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Audio's Impact on Immersive Experience in Extended Reality and Digital Games: A Systematic Review

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Extended reality and digital games strive to deliver a high level of "immersion," a complex phenomenon influenced by both perceptual and psychological factors. Audio plays a crucial role in shaping immersive experiences, yet there is no clear consensus on its impact or on the best methods to evaluate it. This paper presents a systematic literature review spanning two decades, outlining the methods and findings related to how audio influences immersion in extended reality and digital games. It reveals a strong preference for experiments using virtual reality headsets and headphones and notes a gap in research on augmented and mixed reality environments. Moreover, it underscores the need for audio-specific metrics to better assess the ways that audio variables impact immersion. The findings demonstrate that audio elements like spatial fidelity, music, and the integration of sound in multimodal environments generally contribute to the immersive experience but also highlight a threshold beyond which further enhancements may not perceptibly improve the experience. It emphasizes the need for real-time, objective measures of immersion as well as the consideration of diverse methodological approaches to deepen the understanding of audio's role in immersive technologies.

0 INTRODUCTION

The concept of immersion is a central topic in extended reality (XR), video gaming, and audio technology sectors. Despite its widespread use, there remains a lack of clarity on its precise definition and the methodologies for its assessment [1, 2], including the role of auditory elements in contributing to this experience [3, 4]. The term's meaning is somewhat elusive due its frequent use in marketing to promote various new technologies, leading to its confusion with similar academic terms like "presence." Clarifying the distinctions made in academic circles, [5] points out that "presence" and "immersion" are sometimes used synonymously, although distinctions are made by several studies [e.g., 6–9]. Immersion is viewed by some researchers as a precursor to presence [e.g., 7, 10–13], whereas others propose it as a more encompassing concept [e.g., 14–16].

This ongoing debate over the meaning of immersion has resulted in a range of contrasting perspectives within human-computer interaction research, particularly in how immersion is quantified as a component of user engagement [1]. In the realm of human-computer interaction, XR and video games are frequently at the forefront of discussions on immersion as a critical objective of their output. This is because of their association with entertainment, where delivering an engaging experience is a pivotal aim [17]. These technologies are part of a broader group known as interactive virtual environments (IVEs), which are distinct from noninteractive settings due to their incorporation of user reactions in real time [18]. For instance, in the audio dimension, this might involve a sound that alters in response to a user's action within a game.

Similarly, in XR, technologies like head-mounted displays (HMDs) may utilize head-tracking and sensorimotor contingencies to modify audio spatialization in response to the user's focus [19]. Unlike these interactive scenarios, a non-IVE would have a fixed audio playback, irrespective of user input. Given the significance of immersion in IVEs, this article will explore the influence of audio on immersive experiences within such platforms through a comprehensive review.

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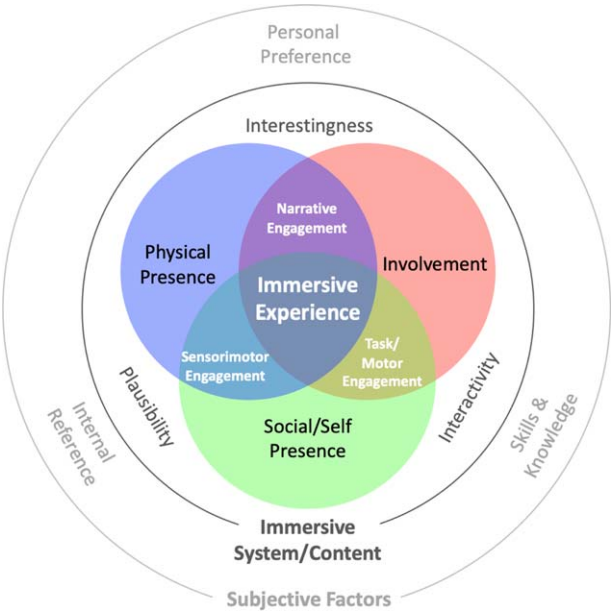

Fig. 1. Lee's [5] conceptual model of immersive experience in XR.

1 BACKGROUND

1.1 Defining Immersive Experience

To navigate the ambiguity surrounding the notion of "immersion," [5] offers a structured conceptual framework for immersive experiences within XR, as illustrated in Fig. 1. This framework places immersive experience as the highest-level construct, shaped by elements like physical presence, social and self-presence, and involvement. It delineates immersion into two key components: the technological attributes, similar to "system immersion" as described in [20], and the psychological aspect, similar to the experiential immersion detailed in [21]. Moreover, it acknowledges the influence of subjective variables on immersion levels, which this article will further discuss.

The model presented by [5] emphasizes the crucial roles of presence and involvement in developing IVEs. Enhancing the sense of presence is essential because it serves as a key indicator for assessing user experiences in IVEs across multiple fields such as entertainment, educational ventures, and therapeutic settings [22–24]. Biocca [25] breaks down presence into three distinct components, which are expanded upon in [26]. These components are defined as the following:

(1) Physical Presence: Virtual physical objects are experienced as actual physical objects.
(2) Social Presence: Virtual social actors are experienced as actual social actors.
(3) Self Presence: The virtual self is experienced as the actual self.

The concept of involvement, often equated with cognitive absorption, has its roots in video game studies and is a fundamental factor in immersion [27, 28]. Calleja [28] presents a model for game involvement, suggesting that deep involvement creates a state of "incorporation," which is defined similarly to "immersive experience." The term "flow," common in gaming discourse [29], also shares similarities with immersive experience, encompassing engagement and detachment from reality. However, unlike flow, which is typically associated with pleasure and a positive mental state, immersive experiences can evoke a spectrum of emotions and do not always involve tasks that have a clear path to success or a sense of control [5].

1.2 Auditory Immersion

In considering the influence of audio on immersive experiences as defined by the framework in [5], it is crucial to assess its impact on each component individually. Previous research has investigated how auditory elements affect the sense of presence (i.e., the feeling of "being there" in IVEs). Notable audio factors that have been observed to influence presence include spatial sound characteristics, the auditory background, the congruence of sensory inputs, and the quality and contents of sound [3, 4].

The spatial attributes of audio, encompassing acoustic cues and sound localization, are recognized for their substantial effect on the sense of presence in IVEs, as supported by numerous studies [30–33]. The auditory backdrop, which delivers a constant flow of sound information, is vital for mimicking the complex auditory scenes encountered in the real world [3, 30, 34]. Equally, the congruence of sensory feedback in multimodal IVEs is imperative; discrepancies between senses can fracture the sense of presence in these environments [35–37]. Furthermore, the audio quality and content, from its spectral features to the emotional associations it evokes, are also identified as key factors in eliciting a sense of presence [37, 38].

However, the sense of presence as outlined by the model in [5] is only one facet of immersion, with involvement constituting the other key element. van Elferen [39] explores this in the context of audio through a theoretical model of musical immersion in video games, identifying three avenues through which music enhances involvement: affect (emotional impact), musical literacy, and interactive responsiveness. The emotional impact of music deepens engagement by fostering a stronger personal connection with the IVE [40]. Understanding the musical cues and their referential context (i.e., musical literacy) within the game also significantly contributes to immersion [41]. Lastly, the interactivity of music—how it responds to player actions—fortifies this engagement [39]. Nevertheless, the literature still lacks extensive research into the specifics of how sound influences involvement within the realm of XR and digital games.

1.3 Measuring Immersion

Research on immersive experiences often utilizes post-experience questionnaires to measure presence, with the Slater-Usoh-Steed [42] and Presence Questionnaire [13] being notably prominent, as identified in a recent systematic review [2]. Efforts to unify these varying approaches include the Multimodal Presence Scale [43], designed to

correspond with an established model of presence [26]. Objective methods like electroencephalography and physiological monitoring offer a direct measurement of presence but have yet to gain uniform acceptance because of inconsistencies in the repeatability of results [1, 44–48].

While standard questionnaires seldom include audio-specific inquiries [e.g., 13], there have been endeavors to address this gap with tailored tools assessing audio in immersive contexts [33, 49]. These tools, however, confront challenges related to their theoretical basis and practical application. The "Immersive Music Experience Inventory" developed by Wycisk et al. [50] is a step forward for immersive musical evaluation but awaits further validation in interactive environments. Literature reviews across virtual reality (VR) [17], augmented reality (AR) [51, 52], and digital games [53] underscore the importance of a more nuanced review that integrates various audio factors, emphasizing the impact of audio on immersive experiences in XR and digital games for a more refined understanding of the area.

2 METHODS

The focus of this review is to provide an overview of numerous factors that are crucial to understanding audio's role in immersion across the literature. These include trends in methodological approaches, the audio variables that are tested, and other important observations relevant to the varied research approaches taken. The following research questions are put forward to ensure this review brings clarity to these important factors, in the context of IVEs:

RQ1: What are the specific audio elements being studied?
RQ2: Which aspects of immersive experience are being studied?
RQ3: What are the methodological trends and challenges?
RQ4: What insights does the literature research provide about the effect of audio on immersive experiences in XR and digital games?

The current investigation adopts the methodological framework outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to structure the systematic review [54]. A thorough search was conducted to gather relevant peer-reviewed studies. An initial review of titles and abstracts served as a preliminary screening step. Subsequently, a selection of these studies was subjected to a detailed full-text analysis. The culmination of this process involved the collection of insights from the evaluated studies, which were methodically arranged to address the research questions put forward by this study.

2.1 Search Strategy

To ensure a thorough literature search, a strategy was taken that encompassed the key elements of the authors' research aims: audio, immersive experiences, and IVEs, which include both XR and digital games. The search was conducted through well-regarded databases such as ACM, IEEE, Scopus, and selected journals like the *Frontiers in Signal Processing*, recognized for their relevance to the research focus and their frequent use in related literature reviews [17, 51, 52]. The search, executed on April 8, 2023, filtered publications by matching terms in the titles and abstracts, utilizing the following search string tailored to the study's focus:

("Audio" OR "Auditory" OR "Sound" OR "Music") AND ("Immersion" OR "Immersive" OR "Presence" OR "Involvement") AND ("Extended Reality" OR "Virtual Reality" OR "Augmented Reality" OR "Mixed Reality" OR "Virtual Environment" OR "Games")

The search, executed on April 8, 2023, filtered publications by matching terms in the titles and abstracts, utilizing the following search string tailored to the study's focus. For the databases ACM and IEEE, specific operators were applied to the "Title" and "Abstract" fields to align with the distinct search functionalities of each database.

2.2 Review Procedure

Selection criteria were meticulously applied to determine the inclusion of papers. The papers needed to be: (1) peer-reviewed, (2) written in English, and (3) focused on the study's central theme—the impact of audio on immersive experiences in XR and digital games. The specific criteria for assessing the relevance of the studies for inclusion in the review are as follows:

Audio: Research that failed to specifically isolate audio's impact, risking the conflation of results with other sensory inputs, was not considered. For example, studies examining both audio and haptic feedback needed distinct conditions for each to be included. This approach ensures clarity in attributing outcomes to audio alone, without the confounding influence of a multisensory setup.

Immersive Experience: The selection excluded studies that did not clearly connect their research to aspects of immersive experience as defined in the model by [5]. This was critical to ensure that the outcomes reviewed were directly related to immersive experience, maintaining the integrity of the study's focus.

IVEs: The scope was confined to studies examining "active" IVEs, characterized by environments that users can manipulate through their actions, including either digital games or XR settings, or both if the study included both separately. The distinction between XR and digital games was made by assessing the experimental medium used (e.g., VR HMD would indicate an XR study, whereas a screen with a controller would indicate a digital game study). Additionally, for an XR or audio-driven environment to qualify as "active" within this review, it had to feature dynamic elements like head tracking or interactive sound elements that react to user interactions.

It should be noted that while studies that do not explicitly mention immersion were excluded because of the search criteria, there are a number of studies that precede immersion-specific research in the realm of audio that

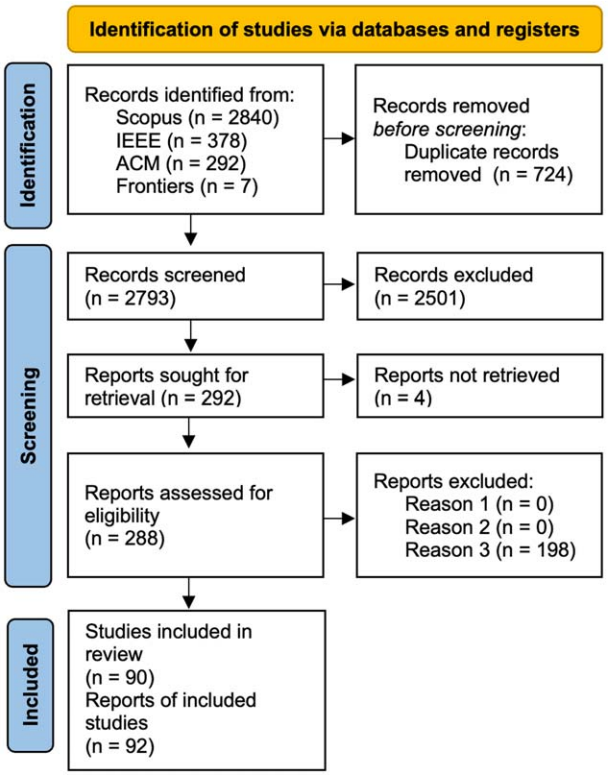

Fig. 2. PRISMA flow diagram for the screening process.

would be potentially relevant to this review. Most notably, studies on perceptual attributes of spatial audio such as listener envelopment, spaciousness, and engulfment have contributed to the scope of immersion studies, and in some cases, these terms are given analogous definitions to immersion [e.g., 55–59]. While the authors acknowledge this area of research as important to the overall understanding of audio and immersion, the scope of this study remains with publications that explicitly measure immersion.

Initially, the search string gathered 3,517 records from the chosen databases. These records were then imported into Endnote 20 for organization, where duplicates were identified and discarded (n = 724), leaving 2,793 for title and abstract evaluation according to the authors' criteria. Consequently, this process eliminated 2,501 papers, resulting in 292 for a detailed full-text review. Four articles were inaccessible, and an additional 198 did not meet the inclusion standards, culminating in 90 studies for the final corpus. Notably, two of these studies detailed outcomes from two separate experiments; hence, the total count of unique experimental reports assessed brought the total to 92. A flowchart of this process is presented in Fig. 2.

2.3 Data Extraction and Analysis

For the data extraction and analytical phase, each study was analyzed to collect crucial information such as the type and year of publication, experimental design, IVE medium, auditory display type, participant count, research domain, variables (both independent and dependent), data collection instruments, and specific questionnaires or scales utilized. This structured approach facilitated a comprehensive understanding of the field, identifying patterns and potential gaps in the range of studies assessed. The data were organized into tables and subjected to an in-depth critical analysis to help answer the research questions for this study.

Table 1. Domains of interest observed across the studies.

Domain of Interest	Number of Studies
XR environments*	37
game music & sound design	21
Virtual music performance	3
Virtual environment storytelling	2
Education & training	14
Health & wellbeing	7
Soundscape studies	3
Culture & heritage	3
Data sonification	2

* These studies are subcategories of the "Art & Entertainment" category.

3 RESULTS

3.1 Publication Details

The details including the publication year and format of the included studies are depicted in Fig. 3. Within the pool of 90 studies analyzed, there were 51 conference papers, alongside 38 journal articles and a solitary book chapter. The peak year for publications within this set was 2019, contributing 15 individual studies. This data underscores a burgeoning interest in the subject matter over recent years, with exactly half of the publications (45 in total) dated before 2019, ranging from 2003 to 2018. Notably, there is an observable surge in the volume of publications between 2019 and 2023. The solitary publication from 2023 should be contextualized by the fact that the data collection was completed in the early part of that year.

3.2 Domain of Interest

The domain of interest that each study focused on was documented during the review process, because this provides useful knowledge into the areas that are commonly studied and those that are underexplored. As the domain of interest is often not explicitly stated in the studies, categories were created based on commonly observed themes during the review process. Since a vast majority of papers (n = 63) were attributed to the "Art & Entertainment" category, subcategories were formed to allow for a more nuanced observation of the specific areas researched. Table 1 below shows the distribution of the domains of interest across the studies included in the review.

From Table 1, it can be seen that the domain "Art & Entertainment" dominates the field, with a particular focus on "XR Environments" and "Video Game Music and Sound Design." The presence of smaller yet substantial research clusters in "Education & Training" and "Health & Wellbeing" indicates emerging interests that could offer fresh perspectives on audio's impact on immersion across broader applications. It is important to note the potential bias of this data due to both the search terms and databases included, as well as the subjective categorization by the authors.

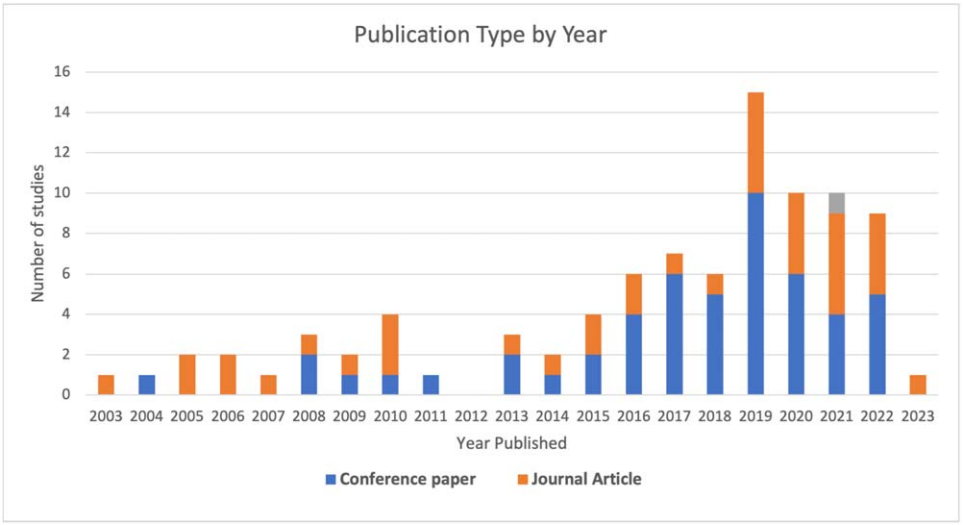

Fig. 3. Distribution of publication by year for reports included in the study.

3.3 Experimental Setup

The review analyzed 92 distinct experimental setups, emphasizing the types of media used, participant numbers, and design formats. Fig. 4 shows the distribution of the experimental medium and audio reproduction types used. The overall count of media-specific studies rose to 93 because of a study comparing immersive experiences in VR HMD and screen with keyboard and mouse conditions [60]. The analysis revealed that 61 studies employed an XR environment as their experimental medium. Within this, VR HMDs were the most common media type (n = 49), while mixed reality (MR) HMD and MR Audio Only were utilized in three experiments each and AR HMD, VR CAVE, and MR Screen appeared in two studies each.

Digital game environments were employed in 32 studies with the most frequent being screens with keyboards and mice (n = 21) followed by screens with controllers (n = 8), and touchscreens (n = 3). Audio reproduction was dominated by headphones (n = 67) over loudspeakers (n = 12), with 14 studies not specifying the audio method. Headphones are likely favored due to their integration with commonly used VR HMDs (e.g., Oculus Quest 2, HTC Vive Pro).

Table 2. Distribution of number of participants across the studies.

Number of Participants	Frequency
0–10	2
11–20	24
21–30	17
31–40	22
41–50	5
51–60	6
61–70	6
71–80	5
81–90	0
91–10	0
101+	5

Table 2 shows the results for the number of participants and experimental designs used. Participant distribution across these studies showed a tendency toward small-scale experiments, with the 11–20 participant range being

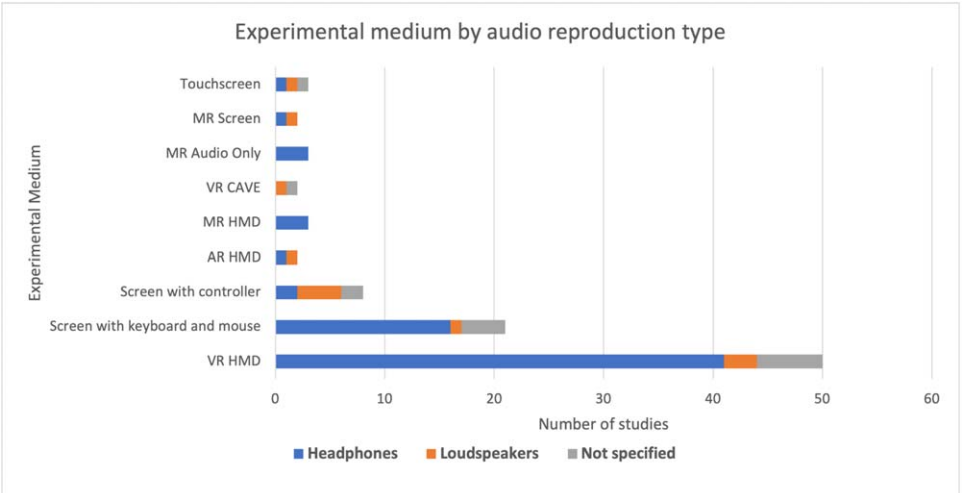

Fig. 4. Distribution of media type and reproduction methods used.

Table 3. Experimental designs observed across the studies.

Experimental design	Frequency
Within-subjects	39
Between-subjects	42
Mixed	11

Table 4. Specific questionnaires used.

Questionnaire Used (Source Reference)	n
Presence questionnaire [13]	14
Immersive experience questionnaire [8], igroup presence questionnaire [115], slater-usoh-steed questionnaire [42]	10
Game experience questionnaire [116], player experience inventory [117]	5
MEC spatial presence questionnaire [118], ITC-sense of presence inventory [119]	3
Swedish viewer-user presence questionnaire [120], player-avatar identification [121], social presence survey [89], game engagement questionnaire [122], spatial presence experience scale [123]	2
Networked minds social presence questionnaire [124], illusion of virtual body ownership questionnaire [115], immersive response questionnaire [126], film IEQ [127], player identification scale [128], hendrix & barfield questionnaire [30], draper & blair questionnaire [129], virtual body extension questionnaire [130], temple presence inventory [131], presence SAM [132]	1
Bespoke questionnaire	29
Adapted questionnaire	20

the most common (n = 24) and the majority of studies involving 11–40 participants. This scale is further evidenced by the median participant number being 32, which more accurately reflects the central tendency due to the presence of extreme values, such as a study with 1,527 participants. As seen in Table 3, the experimental designs were fairly balanced, with a slight preference for between-subjects designs (n = 42) compared with within-subjects designs (n = 39), while mixed designs were less common (n = 11), indicating a diverse approach to experimental design within the field.

3.4 Methodological Approaches

Questionnaires surfaced as the principal tool for assessing immersive experiences, with bespoke versions crafted for specific studies being the most used (n = 29) and amended versions of existing studies also dominating (n = 20), as shown in Table 4. Standardized questionnaires like the Presence Questionnaire [13] (n = 14) were frequently employed, although a notable diversity with some used only once, indicating varied methodological preferences. Rating scales were the most common for subjective assessment, with seven-point scales leading (n = 47), followed by five-point options (n = 25), as detailed in Table 5. Other discrete rating scales such as 100 and 101-point rating

Table 5. Measurement scales used.

Scale Used	n
7-point rating scale	47
5-point rating scale	25
100-point, 9-point rating scale	2
101-point, 11-point rating scale, 10-point rating scale, 6-point rating scale, 4-point rating scale, 3-point rating scale, open-ended questions	1
Not specified	13

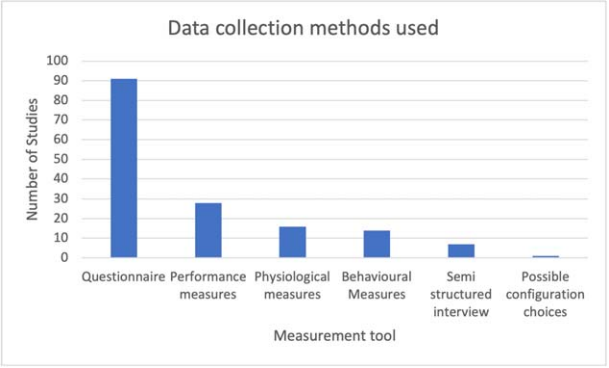

Fig. 5. Distribution of data collection methods used.

scales were also employed. It should be noted that during the data collection for the review, it became clear that finding the specific rating scale type used (e.g., Likert, semantic differential, etc.) was unreliable because many publications did not include direct evidence of the scale used. Therefore, the data collected represent rating scales in general.

Objective measurements supplemented subjective reports, using performance measures in 28 studies, physiological tracking in 16, and behavioral observations in 14, as depicted in Fig. 5. While performance measures gauged task efficiency, physiological and behavioral data offered concrete insights into physical responses to immersive stimuli. Despite the prevalence of questionnaires, semi-structured interviews (n = 7) provided depth beyond numerical data, capturing nuanced aspects of immersive experiences not easily quantified. Further details on the measurement approaches for this study can be found in [61], which served as a preliminary presentation of the findings with a focus on measurement approaches.

3.5 Independent Variables

From the extracted data across the studies included in the review, a wide array of independent variables were identified. To facilitate analysis, these variables were grouped into distinct categories based on their relevance to certain audio factors. The categories are identified below:

- Spatial Fidelity: Studies in this category tested independent variables that were specifically related to spatial fidelity (e.g., mono, stereo, binaural).
- Modality: Studies in this category tested independent variables that were separated by the modality presented

Table 6. Studies included within the analysis and their independent variable categories.

Independent Variable Category	Studies Included	Number of Studies
Spatial fidelity	[94, 28, 65, 67, 68, 63, 66, 133, 64, 62, 132, 90, 69, 134, 96, 135, 136, 137, 138, 91, 139, 97, 92, 93]	27
Modality	[103, 84, 104, 86, 105, 85, 87, 140, 141, 110, 88, 142, 143, 144, 145, 109, 112, 146, 147, 148, 149, 150, 114, 151, 113, 152]	26
Auditory condition	[70, 98, 71, 99, 100, 83, 153, 154, 155, 156, 157, 73, 158, 159, 160, 161, 162, 163, 164, 165, 166, 75, 167, 74, 168, 72]	24
Music condition	[101, 82, 76, 77, 78, 81, 79, 169, 80, 170, 171, 111, 172, 102]	15
Total		92

in a multimodal environment (e.g., visual only, audio + visual, audio + visual + haptic).
- Music Condition: Studies in this category tested independent variables that were specifically related to the music reproduction approach (e.g., traditional score, generative score).
- Auditory Condition: Studies in this category tested independent variables that presented separate audio-related conditions that were not specifically related to spatial fidelity, music, or multimodality (e.g., various levels of audio layers: SFX only, Music only, SFX + Music).

Some studies employed a crossover design that used multiple sets of audio related independent variables, which, therefore, fell into multiple categories. To simplify the analysis, the most prominent category in relation to the study was allocated. Table 6 shows the distribution of studies across these categories. The analysis reveals a relatively even distribution across three categories—"Auditory Condition," "Modality," and "Spatial Fidelity"—each commanding a significant focus within the research. However, the "Music Condition" is noticeably less represented in the research, pointing to an area for further investigation.

In terms of the specific independent variables used in the Spatial Fidelity category, the most common factors included testing between mono, stereo, and higher fidelity reproductions such as binaural and Ambisonics [62, 63, 64, 65, 66]. While the majority of these studies indicated an increase in immersive experience was correlated to an increase in spatial fidelity, some studies reported no significant impact [67, 68, 69], indicating that there is further nuance in how spatial audio impacts immersive experiences.

Within the Modality category, the studies varied with different combinations of sensory modalities within a multimodal virtual environment. The independent variables tested ranged from different combinations of audiovisual feedback [70, 71, 72], to those testing audiovisual-haptic feedback [73, 74]. Further studies included more unique modalities, such as [75], which considered the integration of text with audio and visual modalities. Overall, the majority of outcomes reported an increase in immersive experience when adding audio as a modality; however, it is important to consider that cognitive load can negatively affect user experience, and so, audio design in multimodal environments should consider this [17].

Exploring the Music Condition in virtual environments, research has sought to understand how different music production techniques influence immersion. [76] compared traditional, linear music scores with procedural music in games, noting an increase in player engagement when procedural music was used, while [77] showed that algorithmically generated music can increase the sense of presence. A number of studies observed the role that adaptive music (i.e., music that changed based on the users' interactions) has in enhancing player immersion [78, 79, 80, 81]. However, studies such as [82] observed that various game music styles had only a minimal impact on increasing immersion, and therefore, care should be taken when considering the significance of these results.

The Auditory Condition category contained a widely varied range of independent variables tested. Studies like those of [83] and [84] have assessed how various audio elements, from diegetic and nondiegetic sounds to auditory consonance and dissonance, contribute to the feeling of being immersed. The absence of sound was uniquely addressed by [85], whereas [86] and [87] assessed the presence of background sounds. Various environmental audio cues were explored by [88]. These varied investigations provide a rich landscape of how sound design intricacies can deepen immersive experiences in virtual settings.

3.6 Immersive Experience Domain

This review also aims to analyze which subdimensions of immersive experience, as outlined in Lee's [5] model, are being measured within the context of audio research. Understanding how extensively each subdimension has been explored may highlight areas that require further investigation. During the review process, the dependent variables documented from the selected papers were used to assign each study to corresponding subdimensions of immersive experience. For the purposes of presenting a detailed analysis, the subdimension of social/self presence was split into two separate categories—social presence and self presence. Studies that clearly identified the immersive experience measured, such as through the use of targeted question-

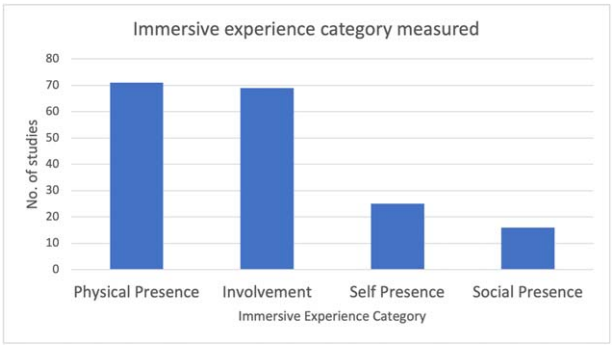

Fig. 6. Distribution of immersive experience category measured.

naires like the "Social Presence Survey" [89], were easily categorized. However, for the majority of studies lacking explicit categorization, the assignment was based on the most prominent immersive experience domains observed within the study by using Lee's [5] model as the guiding framework.

Given that numerous studies assess multiple aspects of immersion, it was common for a single study to be associated with more than one category. Fig. 6 represents the distribution of categories of immersive experiences as identified across the 92 studies. It is important to note that the total count of 181 instances reflects the number of times these categories were identified across all papers, with some papers contributing to multiple categories. Therefore, the chart should be interpreted as showing the relative prevalence of each category within the scope of this analysis, highlighting which aspects of immersive experience are most frequently addressed in the literature.

In the landscape of immersive audio research, "Physical Presence" and "Involvement" stand out as the most commonly studied subdimensions, reflecting a significant portion of the studies. Although "Self Presence" and "Social Presence" are individually less represented, it is worth noting that Lee's [5] model treats these concepts as closely related. When their percentages are combined, they account for a more considerable segment of the research, suggesting that personal and social aspects of immersion collectively receive reasonable attention.

4 DISCUSSION

Because a main focus of the study was observing how individual audio factors influence immersive experience across the scope of the review, the following sections at the beginning of this discussion will outline insights gained from each category of audio factors observed. Later sections will draw insights on trends observed in terms of experimental and methodological traits, as well as potential gaps in the research.

4.1 Spatial Fidelity and Immersion

One of the most frequently explored ways to enhance immersive experience in virtual environments with audio is by manipulating the spatial fidelity of the audio playback. The studies in the review that examined this concept offer a complex understanding of its impact. Studies [90, 91, 92, 93] suggest that increased spatial fidelity typically enhances immersion and spatial awareness. This is further supported by findings from [94, 65, 95], which demonstrate that spatialized sound positively influences user engagement in various virtual settings such as virtual performances and storytelling.

An interesting approach in [96] shows how attention-based spatial audio reproduction opens an intriguing line of research into how spatial audio can react to the user's focus to increase immersion. This system, used in the context of VR image-based virtual tours, showed that having the auditory scene react spatially to the user's attention (determined by their pointing) significantly increased social presence and vocal intelligibility while also requiring less cognitive load. Utilizing interactive elements to signify the user's attention and adapting the audio playback is a unique approach to increasing the immersive experience through audio.

However, the research also presents mixed outcomes. While some studies report significant improvements in immersion with the introduction of complex 3D sound reproduction and HRTF adjustments, others like [68, 69] report no significant impact. Also, [97] observed that similar realism and immersion ratings can be achieved through lower reflection orders in the auralization of certain sound sources. These inconclusive results may point to a threshold in perceptual detection, suggesting that not all spatial audio enhancements translate to a perceivable increase in immersion. These results might reflect limitations in the experimental designs and may also be influenced by how immersion was defined by the researchers.

The diversity of independent variables across studies, ranging from simple mono or stereo to multichannel, or ambient, directional, and dynamic spatial reproduction, indicates a broad research field with many methods to manipulate the spatial aspects of audio for studying its effects on immersion. While the role of spatial audio in creating immersive virtual environments is substantiated, its effectiveness is not consistent across all settings. The variability in impact depends on a range of factors, including how immersion is defined, the types of spatial audio processing used, and the specific contexts in which they are implemented. Further research is required to understand the nuances of spatial audio's influence on immersion.

4.2 Audio in Multimodal Environments

Integrating auditory feedback in multimodal environments to observe its effect on immersive experience was one of the most frequent approaches across the studies in this review. These studies, spanning across cultural heritage, education, training, and entertainment domains, offer rich insights into how auditory feedback contributes to immersion in multimodal environments.

[70] and [98] found that the combination of auditory and visual stimuli significantly enriches the immersive experience in virtual environments. For instance, auditory ac-

companiment to visual stimuli, such as paintings, not only fosters a sense of presence but also enhances spatial cognition. This suggests that a multimodal approach can create a more engaging storytelling and learning environment. Research in [99, 71, 100] highlights the importance of auditory feedback in reinforcing the integration of virtual and physical spaces and in shaping user interactions through spatial understanding. Auditory elements, whether used alone or with other sensory modalities, are key in creating cohesive and immersive virtual experiences.

The collective research underscores a clear trend: The integration of multiple sensory modalities, especially audio and visual, consistently elevates the immersive quality of virtual environments. However, the absence of reported negative effects in these selected studies does not necessarily imply that modality changes are always beneficial. In the broader context of research, it is possible that certain modalities, if not implemented carefully, could lead to sensory overload, distraction, or even discomfort, which could negatively impact the user experience. These outcomes may not be captured in the dataset provided, and it is important for systematic reviews to consider the possibility of publication bias where studies with negative results may be underreported.

4.3 Music and Immersion

The analysis of studies focusing on the Music Condition and its impact on immersive experiences in various environments reveals interesting trends and observations. These studies, primarily within the domain of Art & Entertainment, examine how different approaches to music reproduction influence user perception and engagement.

[101] found that music modulates visual perception in VR, enhancing the overall experience. This suggests that music plays a crucial role in augmenting the sensory experience in VR. [76] observed that video game players exposed to procedural music completed levels faster and had a more positive experience compared with those with traditionally composed backgrounds. This indicates that the method of music composition can significantly influence user engagement and enjoyment in gaming. [78] reported enhanced sensory and imaginary immersion with dynamic music (i.e., interactive music) as opposed to nondynamic music. This highlights the impact of music-player interaction on the depth of the immersive experience. [102] contributed an important aspect to this narrative by showing that the presence or absence of music can variably influence time perception and immersion in video games.

However, some studies show that the impact of music variation on immersive experience can be subtle and not always clear. [82] noted only a slight tendency toward higher immersion levels with different game music versions, implying that while music variations can influence immersion, the effect might be subtle. [77] explored the cognitive aspects of immersion and found that algorithmically-generated music impacts these cognitive elements, suggesting that the composition technique of the music could play a role in how users process and interact with the virtual environment.

Across these studies, music consistently emerges as a key factor in enhancing the sensory dimensions of VR and gaming environments. The approach to music composition techniques appears to have a notable impact on user engagement and cognitive immersion. However, the degree of immersion influenced by music can vary, with some studies noting only slight changes. This suggests that the impact of music might be dependent on other factors like the nature of the content or user expectations.

4.4 Other Audio Variables and Immersion

Studies in the Auditory Condition category did not focus on any of the above-mentioned categories but still manipulated the audio in some way to measure its effect on immersion. The examination of auditory conditions within virtual environments across a spectrum of studies presents a compelling case for the nuanced role of sound in enhancing immersive experiences.

Both [103] and [104] have shown that specific auditory stimuli, such as sampled tool sounds and diegetic sound sets used in data sonification, significantly improve task performance and participant engagement in VR training and data interpretation contexts. These auditory conditions serve to deepen the immersive quality of the virtual environment and aid in skill acquisition and comprehension. Research by [86] further supports the importance of auditory elements, demonstrating that video game environments enriched with diegetic sounds can significantly enhance the sense of immersion and satisfaction of the user's competence and needs. These findings underline the role of diegetic sound in creating an engaging and cohesive user experience.

Contrasting with the above, [105] found that in certain scenarios, the absence of sound can unexpectedly increase the sense of presence and bodily awareness in VR. This indicates that silence, as much as sound, can be strategically employed to influence user perception, suggesting that a balance in auditory design is crucial. [84] highlighted the potential of auditory conditions to evoke emotional responses such as awe, demonstrating the therapeutic applications of VR and music. This shows that sound not only serves an immersive or informational role but also has the potential to impact emotional states and wellbeing.

In summary, the strategic use of sound in virtual environments—whether through its addition, modification, or exclusion—is pivotal in shaping immersive experiences. The ability of auditory conditions to affect not only the sense of presence and performance but also emotional states and content comprehension is evident across various domains. The collective findings point to the necessity of a tailored auditory design, taking into account the specific needs and contexts of different virtual experiences to optimize user engagement and satisfaction. Future research should further explore this complex interplay to refine our understanding of how best to employ sound within immersive virtual environments.

4.5 Understanding the Complexity of Immersive Experience

In examining the impact of audio on immersive experiences within XR and digital games, this review employs Lee's [5] model as a framework to dissect the varied dimensions of immersion that audio influences. The review identified the most measured subdimensions of immersion related to audio, which align with Lee's conceptualization, and highlighted areas that necessitate further exploration. Notably, the prevalence of studies within certain subdimensions, like social and self presence, underscores the growing recognition of audio's role in enhancing these facets of immersion.

Lee's [5] model suggests that immersive experience is a multifaceted construct, influenced by physical presence, social/self presence, and involvement. This broader view allows for untangling the complex ways in which audio contributes to the psychological experience of immersion, beyond just the technological capacity of an immersive system. This review found that while many studies leverage audio to enhance a sense of physical presence—making virtual objects and environments feel real through spatial audio cues—fewer studies explore how audio affects social presence and the perception of one's virtual self. The studies reviewed here often measure multiple aspects of immersion, indicating a recognition of its complex nature.

The findings from this review point to a need for a more nuanced approach to defining and measuring immersion. While questionnaires are frequently used to assess subjective experiences, they often lack audio-specific questions and fail to capture the continuous nature of immersive experiences. This suggests a gap in the standardization of measurement tools that can adequately reflect the complex interplay of audio's impact on immersive experiences as defined by Lee's [5] model. The diversity of audio's role—from enhancing the realism of virtual environments to influencing player engagement and emotional responses—highlights the intricate relationship between sound and immersion, requiring a more comprehensive approach to both the design and measurement of immersive experiences in audio research.

4.6 Insights Into Experimental Trends

The review uncovers a strong preference for using VR HMDs in over half of the studies, underlining the device's ability to isolate users from real-world stimuli and thus facilitate highly immersive experiences [20]. This is contrasted with screen-based media in digital games, which are also significant in number ($n = 32$), highlighting the robust interest in exploring audio's role in traditional gaming environments. In comparison, AR and MR are less represented, pinpointing a research gap despite their unique ability to merge real-world and virtual audio elements—an aspect that could be highly influential on immersion [52].

Participant numbers tend to be on the smaller side, predominantly falling within the 11–20 range. This preference likely reflects the logistical and temporal demands of immersive experience studies, which require intricate setups and longer session times to adequately measure immersion's temporal dynamics [6]. Experimental designs in the field show a balanced use of within-subjects and between-subjects approaches, each with its trade-offs regarding the control of individual differences and potential for familiarity effects, respectively [6]. This balance suggests a nuanced understanding among researchers of how design choices can impact the measurement of audio's influence on immersion.

In terms of research domains, "Art & Entertainment" stands out, particularly in "XR Environments" and "Video Game Music and Sound Design," with 63 studies focusing on these areas. This emphasis reflects an acute interest in how audio enhances immersive qualities within digital and extended realities, suggesting that the auditory experience is critical in these environments. Emerging research clusters in "Education & Training" and "Health & Wellbeing" indicate that the field is expanding, recognizing the potential for audio to influence immersive experiences in educational and therapeutic contexts. The concentration of studies within certain domains might, however, be influenced by the search strategies and categorization biases inherent in systematic reviews.

The insights from this review demonstrate that while VR HMDs are currently the preferred medium for studying audio's impact on immersion, there is a need to broaden the scope to include AR and MR environments. Understanding the interaction between audio and user engagement in these underexplored areas could provide a more comprehensive view of how audio influences immersive experiences across various contexts.

4.7 Insights Into Methodological Trends

This systematic review indicates a preference for post-experience questionnaires in studies investigating audio's influence on immersive experiences, favored for their established effectiveness in capturing subjective experiences [1]. However, this method's predominance also underscores a gap in the use of continuous, objective measurement techniques, which could offer more reliable immersion metrics and mitigate recall bias. While objective measures such as electroencephalography have shown promise in audio-only settings [e.g., 47, 48], their reliability in multimodal IVEs requires further validation before they can be used reliably.

Performance, behavioral, and physiological measures form a spectrum of objective tools, often used to corroborate questionnaire data and mitigate the subjectivity of user-reported data. The emergence of frameworks like the one presented by [106] for assessing social presence in virtual interactions illustrates an evolving methodological landscape. Notably, over half of the studies combined various tools to assess not just immersion but related aspects such as arousal and cybersickness, reflecting a multifaceted approach to understanding immersive experiences.

Regarding questionnaires, the lack of standardization is evident, with many studies opting for bespoke or amended questionnaires to fit their unique requirements. This practice, while adaptive, reveals a shortfall in tools specifi-

cally designed to evaluate audio's impact on immersion. The Presence Questionnaire [13], the most frequently employed, was the only one to include audio-specific items but was used in only 14 studies. The research community acknowledges the necessity for an audio-specific measurement tool to better gauge the effect of audio on immersive experience [107, 108].

The use of seven-point and five-point rating scales is common, yet this may not fully capture the nuanced spectrum of immersive experiences. This points to a broader issue within the field: the need for a more diversified range of measurement scales and tools tailored to the multifaceted nature of immersion influenced by audio in IVEs.

4.8 Sound Design Approaches for Immersion in IVEs.

While many of the studies assessed the importance of adding sound as a modality or manipulating spatial fidelity to increase immersion in IVEs, this section will focus more granularly on specific sound design approaches employed in studies that measured audio's impact on immersion. The analysis reveals that it is through a careful balance of these approaches that tends to lead to more immersive audio experiences, which further solidifies Lee's multifactor model of immersive experience [5]. For example, combining interactivity with music to create dynamically changing musical elements is often employed as a technique to increase immersion. Five key sound design approaches emerged from the range of studies that have an impact on the immersive experience:

4.8.1 Audio Dimensionality

Audio dimensionality involves manipulating the balance of multiple sound elements within a virtual space to enhance the sense of immersion. [95] demonstrated that combining ambient and spatial audio conditions significantly elevates immersion by constructing a more compelling narrative and evoking stronger emotional responses. [74] found that diegetic sound increases immersion and flow, with music further enhancing this effect, and [103] added that while diegetic sounds decrease cognitive workload, abstract sounds have the opposite effect, increasing stress. However, [109] found that adding complex audio dimensions did not significantly enhance immersive experience in their VR study. This approach underscores the importance of creating a balanced and coherent audio environment in virtual settings.

4.8.2 Dynamic Sound Cues

Dynamic sound cues refer to the use of evolving auditory elements that change in response to the virtual environment. [98] observed that soundscape landmarks provide higher levels of immersiveness compared with visual landmarks, highlighting their use as navigational cues in virtual environments. This was further supported by [110], showing that dynamic sound sources and the sound of egomotion significantly enhanced the perception of movement within the environment. These studies highlight the potential of dynamic sound cues to create a more engaging and realistic virtual experience.

4.8.3 Dynamic Music

Dynamic music involves music that changes in response to the virtual environment, playing a crucial role in immersive experiences. Both [78] and [81] showed that dynamic music influences immersive presence, gameplay performance, spatial experience, and emotional engagement. Furthermore, [105] and [111] found that adaptive music systems and music tempo adjustments can have a positive effect on immersion. These findings indicate that dynamic music can effectively enhance the sensory-spatial aspects of virtual environments and emotionally engage users.

4.8.4 Interactivity

Interactivity in sound design focuses on the relationship between user actions and auditory feedback. [63] found that the interaction between spatial sound rendering and user interactivity enhances immersion and elicits fear-induced emotions. [85] observed that reproducing self-generated footstep sounds increases realism, with [112] and [113] also highlighting the importance of interactive sound elements like tempo sonification and responsive audio feedback, significantly enhancing the sense of presence and environmental realism. These studies illustrate that interactive sound elements can profoundly affect user experience by enhancing realism and emotional response.

4.8.5 Multimodal Congruency

Multimodal congruency involves the harmonious integration of auditory feedback with other sensory modalities. [87] found that audiovisual congruence contributes significantly to immersion and presence. [69] explored the impact of disparity in horizontal correspondence between sound and source positioning on spatial presence, suggesting a tolerance limit for cross-modal conflict. Furthermore, [114] discovered that multimodal feedback, including auditory elements, influences mindfulness and presence, though certain sounds can be disruptive. These findings suggest that ensuring congruency between audio and other sensory inputs is critical for maintaining immersion and presence in virtual environments.

5 LIMITATIONS

There are a number of constraints that should be acknowledged in the context of the study. Firstly, the use of Lee's [5] model as the conceptual framework for defining immersion in the study introduces a bias to studies that do not fit within this conceptual framework but still may measure audio's effect on immersion in some way. The justification for this is that the model is a holistic approach that includes a number of subdimensions that are commonly referred to in immersion literature. Also, the selection of search terms and databases might have inadvertently excluded some pertinent studies that met the inclusion criteria.

Nevertheless, the initial yield of 3,517 records from the search was deemed ample for the research objectives, validating the choices made in this regard. Moreover, the systematic review was limited to scrutinizing peer-reviewed articles and conference papers in English, which may have neglected relevant contributions published in other languages or through non–peer-reviewed avenues. Additionally, the review process was conducted solely by the lead author, which, despite being a departure from the multi-screener approach that is usually advocated to minimize bias, was considered an acceptable method within the confines of this research's scope, particularly since PRISMA guidelines do not mandate such conditions [54, 113].

6 CONCLUSION

This systematic literature review was undertaken to address the complex role of audio in enhancing immersion within XR and digital games. The review's background analysis shed light on the critical constructs of presence and involvement—essential in crafting immersive experiences within IVEs—and examined how audio factors influence these constructs. Adhering to the PRISMA guidelines, the authors' methodical inquiry spanned several databases to curate literature on the subject, aiming to develop insights into the role of audio elements in immersive experiences and to map the current research landscape, highlighting methodological inclinations and knowledge gaps within the domain of XR and digital games.

The review's findings highlight many aspects that influence the impact of audio on immersive experience in XR and digital games. The findings confirm the crucial influence of spatial audio fidelity in virtual environments, suggesting developers should emphasize this aspect to bolster immersion and user engagement. However, while spatial audio consistently enhances the immersive experience, the varied impact across different studies suggests a complex relationship between audio enhancements and perceived immersion, hinting at the existence of perceptual thresholds. This complexity calls for a nuanced approach to audio design, one that not only considers technological capabilities but also user perception and experience.

Methodologically, the reliance on subjective post-experience questionnaires points to a need for more robust, objective measures of immersion that can track the user's experience in real time. Future research should focus on developing these measures as well as allowing more focus to augmented and MR settings, which remain less explored despite their potential. By evolving research methods and broadening the scope of study domains, the field can better understand and harness audio's power to create deeply immersive and engaging experiences across all forms of XR and digital games.

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