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Perspectives of Sound Designers on Real-Time Sound Propagation in Games

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***Abstract*—Realistic sound propagation is important for immersive game audio, yet its implementation remains a balance between physics-based accuracy and creative design. This paper presents a survey on physics-based techniques for sound propagation rendering in video games. It explores the perspectives of professional sound designers working in the video games industry, examining their approaches and prioritization in implementation. The key findings reveal a complex relationship between physics-based calculation and creative design preferences, highlighting a significant gap between academic theory and practical solution design. The study offers a practical discussion and insights for implementing sound propagation effects in industry projects.**

***Index Terms*—game audio rendering, sound propagation, perceptual, psychoacoustic, sound design.**

I. Introduction

Realistic sound propagation is crucial in modern game audio design as it enhances immersion by accurately simulating how sound interacts with virtual environments. However, despite significant advancements in computational acoustic methods, the real-time implementation of physics-based sound propagation remains a challenge [1]. Developers must often make trade-offs between acoustic accuracy and real-time performance, leading to approximations that influence the player's auditory experience. The question of how to achieve perceptually convincing results designers desire yet computationally feasible sound propagation for real-time interactive audio continues to challenge research and development efforts in game audio.

Existing techniques such as acoustic ray-tracing and binaural audio have improved spatial realism in game sound design. However, existing implementations face practical constraints, including computational demands, integration complexity, and the priorities of industry practitioners. Prior research has primarily focused on technical innovations [2], but understanding how sound designers navigate these challenges in practice remains underexplored. Gaining insight into their strategies and decision-making processes is critical for developing sound propagation techniques that align with both technical feasibility and creative expectations.

This study builds on these challenges by conducting an online survey of professional sound designers to explore their perceptions, challenges, and decision-making processes when implementing sound propagation techniques in games. Specifically, this research investigates the following research questions:

1) What are the challenges of applying advanced sound propagation models in practical video game development?
2) To what extent does accuracy influence designers' expectations and implementation of sound propagation effects? (*"accuracy"* here refers to physical acoustic correctness: real-world sound propagation principles).
3) How can these insights inform future research and development in game audio?

By engaging directly with practitioners, this study seeks to redefine how we approach real-time sound propagation in game audio design. The findings aim to provide developers with practical insights for achieving perceptually convincing sound propagation effects, ensuring that future sound propagation models align with the needs of both designers and players.

II. Previous Work

This section reviews the basics of room acoustic modelling in virtual spaces and practical methods employed in different game projects. Generally, generating sound propagation effects for a specific environment involves creating audible sound from computer-generated data and simulating how sound would be perceived in that environment. This process necessitates considering interactions between sound and the environment, including reflections with absorption and diffraction, etc. and other related acoustic phenomena [3].

Physics-based techniques in the room acoustic modelling domain are broadly classified into wave-based methods and geometry-based methods [4]. Wave-based methods rely on the fundamental wave equation that describes how waves propagate through a medium [5]. By directly solving this equation, these methods capture detailed phenomena such as reflection, diffraction, and interference. In contrast, geometry-based methods approximate sound propagation by taking advantage of the wave-particle duality of sound, which is more similar to those used for graphics rendering as light [6], significantly improving computational efficiency. These geometry-based methods simulate the paths that sound waves take as they interact with various surfaces, providing a practical approach to achieving sound propagation effects in virtual environments [7].

A. Implementation Challenges in games

Acoustic rendering in virtual environments has been extensively studied, and its integration into real-time game development gained traction around the year 2000. Some successful cases have been shared publicly, with the Game Developers Conference (GDC) serving as one of the prominent platforms where different project teams can showcase their approaches to sound propagation.

An early attempt to integrate wave-based sound rendering into interactive applications was presented in 2017 [8]. This was later applied in Gears of War 4, leveraging Microsoft's Project Triton precomputed wave acoustic to model diffraction, obstruction, and reverb decay with efficient runtime lookups [9]. While this method significantly improved realism, it was constrained by high memory demands and static scene geometry, limiting its adaptability to dynamic environments.

Parallel to wave-based methods, geometric approaches have also been explored to optimize real-time performance. In 2012, Ubisoft introduced a system that computes the shortest sound propagation paths between static geometry elements [10]. Their approach used portal-based zoning to improve efficiency, ensuring smooth sound transitions between indoor and outdoor environments while keeping computational overhead low. More recently, Cyberpunk 2077 (2023) presented an acoustic graph system, voxelizing the game world into 3D spatial nodes to simulate occlusion and environmental reflection using pathfinding algorithms [11]. Another example is Budget Cuts (2019), which employed HRTF-based binaural rendering for precise spatial audio localization in VR [12]. This system separated early reflections (ER) and reverb tail modelling because full real-time sound propagation demands too much of the Central processing unit (CPU).

Some projects' solutions relied on middleware-based approaches that integrate precomputed or procedural acoustic effects into existing engines. Ghost of Tsushima (2021) adopted an ER plug-in combined with Wwise[1] delay plug-ins, adjusting delay times via Real-Time Parameter Controls (RTPC) curves [13]. Similarly, It Takes Two (2021) implemented convolution reverb with custom impulse responses (IRs) derived from real-world field recordings. These IRs provided distinct environmental reverberation effects while minimizing real-time processing overhead [14]. Gotham Knights (2023) took a hybrid approach, integrating reflect plug-ins to combine procedural reverb with convolution-based techniques [15]. Its real-time ER system, leveraging pre-computation of fixed points with only first order stored in Octree structures, improved CPU efficiency and spatial consistency, particularly in complex urban environments.

While the cases reviewed above demonstrate significant advancements in sound propagation design, their implementations present persistent challenges. Computational efficiency remains a primary concern: physics-based models require significant processing power, making them impractical for real-time use, especially in large open-world games. To address this, designers have adopted precomputed solutions, such as Project Triton's wave-based baking[2] or Gotham Knights's ER system. Even in recent cases from 2023, implementations still rely on precomputed data and manual intervention to ensure performance stability, underscoring the continued difficulty of real-time physics-based audio simulation in games.

Additionally, it can be observed that the implementation in game projects is inherently complex and requires extensive engineering support. Successful execution demands collaboration between audio designers, programmers, and engine developers, making it a resource-intensive process. Beyond the technical challenges, industry constraints such as tight production timelines or cost efficiency further shape which solutions are viable, ultimately influencing how this effect is approached in project development.

III. Methodology

A. Data collection

Approval for the study was obtained from the University of York School of Physics Engineering and Technology Ethics Committee (approval number Han20240603). Participants accessed the study online using a link to the participant information sheet and were required to provide their consent before viewing and completing the questionnaire, which was hosted on the Qualtrics online survey platform. Recruitment was conducted through multiple channels, including social media posts (e.g., LinkedIn, X, or relevant forums), conference promotions, research group networks, and personal contacts. Data collection was taken between August 2024 and February 2025.

B. Participants

Data cleaning was undertaken to ensure the responses' quality and relevance. There were 110 people responding to this survey. Primary filtering ensured that respondents identify 1) as sound designers, 2) have experience in game project delivery, and 3) have direct experience with sound propagation implementation in game, which resulted in the final set of 41 responses. In addition, due to the inclusion of open-ended items, a secondary screening process evaluated the completeness of critical responses—using a threshold of 50% completeness—along with their consistency and technical depth. It should be noted that, in some cases, respondents hesitated to disclose detailed implementation information, possibly due to concerns about revealing proprietary commercial solutions. Consequently, certain open-ended questions were either left unanswered or received only brief responses.

Following the screening process, a final sample of 20 responses was retained, ensuring that only highly subject-focused participants were included in the dataset. These respondents exhibited a diverse range of experience levels and organizational contexts, ultimately providing important perspectives into industry practices in the implementation of sound propagation effects in video games.

[1] https://www.audiokinetic.com/en/wwise/overview/

[2] https://www.microsoft.com/en-us/research/project/project-triton/

C. Survey Design

The survey was designed to investigate the practices of sound designers in implementing dynamic sound propagation effects within game development, with a particular emphasis on those with project delivery experience in the industry. It was organized into four primary sections:

1) *Demographics:* Collects information on participants' educational background, industry experience, team composition and tools used (e.g., middleware platforms like Wwise or FMOD), etc. Understanding these factors helps contextualize the responses and identify potential influences on design choices and technical preferences.
2) *Practical Approaches:* In our study, sound propagation effects are the sole subject under examination. Sound designers were asked to rank the performance criteria according to their priority, how much effort they put into the project, how important the physics-based method is, the challenges between them and audio programmers regarding the implementation of sound propagation effects in game, etc. This section highlights industry-standard methodologies and potential barriers in the production pipeline.
3) *Diffraction:* As diffraction plays an important role in realistic sound propagation, this section investigates the approaches and parameters designers seek to control to diffraction-related effects in design.
4) *Reverb:* Given that reverb is one of the most significant and commonly used effects in game audio, and ER plays a critical role in reverb designing, shaping the listener's perception of space and room size. This section explores the importance and preferred methods of implementing reverberation and ER in projects.

We prioritized diffraction and reverb in the survey because they represent two fundamental aspects of sound propagation that have the potential to significantly impact player immersion in game environments. Each addresses a distinct and important dimension of spatial audio – how sound interacts with obstacles (diffraction) and how it interacts with enclosed spaces (reverb). The survey employed a combination of various question formats, including single- and multiple-choice, rank-order, and open-ended questions with *"other"* options for participants to offer alternative opinions. Each section was designed with a specific focus to ensure a comprehensive analysis of industry trends, technical challenges, and decision-making processes. Given the exploratory nature of this study, the analysis primarily focuses on interpreting qualitative responses to uncover underlying patterns and insights. Quantitative elements are used in a supportive role to contextualize these findings, ensuring a more in-depth understanding of how different aspects of the responses support or explain each other, providing an opportunity for a more nuanced discussion of the findings.

IV. Results and Analysis

This section describes the analysis of the quantitative data collected from the participants. We employed a combination of descriptive statistics, ranking analysis, and comparative analysis. Specifically, the ranking questions were applied to assess priorities by assigning weighted scores (the first choice received the highest weight, and then summing the assigned weights across all responses to comparing each option), allowing for an evaluation of relative importance among different criteria.

A. Demographics

The majority of the responses were from participants working in companies based in the USA (8) and the UK (6), each accounting for approximately one-third of the sample. The remaining participants, representing Canada (2), France (1), Australia (1), China (1), and Japan (1), provided additional regional perspectives.

Most designers had a design-oriented study foundation, with educational qualifications in music, audio production, film design, and related fields. In contrast, only about 15% reported an engineering background. Moreover, around 20% of the participants indicated that they did not receive formal audio training and acquired expertise through industry experience. In general, our sample consists mainly of experienced professional designers. 9 out of 20 participants have between 5 and 15 years of experience. Additionally, 4 respondents reported over 15 years of experience, potentially offering deep insights into the technology evolution of this subject in the game industry.

To better understand collaboration challenges, we also examined the presence of audio programmers in audio teams. Figure 1 presents the distribution of audio programmers within the audio teams and further indicates that approximately 44% of small teams (comprising 1–5 members) operate with no or only one programmer, while medium-sized teams (comprising 5–15 members) often have either one or two programmers. In larger, more stable teams (over 15 members), two programmers appear to be standard, although their responsibilities tend to be broader and more diverse.

The survey captured detailed information on the software tools and workflows employed by sound designers. According to the responses, Wwise is the predominant audio engine used in game projects, with approximately 60% of designers reporting its use in their design work. Other platforms, such as FMOD[3], Unreal Audio[4], Unity Audio[5], and various in-house solutions, accounted for around 10% of usage. Respondents generally believe they have high proficiency with these tools, averaging above 80%.

In addition, the scope of participants' work includes a wide range of tasks, from audio sample design to configuring playback behaviour settings. To systematically capture these tasks, the IEZA [16] framework (Interface, Effect, Zone and Affect) was applied, which has proven effective in structuring sound design practices. This framework is validated by an

[3]https://www.fmod.com/

[4]https://dev.epicgames.com/documentation/en-us/unreal-engine/audio-in-unreal-engine-5

[5]https://docs.unity3d.com/6000.0/Documentation/Manual/Audio.html

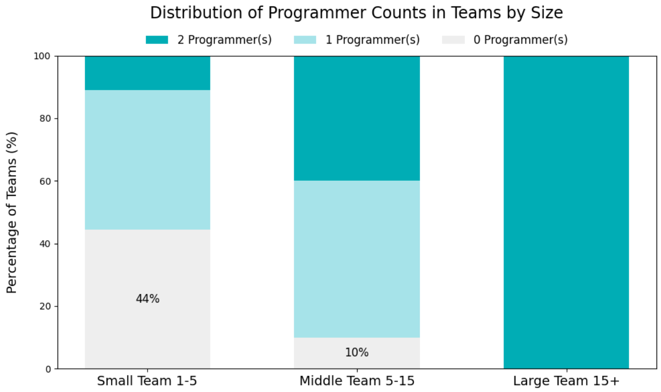


Fig. 1: Example of audio teams size

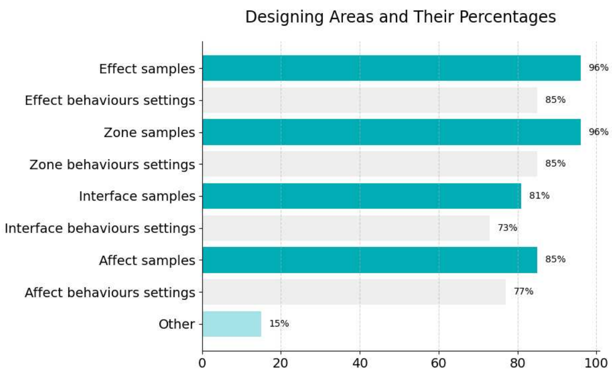


Fig. 2: Example of sound design work in video game (IEZA Framework)

exceptionally low selection rate for the "Other tasks" category and consistently high engagement rates across all predefined categories (ranging from 73% to 96% shown in Figure 2). These results suggest that: first, participants are well-versed in industry standards; and second, the consistency across task categories reflected the reliability of the survey as a measurement tool and confirmed that our sample is representative of professional sound design expertise.

Nevertheless, while the creation of sound assets has become widely accessible through various tools, gaps remain in systemic integration. Nearly all respondents (96%) demonstrate proficiency in generating core audio assets. For example, environmental effects (Zone samples) and object interactions (Interface samples), their proficiency in implementing interactive playback behaviours was lower by 10–15%. This reflected the complexity of integrating content production with implemented solutions no matter what game engines, middleware or software tools they used.

B. Practical Approaches

The survey started from the challenges between sound designers and programmers regarding the implementation of sound propagation effects. Among those who acknowledged such challenges, the top-ranked issue was *"the difficulty in developing adequate tools to support implementation"*. These findings call for a deeper analysis to understand how collaboration challenges intersect with performance priorities and implementation trade-offs, which will be further discussed in subsequent sections.

1) Performance Priority: Designers were asked to rank the performance criteria according to their priority, with options assigned weights on a scale from 1 to 3, presented in Figure 3. Two separate lists were generated: one reflecting desired performance requirements and another capturing the challenges encountered during implementation.

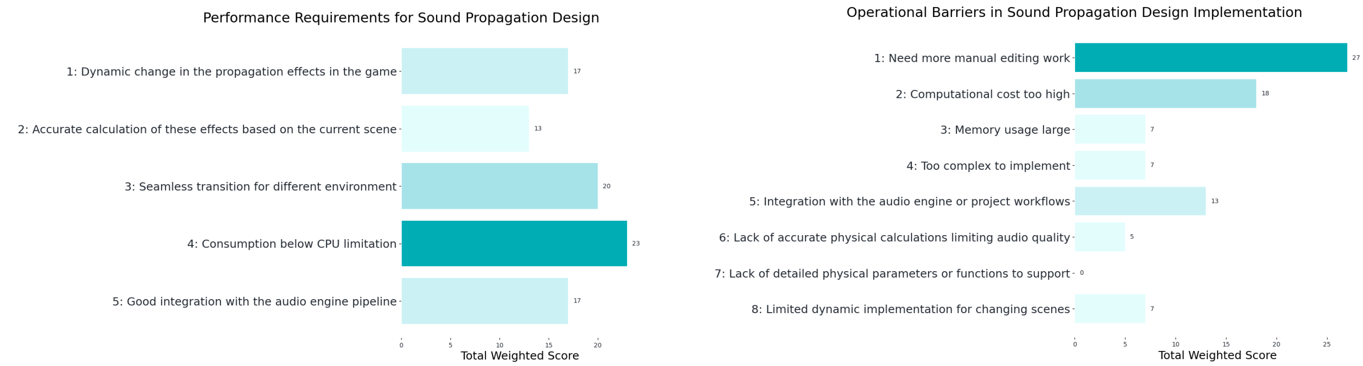
Among the highest-ranked performance requirements were keeping *"computational consumption within CPU limitations"* and ensuring *"seamless transitions across different environments"*, meaning sound changes smoothly and naturally when a player moves between areas, which is shown in Figure 3a. Notably, these priorities closely correspond to the key challenges identified in Figure 3b, where the most significant barriers to achieving these goals were the "*need for extensive manual editing*" and excessive "*computational cost*."

Computational constraints remain a persistent challenge, often compelling designers to compromise by opting for already field-tested solutions rather than experimenting with other, more accurate but resource-intensive approaches. Preprocessing acoustic data is a common workaround that reduces runtime load, but it doesn't lower the overall computation and lacks flexibility for dynamic environments, making interactive updates challenging for anything beyond basic physics-based solutions. Similarly, achieving smooth transitions between different environments still requires significant manual effort, as current tools offer only basic transition support. As game environments become more complex, the workload for designers increases substantially.

Interestingly, highly accurate physical calculations for sound propagation were ranked the lowest priority. Only one designer reported validating their sound propagation effects against physical measurements. This perspective naturally leads us to further examine the specific trade-offs encountered during implementation.

2) Trade off in Implementation: Our analysis examined how designers allocate effort among four key sound propagation effects in their projects. Reverb ranked as the highest priority, followed closely by occlusion (32% of total effort). In contrast, the decision to invest additional effort in diffraction-related effects appears to be context-dependent, driven by factors such as the need for *"significant playtime"*, *"clarity of sound"*, or *"support for narrative elements"*.

Another aspect examined was the importance of using physically accurate methods, such as simulation or calculation, in real-time dynamic sound design for games, rated on a scale from 1 to 10. On average, respondents rated this criterion a moderate 6 out of 10, indicating that while they acknowledge the benefits of physical accuracy, they do not consider it critical for achieving the desired auditory outcome. When considering the relationship between improved physical accuracy and overall gaming experience, three distinct preferences



(a) (b)

Fig. 3: Example of performance and challenges rank (scores weighted)

emerged: roughly 54% of respondents advocate for balancing accuracy with creative control, about 31% believe that accuracy is fundamental to achieving immersive experiences, and the remainder adopt a context-dependent approach. While accurate acoustic modelling can provide realism, its benefits must be weighed against practical limitations and the overall impact on user experience.

C. Diffraction

Practical implementation choice were investigated in the survey for handling diffraction, obstruction, and occlusion, as well as the critical parameters designers seek to control. Analysis of the responses revealed that built-in audio engine features are by far the most commonly used solution, likely reflecting the widespread reliance on middleware in the industry. However, approximately one-third of respondents indicated that they supplement these middleware solutions with in-house algorithms, implying that the standard offerings sometimes fall short of their needs.

One key question was whether low-pass filtering (LPF) alone is adequate for achieving specific desired diffraction effects. Responses were split almost evenly—roughly 53% of participants viewed low-pass filtering as adequate, while around 41% deemed it insufficient to achieve the effect they intended. Respondents who supported low-pass filtering emphasized its practical advantages, particularly its computational efficiency and conventional use in game audio. One respondent noted: *"It is simple, obvious, effective, cheap and players understand the conventions"*. Several respondents highlighted the effectiveness of low-pass filtering when combined with other parameters, such as volume control and reverb send levels, suggesting a layered approach to sound propagation implementation. Conversely, critics of low-pass filtering noted its limitations for player immersion, with one noting: *"It's a good base, but immersion is improved by reverb, multi-band freq(uency) control, and reflections"*. The artificial nature of filtering implementation was also raised as a concern, with one respondent observing that it sounds too much as if it were manually processed. Some respondents pointed out that *"low-pass can't really add the depth in it, it can't perform by itself"*, and suggested that high-pass shelf filtering is more natural, and *"allows for better sound/ accuracy/ believability"*. Even those who answered *"no"* typically qualified their responses with alternatives that still used some forms of filtering rather than other techniques.

Furthermore, to examine the parameters designers prioritize when modifying diffraction, obstruction, and occlusion in game audio, respondents were asked to rank the top three aspects they consider most important for adjustment. The most frequently selected parameters were (1) *"the relative position of the source and listener for diffraction"* and (2) *"the transmission loss coefficient of the obstacle"* for obstruction and occlusion.

D. Reverberation

Reverb emerged as the most critical and perceptually noticeable effect in spatial audio among our respondents. Participants consistently allocated the highest proportion of their implementation effort to reverb and ER in their projects.

The order of ER is related to geometry-based calculations, with increasing orders leading to significantly greater computational complexity. In our survey, approximately 70% of respondents indicated that one or two orders of reflections were sufficient for achieving the desired spatial effect. Only a small number advocated for higher-order reflections. When asked to describe how they conceptualize ER in games, most responses reflected a practical rather than a theoretical understanding of the concept: *"early"* and *"reflection"* were consistently acknowledged, but few participants referenced specific temporal thresholds, such as milliseconds or initial time delay windows [5]. Some responses, however, described ER in more subjective terms, referring to it as the *"second sound"* or an *"indirect sound"*.

Another key aspect of ER explored in the survey was the perceived directionality of it. Over 70% of respondents considered ER's directional cues to be important for player immersion, and they believed the direction of ER could be heard. Their estimates of the distance at which ER directionality becomes noticeable varied widely from as little as 1m to as much as 100m. Others mentioned distances in the range of 5m to 20m or 80m to 100m, suggesting a broad diversity in how ER was conceptualized and implemented across different game development contexts and subjective experiences.

To examine how designers implement ER and reverb, the survey asked about participants' preferred methods and prioritised parameters. The results revealed two dominant approaches: One is middleware solution or plugins, and the other one is in-house solutions. Only one respondent mentioned using baked ER solutions to optimize computational efficiency. When asked about their most priority parameter for modifying reverb design, the top-ranked was *"accuracy of the acoustic space"*. However, *"accuracy"* in this context does not necessarily refer to strict physical precision but rather to perceived authenticity, aligning with the game's narrative and emotional objectives.

V. Discussion and Implications

This section will revisit the research questions outlined in the introduction and provide a discussion based on the survey results and their broader implications. The questions are as follows:

1) What are the challenges to applying advanced sound propagation models in practical game development?
2) To what extent does accuracy influence designers' expectations and implementation of sound propagation effects?
3) How can these insights inform future research and development in game audio?

A. RQ1: The Pragmatics of Design Work

1) The Gap Between Theory and Practice: Survey responses reveal a clear disconnect between academic acoustic and audio research and practical game audio implementation. What reflects this is that acoustic-related terms such as *"obstruction"* and *"occlusion"* are employed in a practical, engineering context rather than defined by rigorous theoretical formulations. Although diffraction is well established in physics, its implementation in game audio has evolved into several specialized variants. This indicates that designers are primarily concerned with using terminology that effectively communicates practical functionality rather than adhering strictly to formal acoustic definitions. Similarly, respondents did not indicate a distinct separation in their approach to implementing diffraction, obstruction, and occlusion effects. They were more interested in similar practical approaches and integration, suggesting their more interests in methods that reliably *"get the job done"*.

Given this, rather than requiring designers to adopt a more rigorous acoustic understanding, it may be more effective for developers to tailor tools that align with designers' intuitive workflows while still leveraging acoustic principles.

2) Tool Limitations and Integration Challenges: After comparing the desired performance requirements with the challenges encountered during implementation, one unavoidable constraint emerges—the limitations of existing tools. Designers reported difficulties in accessing adequate tools to effectively support their workflow, suggesting that developing an efficient and accessible tool for testing and refining these effects remains a significant challenge.

In addition, CPU constraints and the high manual workload continue to pose substantial barriers. While excellent algorithms or technology exist, the practical challenges lie in integrating these effects seamlessly into the overall game architecture. It was suggested that engineering integration issues may outweigh the challenges inherent in an acoustic effect's implementation.

While physics-based methods provide valuable frameworks, they are often too computationally demanding or inflexible for real-time applications. Researchers continue to develop high-fidelity algorithms, designers continue to struggle with compatibility, performance constraints, and the lack of efficient methods to integrate these into real-time applications. The need for more intuitive, adaptable solutions calls for closer collaboration between researchers and industry professionals, which meets practical demands.

B. RQ2: Rethinking the Relationship

In games where sound propagation is considered, immersion and presence are frequently cited as essential components of the player experience in the game worlds. For example, [17] explores the relationship between audio (as a concept) and PX, yet there is limited research on the more granular aspects of audio creation and individual elements. To explore whether a higher level of precision in sound modelling helps designers achieve their intended goals, we examined how accuracy shapes designers' expectations and decision-making processes. One of the most revealing insights from the study is the complex relationship between physical accuracy and perceived immersion.

1) The Role of Tools: In current industry practice, the development and integration of tools play a more significant role in shaping sound designers' workflows. The dominance of middleware solutions, such as Wwise and FMOD, highlights how existing tools influence both technical and conceptual approaches to sound propagation. Designers often rely on these platforms not only for implementation but also as a reference for defining their understanding of key acoustic concepts without necessarily understanding the underlying physics. As one participant noted, *"Before that, I hadn't had the slightest idea how to change these things"*, suggesting an insight: the available tools actively shape the way sound designers conceptualize and implement spatial audio. Similarly, when implementing obstruction and occlusion effects, designers prioritize the same parameters, suggesting that the existing tools are shaping their practical differentiation.

2) Experiential Accuracy: When asked about the order numbers of ER, one participant stated that the number should be determined purely by perceptual validation – "*until it sounds right*." This raises the question: What does it mean for ER to "*sound right*"?

Our findings indicate that designers often associate ER with spatial perception, particularly in terms of room size and surface material properties. According to acoustic theory, the first few reflections that reach a listener's ears within approximately 100 milliseconds constitute ER [18]. When the interval between successive reflections is below 50 milliseconds, human auditory perception tends to fuse them into a single auditory event due to the Haas effect [5]. If a single reflection can be heard at intervals greater than 50 milliseconds, it will be perceived as a distinct *"echo"* rather than part of ER. This usually occurs when the reflective path length is at least 17m (simply multiplying sound speed and time), which is more likely in large spaces or outdoors. This might explain some designers' responses when they referenced ER using terms like *"first indirect sound"* or *"perceivable delayed sound"*, suggesting that they were referring to an audible reflection rather than a strictly defined ER. A similar observation was made about the direction of the ER. Some respondents noted that *"even a meter away, (I) would like to be able to hear coming from the left or right"*. This aligns with their preference for perceiving this kind of reflection in outdoor environments, where reflections travel longer distances before reaching the listener. In contrast, in closed rooms such experiences are less familiar since the reflections in them are usually masked by the general reverberation of the room, making its perception less distinct [5].

Given this, efforts to artificially exaggerate the perception of ERs in indoor scenes may extend beyond conventional acoustical modelling and enter the realm of creative sound design: a preference for implementing ERs (or should be described as echo) in a way that allows dynamic control over its level and distance has been expressed. An ideal implementation would allow for transitions between being imperceptible and *"giving the slapback feel"* with distance changing, like *"push meters out" "rather than specific numbers"*. The term *"echo"* might still be too formal to describe the effect sound designers want, as echo involves specific requirements for time intervals or distances. It might be clearer to refer to this effect only as *"reflection"* without *"early"*, which could be changed and scaled as a parameter. This assumption was emphasized when participants were asked how to achieve directionality if they believe an ER's direction is important, as they think *"this is where having a system that places early reflection slapback on a wall or geometry is useful"*. This suggests a strong inclination toward parameterized control, where designers can adjust their ER characteristics to match the desired spatial effect, rather than relying on rigid, physically accurate modelling.

At this point, whether ERs can be accurately perceived as it occurs in a physically correct manner becomes a secondary concern. It is clear that many participants leveraged ER (or echo) not for strict physical accuracy, but as a tool to enhance spatial impression and immersion for players' auditory experience to *"add some depth to the sound"*, or *"game it by having discrete left and right channel delays"*. One respondent stated: *"I pick reverb first, and then adjust ER on the reverb based on the size of the room"*, indicating more artistic manipulation of perceived space.

Despite their belief that the above approach brings participants closer to or justifies the world's realism and aesthetics, it is clear that the true nature of the real world does not align with their preferences. While physics-based approaches provide a foundation for realism, designers prioritize creative flexibility that allows for deviation from real-world acoustics when necessary. This conclusion is also highly consistent with the response to the last survey question: what is the priority parameter to modify for reverb design? As it was mentioned in the results part, *"Accuracy of the acoustic space"* becomes the most critical parameter. They're seeking what is called *"experience accuracy"* - how well the acoustic space serves the game's creative intent rather than how precisely it models a real-world acoustic. It is interesting to note that *"accuracy"* is likely a flexible parameter that can be adjusted to align with the artistic direction.

This top priority also reveals a fascinating paradox in game audio development practice: designers simultaneously embrace physics-based acoustic simulation while they also desire creative freedom to deviate from physical accuracy. This duality reflects how scientific accuracy serves not as an end goal but as a springboard for creative expression that can enhance or transcend reality based on artistic vision and gameplay needs, which also observed in game designing [19].

This finding has significant implications for the future development of sound propagation effects in games. The assumption that increasing computational power will naturally lead to better audio realism is challenged by the observed industry trends: As seen in this discussion, designers favour methods that allow for greater artistic control that impacts player experience rather than strictly adhering to physically accurate simulations. This indicates an industry trend toward perceived plausibility, ensuring that sound design serves the narrative and gameplay experience. Even if computational advances enable high-fidelity physics-based simulations, their practical value is often diluted by the complexities of game design. As a result, pursuing increasing realism is not necessarily a priority in game audio development. This was emphasized by a participant *"Reverb is a good example of an area where sound designers waste far too much time worrying about how accurate and realistic it is, only for it to be lost in the mix of music and effects"*. In other words, how immersive the experience may be might not increase proportionally with resource investment. The improvements in physical accuracy resulting from increased computational power may exceed the perceptual threshold of players, rendering such improvements risk diminishing returns. This was also observed by a participant who explained: *"Not many players will be able to tell the difference, even when asked to comment on this in a playtest"*.

Furthermore, allocating additional computational resources to improve physical accuracy could increase the operational complexity of tools, potentially burdening designers rather than alleviating their workload.

C. RQ3: Implications for Future Development

Based on these insights, some implications can be made for future development in game audio workflows and research, which also answer the last research question:

1) Perceptual-driven over physical accuracy: Research could explore how to optimize sound propagation for perceptual effectiveness, ensuring that computational resources are allocated efficiently.
2) Tool-driven innovation: Future advancements could focus on streamlining implementation workflows and reducing the workload.
3) Cross-disciplinary collaboration: Bridging the gap between academia and industry has been a challenge for games research (see e.g. [20]). This requires ongoing dialogue between researchers, game developers, and audio professionals to create solutions that align with both scientific principles and industry demands.

D. Limitation

As with any survey-based research, this study has limitations. The sample size was relatively small as the study targeted experienced professionals, which limits the potential generalizability. While this approach ensured in-depth insights from experienced designers working within established industry frameworks, it potentially under-represented independent designers with different constraints.

This study focuses exclusively on physics-based effects without considering other implementation approaches. It was restricted to specific game genres, such as simulation games, focusing only on cases where sound propagation plays a critical role in design, thereby excluding broader discussions on general audio implementation. Meanwhile, the structure of the survey itself also introduced certain limitations. The predefined response options may have constrained participants' answers, potentially overlooking nuances in their decision-making processes. The length of the survey was constrained to ensure participant engagement and completion rates, limiting the number of questions that could be included. As a result, some topics could not be explored in depth, and certain nuances in sound propagation design may not have been fully captured.

E. Future work

Further research can focus on creating approaches that balance physical accuracy with real-time adaptability. For instance, perceptually optimized propagation models dynamically approximate spatial effects and can provide an efficient alternative to traditional simulation or precomputed methods, as well as middleware enhancements that integrate streamlined, automated processes for designers without imposing technical overhead.

VI. Conclusion

This study offered an overview of current industry practices and tried to bridge the gaps between academic research and game-world implementation. The findings suggest that while physics-based models provide a valuable foundation, practical implementation prioritizes perceptual plausibility, computational efficiency, and workflow adaptability.

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