2014	Vibration Analysis	Western Instruments	Experimental Studies	Musical Performance

RESULTS AND DISCUSSION

This section presents the key findings derived from the classification of the 119 studies reviewed. The trends and gaps in the literature are analyzed based on the four categories introduced in the last section of the present wprk: research focus, instrument type, research methodology, and application area. The goal of this section is to provide a clear overview of where the current research efforts are concentrated and where notable gaps exist.

The distribution of references analyzed shows a clear growth in publications over time. From a modest number of papers published before 1990, there is a noticeable rise in the 1990s, reflecting increased academic interest. The peak periods are between 2000 and 2019, with around 40 publications in each decade, indicating that this topic gained widespread attention and became a focal area of research. However, post-2020, there is a decline, possibly due to the ongoing nature of recent research or a shift in focus within the field. Overall, the data highlights the steady growth of scholarly contributions, particularly in the last two decades.

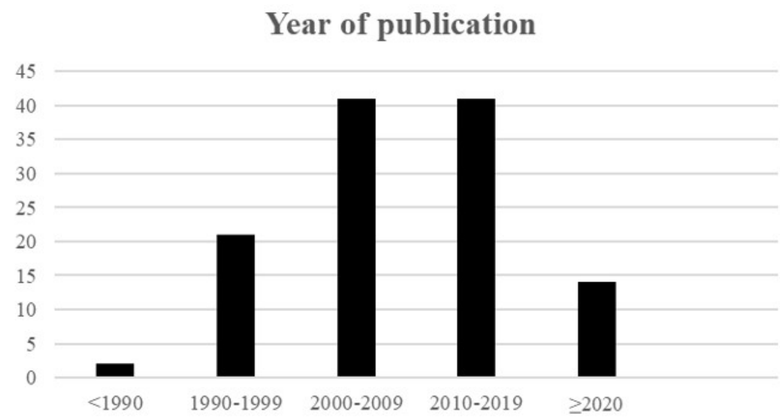


Figure 1: Year of publication – distribution of the references

The categorization of studies by research focus reveals a strong emphasis on certain technical aspects of free reed instruments, while other areas remain underexplored:

• Dominance of Sound Production Mechanisms and Vibration Analysis

○ Over 40% (48 out of 119) of the reviewed studies focus on understanding how free reed instruments produce sound and over 25% (30 out of 119) how things vibrates in free reed instruments. This research is concentrated on airflow dynamics, reed vibration, and interactions between the reed and resonator, especially for Western instruments like the accordion and harmonica.

○ This trend highlights the centrality of sound optimization in free reed instrument research, but also suggests a heavy focus on a relatively narrow aspect of these instruments.

• Underrepresentation of Structural and Thermal Studies

○ Studies focusing on the structural integrity (7 out of 119) and thermal effects (0 out of 119) of free reed instruments represent less than 10% of the reviewed literature. Research into how environmental factors like humidity and temperature affect instrument performance is notably lacking, despite its practical importance for performers.

○ This presents a clear opportunity for future research, particularly in the context of improving the durability and reliability of instruments across varied climates.

• Material Characterization and Sustainability

○ There is a portion of around 11% of papers (13 out of 119) interested in exploring how different materials affect sound production and durability, but the investigation into sustainable materials remains scarce. Only a handful of studies consider eco-friendly alternatives to traditional materials, suggesting a significant gap in research.

○ This trend points toward the potential for future work to focus on sustainable instrument design, aligning with broader environmental concerns in manufacturing.

• Other: Around 18% of the references (21 out of 119) could not clearly be classified. This percentage is relatively low, showing a good selection of the proposed categorization.

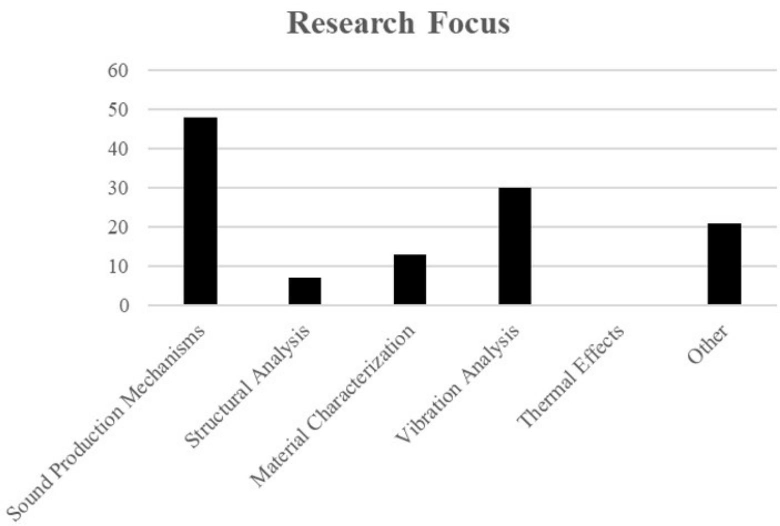


Figure 2: Research focus – distribution of the references

The distribution of studies across different instrument types reveals a clear bias towards Western instruments, with non-Western instruments receiving comparatively little attention:

• Overrepresentation of Western Instruments

○ Western instruments, particularly the accordion and harmonica, dominate the literature. Over 60% of the reviewed studies (73 out of 119) focus on these instruments, particularly in areas of sound production and material analysis.

○ This suggests that Western instruments have been prioritized for both historical and technological reasons, leaving other types of free reed instruments under-researched.

• Underrepresentation of Asian Instruments

○ Around 21% of studies (25 out of 119) focus on Asian instruments such as the sheng, khaen, and sho. These instruments have unique acoustical and structural properties that are poorly understood compared to their Western counterparts.

○ This disparity highlights a clear gap in the global perspective of free reed instrument research, calling for greater focus on culturally and structurally diverse instruments.

• Emerging Interest in Hybrid Instruments

○ Hybrid instruments, which combine traditional free reed mechanisms with digital or electronic elements, represent an emerging area of interest. However, these studies are still in their infancy, with around 6% of the literature (7 out of 119) focusing on this category.

○ As digital augmentation becomes more prevalent in musical performance, this area is expected to grow, offering new possibilities for instrument design and sound control.

• Other: around 12% of the references (14 out of 119) could not clearly be classified. This percentage is relatively low, showing a good selection of the proposed categorization.

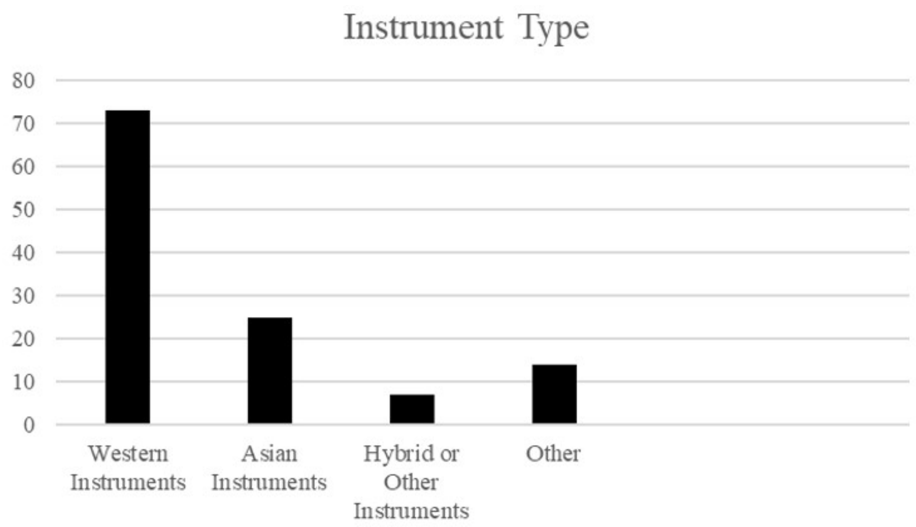


Figure 3: Instrument type – distribution of the references

The research methodologies employed in free reed instrument studies show a strong reliance on experimental approaches, with computational and interdisciplinary methods still underdeveloped:

• Dominance of Experimental Studies: Around 66% of the reviewed literature (78 out of 119) involves experimental studies, where the physical properties of instruments are measured and analyzed in controlled environments. This methodology is crucial for validating theories but may be limited in scope when it comes to predicting the complex behaviors of these instruments in real-world settings.

• Underutilization of Computational Methods and Theoretical Studies

○ Computational studies, including finite element modeling (FEM) and computational fluid dynamics (CFD), make up around 6% (7 out of 119) of the literature. While these techniques offer powerful predictive tools, their potential remains underutilized, particularly in areas like AI-driven sound optimization and material simulation.

○ There is a clear opportunity for computational methods to be expanded, especially as machine learning and AI become more integrated into acoustic research.

○ Theoretical Studies, while being more presents respect to computational studies, represent only around 14% of the analyzed studies (17 out of 119).

• Other: Around 21% of the references (25 out of 119) could not clearly be classified. This percentage is relatively low, showing a good selection of the proposed categorization.

• Lack of Interdisciplinary Approaches

○ A small amount of the studies adopt an interdisciplinary approach, integrating insights from fields like cultural studies, materials science, or digital technology. Most studies remain focused on traditional acoustic or structural analysis, limiting the scope of innovation.

○ Future research could benefit from a more interdisciplinary perspective, particularly when it comes to understanding the cultural significance and potential technological enhancements of free reed instruments.

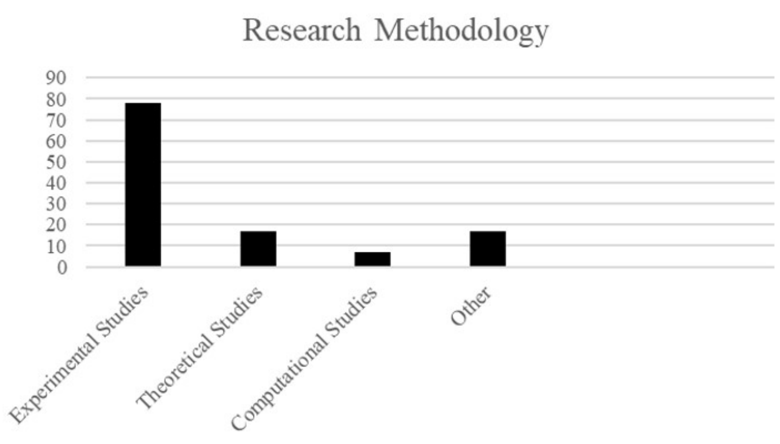


Figure 4: Research Methodology – distribution of the references

The practical applications of the research are similarly concentrated in specific areas, with some notable gaps:

• Focus on Musical Performance and Instrument Design

○ Studies related to design dominate the literature, comprising over 68% of the reviewed studies (81 out of 119). These papers focus on optimizing instrument performance for players, improving sound quality, and refining instrument construction for durability and comfort.

○ The studies that focus on the musical performance, while being indirectly also covered by the optimized instrument design, represent only around 8% of the consulted literature (9 out of 119).

○ This emphasis reflects the practical concerns of both musicians and instrument makers, particularly in Western contexts.

• Limited Research in Education and Pedagogy

○ Around 3% of the reviewed studies (4 put of 119) focus on education and pedagogy, with even fewer studies addressing the role of free reed instruments in non-Western educational systems. This represents a missed opportunity for integrating these instruments into broader musical curricula.

○ There is potential for expanding research in this area, particularly to promote free reed instruments as a key part of music education across cultural boundaries.

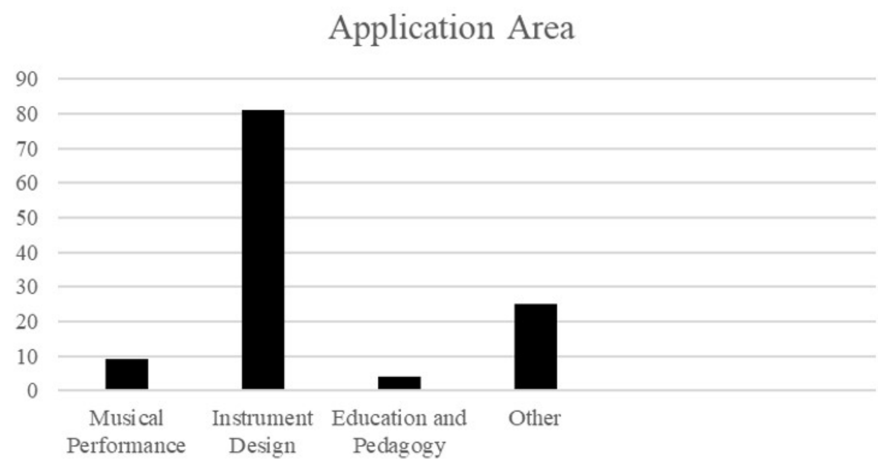
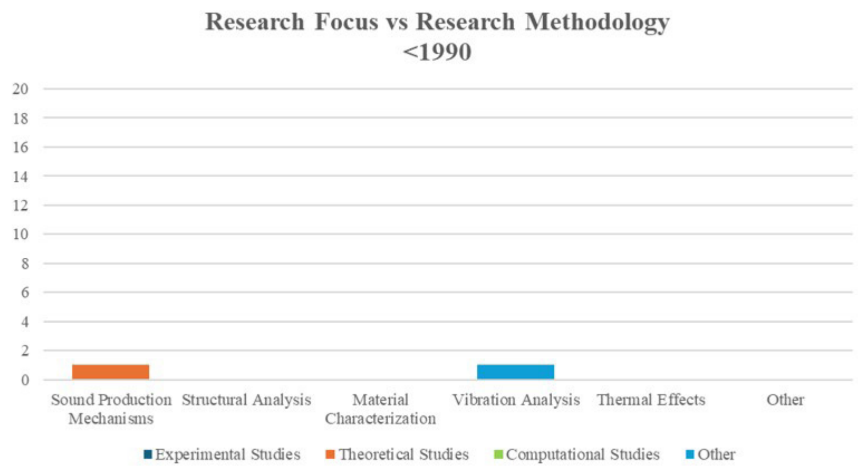


Figure 5: Application Area – distribution of the references

The mixed analysis of research focus and methodology over time is crucial for understanding the evolving technical direction in a given field. By examining how research topics and approaches change across different time frames, we can gain insights into emerging trends, shifts in priorities, and the development of new techniques. This helps to map the trajectory of scientific inquiry, revealing not only what has been explored but also highlighting areas where future research may be directed. Tracking the alignment between focus areas and methodologies provides a comprehensive view of the progression of knowledge and technical advancements.



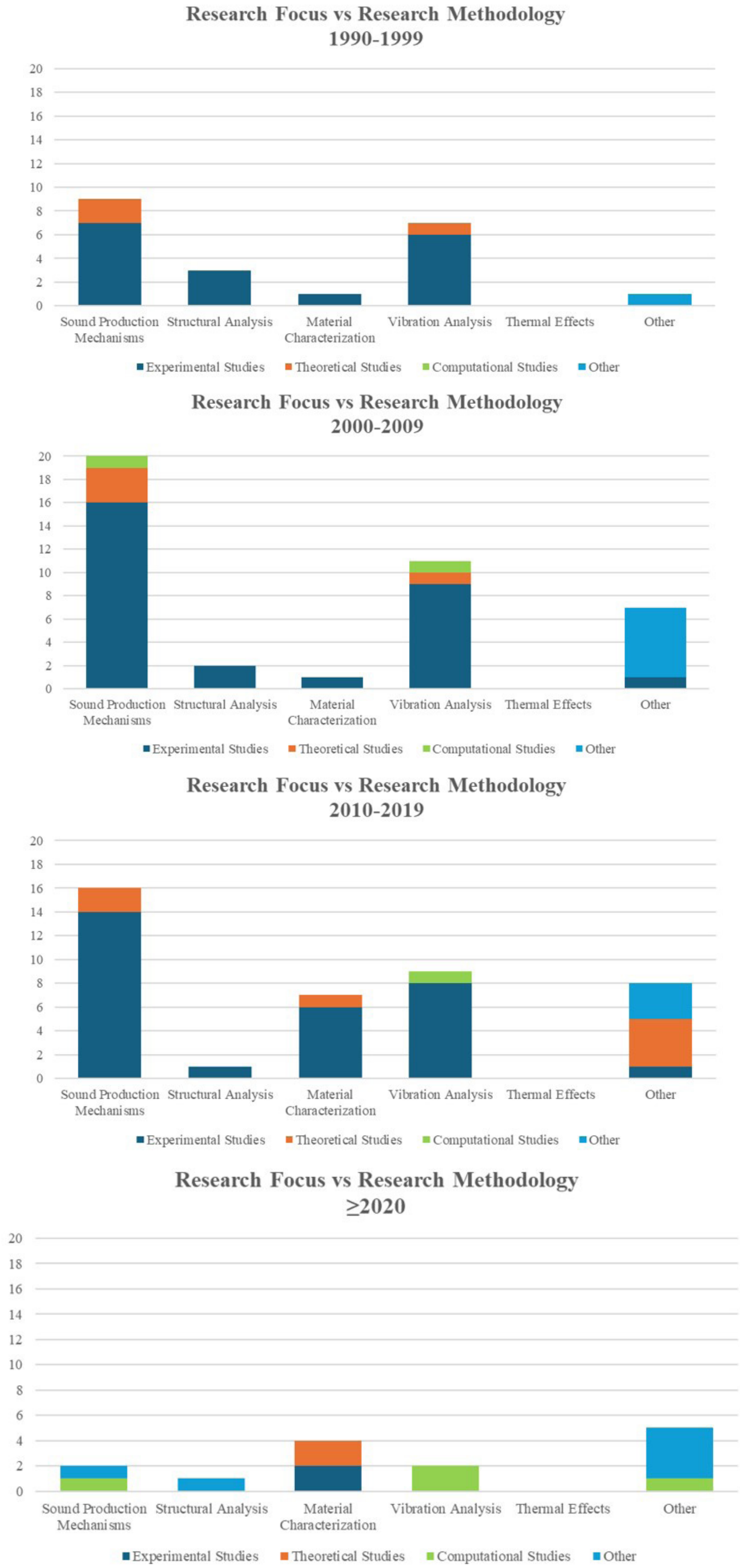
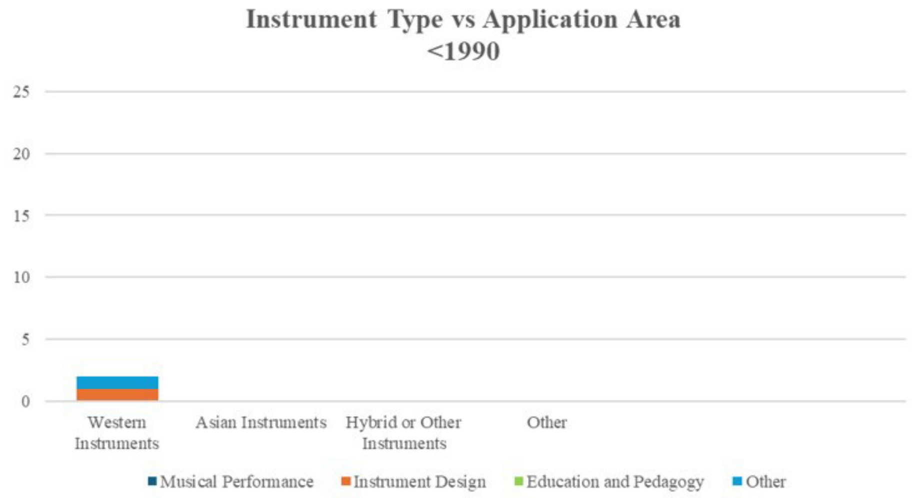
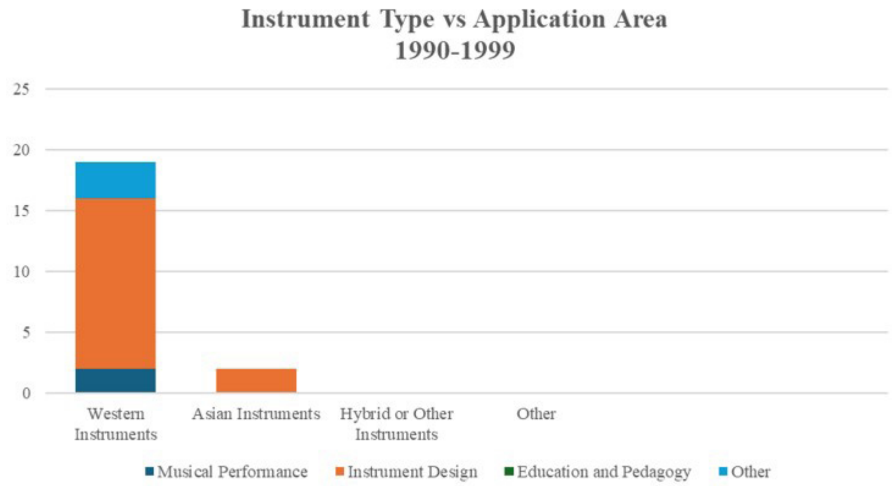
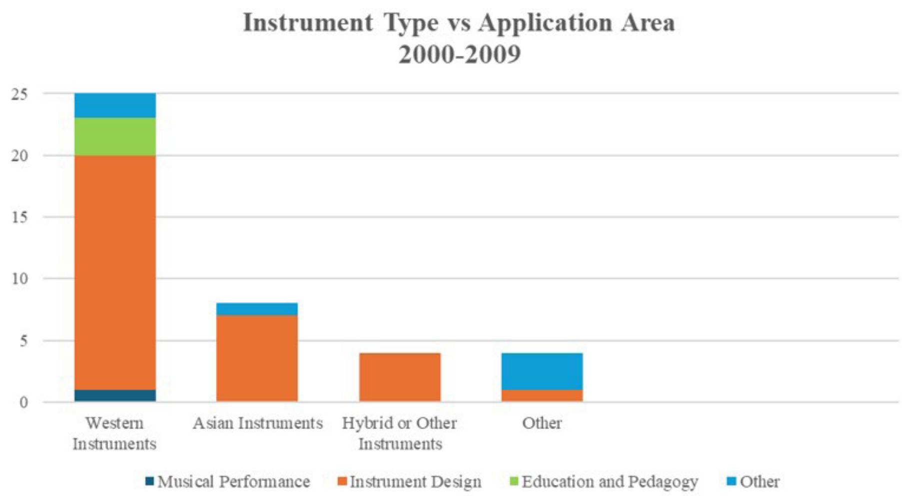


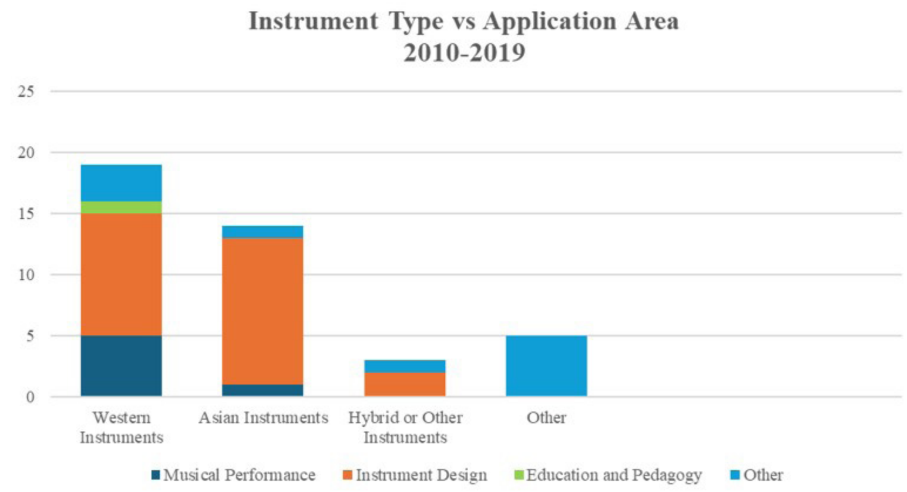
Figure 6: Research focus vs Research Methodology – distribution of the references over decades

Analyzing the relationship between instrument type and application area over time offers valuable insights into how specific instruments are utilized in different fields. This exploration helps to identify trends in the practical applications of various instruments, showing how their use has evolved to meet changing needs in areas such as musical performance, education, and instrument design. Understanding this progression not only highlights the versatility of different instruments but also provides a basis for predicting future innovations and applications in the field.









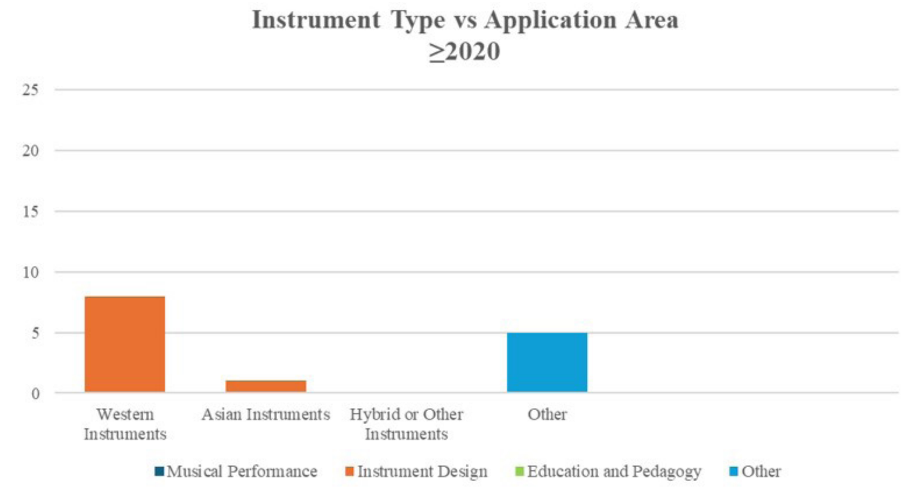


Figure 7: Instrument Type vs Application Area – distribution of the references over decades

Discussion

This section critically examines the trends identified in the literature classification, highlighting both strengths and gaps in free reed instrument research. The discussion also connects these findings to the four key themes—Interdisciplinary Innovation, Global Perspective, Future of Instrument Design, and Sustainability and Cultural Preservation—offering a roadmap for advancing the field.

The literature review reveals a clear dominance of studies focusing on sound production mechanisms, particularly for Western instruments like the accordion and harmonica. While these studies provide valuable insights into the acoustics and performance of these instruments, the heavy concentration on a narrow aspect of free reed instrument research limits the field's growth.

- Interdisciplinary Innovation
  - The sound production studies, while thorough in traditional acoustic and engineering approaches, often lack interdisciplinary integration. There is room to combine sound production research with computational modeling techniques such as FEM-based or AI-based sound optimization or with material science to explore innovative reed materials.
  - Furthermore, integrating cultural studies with acoustical research can offer insights into how cultural practices shape the design and playing techniques of free reed instruments, offering a more holistic understanding.
- Global Perspective: The overwhelming focus on Western instruments suggests a need for a more inclusive, global perspective. Asian instruments like the sheng and khaen, which have unique construction and sound production mechanisms, are vastly underexplored. Broadening the research focus to include non-Western instruments could uncover new acoustical insights and expand the understanding of free reed acoustics across different cultural contexts.

Only a small percentage of studies focus on structural analysis or the thermal effects of free reed instruments. These areas are critical for understanding how instruments perform and endure under real-world playing conditions, especially in diverse climates and environmental conditions.

- Future of Instrument Design: Structural and thermal studies are essential for advancing instrument design, particularly when it comes to improving the durability and reliability of free reed instruments in different performance environments. Instruments such as the harmonica and accordion often undergo intense use, and their structural integrity is crucial for professional players. There is a significant opportunity to develop durable designs that better withstand environmental stressors like humidity, temperature changes, and physical wear.

• Sustainability: The lack of research into sustainable materials in structural analysis presents a missed opportunity. As the world increasingly emphasizes eco-friendly practices, free reed instrument makers could benefit from adopting sustainable materials and processes in their designs. Research into bamboo reeds, recycled metals, or innovative synthetic materials could not only improve the environmental footprint of instrument production but also enhance sound quality and longevity.

The stark imbalance between Western and non-Western instruments in the literature highlights a significant gap in the global scope of free reed instrument research. Instruments such as the sheng, khaen, and sho—important to various Asian musical traditions—remain largely unexplored in scientific studies, particularly in terms of their unique acoustics and structural designs.

• Global Perspective

○ Expanding research to include non-Western free reed instruments is critical for creating a global understanding of the acoustics and construction of these instruments. These instruments offer different reed-resonator interactions and construction materials, which could provide new avenues for acoustical research and instrument design.

○ Additionally, studying non-Western instruments can help preserve cultural heritage, contributing to a cultural preservation agenda that is currently underrepresented in the literature.

• Interdisciplinary Innovation

○ There is significant potential for interdisciplinary research on non-Western instruments. For example, combining ethnomusicology with acoustics could lead to a deeper understanding of the cultural significance of these instruments and how their design and acoustics are influenced by regional musical traditions.

While experimental studies dominate the field, computational methods (such as FEM and CFD) and interdisciplinary research are still underutilized. This is a missed opportunity, given the potential of computational tools to simulate complex reed behaviors and optimize instrument design before physical prototypes are built.

• Interdisciplinary Innovation

○ Expanding the use of computational methods, particularly FEM analysis, AI-driven sound modeling and machine learning, could revolutionize free reed instrument research. These tools can be used to predict how design changes affect sound production, enabling more precise tuning and optimization of instruments. Furthermore, combining computational methods with materials science could help identify new materials that optimize both sound quality and durability.

○ Interdisciplinary collaboration between acousticians, material scientists, engineers, and cultural scholars would also broaden the research scope, creating a more comprehensive understanding of free reed instruments from both a technical and cultural perspective.

Only a small portion of the reviewed studies focus on education and pedagogy, highlighting the lack of research on teaching and learning methods for free reed instruments. This is particularly evident for non-Western instruments, which are often excluded from formal music education curricula.

• Global Perspective and Cultural Preservation: Expanding research in this area could help integrate free reed instruments into music education across different cultural contexts. Incorporating instruments like the sheng or khaen into school programs could help preserve these traditions while introducing new generations of musicians to diverse musical practices.

• Future of Instrument Design: Research on pedagogy could also inform instrument design, particularly for beginner instruments. Understanding how students interact with free reed instruments can lead to innovations in design that make the instruments easier to learn and play.

Sustainability has emerged as a key concern across various industries, but it remains largely underrepresented in free reed instrument research. Only a small number of studies explore the potential for using eco-friendly materials or sustainable manufacturing processes.

• Sustainability and Cultural Preservation: Embracing sustainability in instrument design is not only a response to environmental concerns but also a way to preserve traditional crafting methods that use natural materials. Future research should focus on developing eco-friendly alternatives to traditional materials (e.g., plastic reeds) and explore the use of bamboo, recycled metals, and other sustainable resources.

• Future of Instrument Design: Incorporating sustainable practices into instrument manufacturing could drive innovation, leading to instruments that are both environmentally friendly and acoustically superior. This also ties into the growing consumer demand for eco-conscious products, which could open new markets for sustainable free reed instruments.

CONCLUSION

This literature review on free reed instruments highlights trends, gaps, and future research opportunities. Current studies are heavily focused on Western instruments, particularly sound production mechanisms, with experimental methodologies dominating. Non-Western instruments, interdisciplinary methods, and sustainable design considerations remain underexplored.

The review categorized 119 studies across four dimensions: research focus, instrument type, methodology, and application area. Key findings include:

• Sound production is the primary focus, especially on airflow dynamics and reed vibration.

• Western instruments like accordion and organ are overrepresented, while Asian instruments like the sheng and khaen are understudied.

• Experimental approaches are prevalent, while computational and interdisciplinary methods show potential for growth.

• Sustainability is rarely addressed, particularly in material selection and environmental impact.

This review highlights key directions for future research, stressing the importance of interdisciplinary innovation, global representation, and sustainable design. While expanding research on non-Western instruments is essential, Western instruments continue to play a critical role in fostering innovation. Recommended areas include incorporating computational and interdisciplinary methods, prioritizing sustainable materials, and enhancing educational research for both Western and non-Western music traditions. This comprehensive, inclusive approach can deepen scientific understanding, support cultural preservation, and promote sustainable development in the field of free reed instrument research.

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