

Review

Designing Sustainable and Acoustically Optimized Dental Spaces: A Comprehensive Review of Soundscapes in Dental Office Environments

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Featured Application

This review offers practical guidance for designing acoustically optimized and sustainable dental clinics. It supports architects and clinicians in applying biophilic principles, lean workflows, and sound-reducing strategies to enhance patient experience and operational efficiency.

Abstract

The acoustic environment of dental clinics plays a critical role in shaping patient experience, staff performance, and overall clinical effectiveness. This comprehensive review, supported by systematic search procedures, investigates how soundscapes in dental settings influence psychological, physiological, and operational outcomes. A total of 60 peer-reviewed studies were analyzed across dental, healthcare, architectural, and environmental psychology disciplines. Findings indicate that mechanical noise from dental instruments, ambient reverberation, and inadequate acoustic zoning contribute significantly to patient anxiety and professional fatigue. The review identifies emerging strategies for acoustic optimization, including biophilic and sustainable design principles, sound-masking systems, and adaptive sound environments informed by artificial intelligence. Special attention is given to the integration of lean management and circular economy practices for sustainable dental architecture. A design checklist and practical framework are proposed for use by dental professionals, architects, and healthcare planners. Although limited by the predominance of observational studies and geographic bias in the existing literature, this review offers a comprehensive, interdisciplinary synthesis. It highlights the need for future clinical trials, real-time acoustic assessments, and participatory co-design methods to enhance acoustic quality in dental settings. Overall, the study positions sound design as a foundational element in creating patient-centered, ecologically responsible dental environments.

Keywords: dental acoustics; healthcare soundscapes; biophilic design; sustainable dentistry; lean management; patient-centered care; environmental psychology; clinical architecture



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1. Introduction

Sound in healthcare environments is increasingly recognized as a critical factor influencing well-being, yet dental clinics remain one of the most overlooked settings for

acoustic optimization [1,2]. Characterized by intense, high-pitched mechanical noises and limited auditory insulation, dental soundscapes can generate negative physiological and psychological reactions in patients and practitioners [3]. The dental environment is uniquely vulnerable to acoustic stress due to the proximity of sound sources, the invasive nature of procedures, and often, the lack of noise-absorbing architectural features [2,4].

A growing body of literature has shown that elevated noise levels in dental clinics, often exceeding 80–85 dB, are associated with stress, discomfort, and even temporary hearing disturbances [5]. Studies focusing on patients' perceptions of sound in the dental setting highlight how auditory exposure is often linked to fear, helplessness, and avoidance behaviors [4]. It was further noted that the sonic environment can compromise quality assurance by hindering communication and concentration, while also intensifying patient anxiety [2]. For dental professionals, prolonged exposure to tonal and high-frequency sounds contributes to fatigue, decreased performance, and reduced job satisfaction [2,6]. These sound-related effects are not merely occupational hazards, but systemic challenges that impact operational efficiency and patient trust [7].

Beyond clinical concerns, the architectural and design aspects of dental clinics play a substantial role in shaping the auditory experience. Traditional dental spaces often prioritize spatial efficiency over acoustic comfort, resulting in high reverberation times and sound leakage between operatories [2,8]. Acoustic interventions, such as sound-absorbing ceiling tiles, zoning layouts, and enclosed operatories, drawn from hospital design, have been shown to enhance patient recovery and satisfaction by reducing stress-inducing stimuli [9,10]. In parallel, the integration of biophilic and salutogenic design principles into healthcare architecture has gained momentum as a method for promoting psychological resilience and environmental sustainability [11]. Exposure to natural materials, plants, and daylight, combined with calming soundscapes such as music or water features, has been shown to improve patient mood and perception of care [12–15]. These approaches extend beyond aesthetics, functioning as therapeutic tools that control sensory overstimulation, including noise-related stress [16,17]. Furthermore, the potential for “plant acoustics”, the concept that plants respond to and emit sound, represents an emerging frontier in designing responsive and interactive healing spaces [18].

Despite growing interest in healthcare acoustics more broadly, a significant gap persists in the literature concerning dental clinics specifically. While hospital acoustics are increasingly standardized and regulated, dental settings continue to lack clear guidelines or best practices for soundscape design. Moreover, few studies attempt to integrate acoustic optimization with sustainable or biophilic design practices tailored to dental environments [11,19–21]. This review aims to systematically examine the characteristics and impact of soundscapes in dental environments and to propose integrative design strategies that align with both sustainable development and patient-centered care. Drawing on findings from acoustic engineering, environmental psychology, clinical dentistry, and healthcare architecture, this review addresses the urgent need to reimagine dental spaces as environments of holistic healing, where sound is not an incidental byproduct but a designed and therapeutic component of care.

2. Materials and Methods

2.1. Literature Search Strategy and Eligibility Criteria

This review adopted a comprehensive hybrid approach. While it employed systematic search strategies and structured inclusion criteria, it also integrated conceptual frameworks, narrative insights, and interdisciplinary perspectives, thus adopting a comprehensive review methodology. The aim was to investigate the relationship between soundscapes, user experience, and sustainable acoustic strategies in dental environments, taking into

account literature found in healthcare settings. The review included multiple phases of data collection and analysis to ensure thematic relevance, methodological quality, and interdisciplinary depth [22]. The search was conducted across four major academic databases: PubMed, Scopus, Web of Science, and Google Scholar. Keywords used in various Boolean combinations included the following: “dental acoustics,” “dental clinic noise,” “sound environment in healthcare,” “soundscape in dentistry,” “patient noise perception,” “sustainable architecture dental,” and “biophilic acoustic design.” Additionally, a curated internal dataset in CSV format containing indexed noise-related research was analyzed. To enhance coverage, backward and forward citation tracking was performed, and additional peer-reviewed open-access articles were gathered via Google Scholar. Manual screening ensured that only articles aligned with the acoustic context of dental or healthcare environments were included.

The inclusion criteria were peer-reviewed publications between 2014 and 2025, full-text availability (open access or PMCID), with a focus on acoustic environments, soundscapes, or noise in dental/healthcare settings, and studies assessing psychological, physiological, architectural, or experiential outcomes related to sound. The exclusion criteria were as follows: non-healthcare-related acoustic studies, conference abstracts or non-peer-reviewed documents, articles not in English or not available in full text, studies without methodological transparency or sound relevance, and those with inadequate methodological detail or duplicated content.

2.2. Study Selection, Data Extraction, and Thematic Analysis

A total of 83 studies were initially identified. After the removal of 10 duplicate records, 73 studies remained for initial screening. These were assessed based on predefined inclusion and exclusion criteria, resulting in the exclusion of 23 studies due to reasons such as lack of methodological transparency, irrelevance to healthcare soundscapes, non-peer-reviewed format, language restrictions, or lack of full-text availability. Following this, 50 studies met the criteria and were retained for further analysis.

To enrich the dataset and ensure comprehensive thematic coverage, 10 additional articles were sourced through Google Scholar using the same Boolean keyword combinations applied in the primary database search. The selection of these articles was based on their relevance to dental or healthcare acoustic environments, full-text availability, and compliance with the predefined inclusion criteria. These additions specifically addressed gaps in areas like biophilic architecture, patient-centered sound design, and perception of acoustic environments in clinical and dental settings. In total, 60 studies were included in the final synthesis and subjected to thematic content analysis based on metadata such as authorship, publication year, study type, methodology, outcomes, and relevance to acoustic optimization in healthcare. In Figure 1, the PRISMA flow chart of the study is presented. The review adhered to the PRISMA 2020 guidelines, ensuring methodological strength, transparency, and comprehensive reporting (<https://www.prisma-statement.org/prisma-2020-flow-diagram>, accessed on 16 April 2025) [23].

All included literature was subjected to thematic content analysis. Key data points, authorship, year, study type, methodology, results, and relevance to acoustic optimization were extracted and tabulated. Table 1 was used to classify findings and map the diversity of approaches across disciplines. This triangulation ensured comprehensive coverage of clinical, psychological, architectural, and sustainability-related dimensions of healthcare and dental soundscapes.

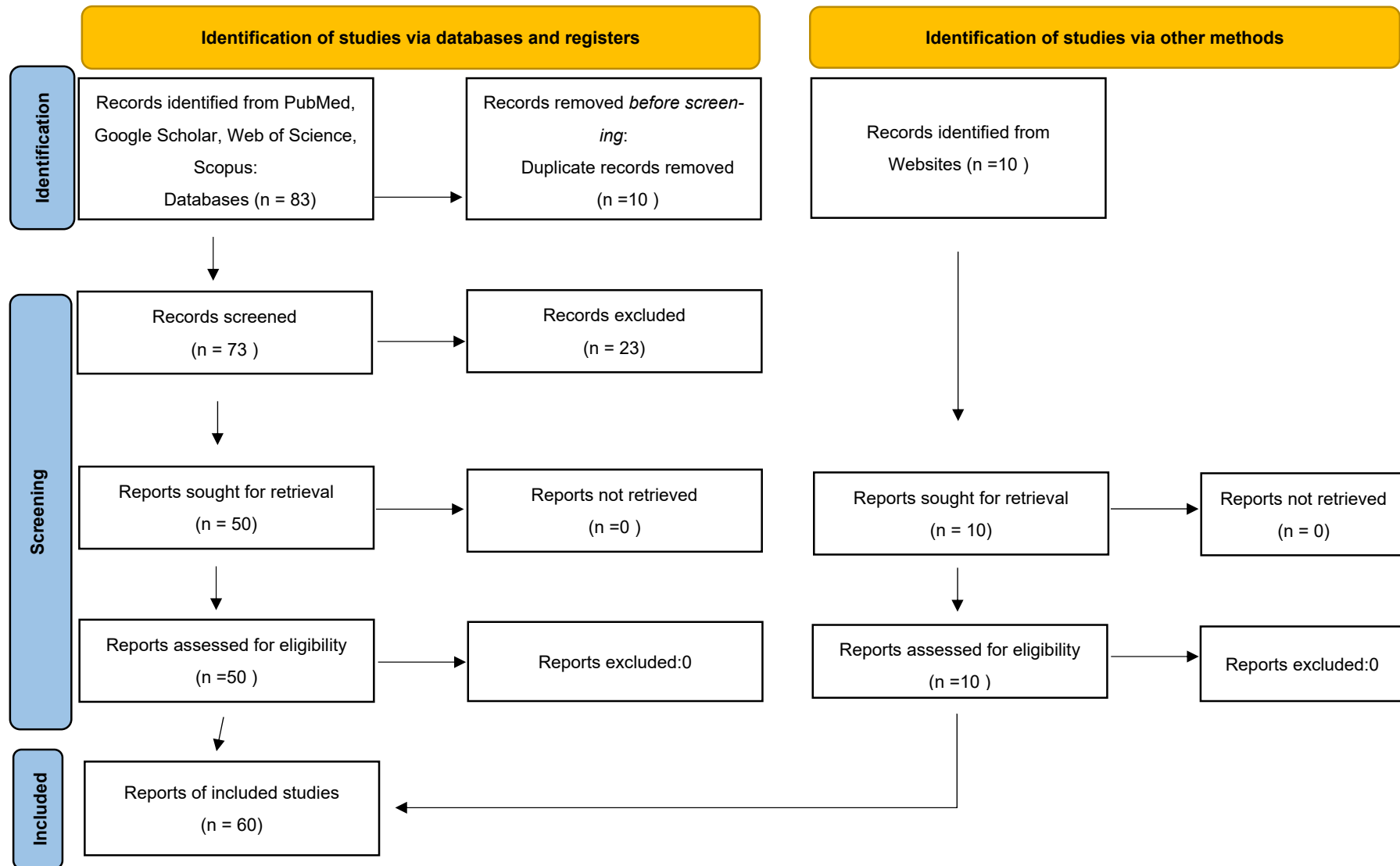


Figure 1. The PRISMA flow chart of the study.

Table 1. Multidisciplinary evidence on acoustic environments in dental and healthcare settings.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
1	Tahvili et al. (2025) [24].	Cohort Study	ICU	Monitored sound levels in the ICU, identifying occurrences of noise levels exceeding 87 dBA.	Found ICU noise frequently surpassed recommended thresholds, posing risks for patients and staff.	General environmental improvements, including noise monitoring, material upgrades, and layout adjustments to reduce sound exposure.
2	Zhang et al. (2024) [19].	Meta-analysis	NICU	Review of RCTs assessing the effects of white noise on preterm infants	White noise reduced pain and improved weight gain and vital signs	General environmental improvement
3	Guidolin et al. (2024) [15].	Scoping Review	Hospital	Comparative studies of inpatient nature exposure	Nature soundscapes aid stress recovery and satisfaction	Biophilic and acoustic comfort design
4	Lin et al. (2024) [25].	Empirical Study	Healthcare	Conducted sensory mapping and assessed perceived soundscapes in healthcare environments, focusing on natural elements.	Demonstrated that incorporating water features and greenery significantly lowered patient anxiety and enhanced comfort.	Recommended biophilic and acoustic comfort design, integrating natural sounds and elements into healthcare spaces.
5	Zhang (2024) [20].	Conceptual Paper	Healthcare	Reviewed design principles and used emotional mapping to examine the sensory impact of healthcare environments.	Highlighted that biophilic design elements positively influence emotional perception through improved acoustic experiences.	Recommended incorporating biophilic and acoustic comfort design strategies, such as natural materials, greenery, and soundscapes, to enhance user well-being.
6	Jonescu et al. (2024) [26].	Modeling Study	ICU	Design-led acoustic modeling intervention	Reduced noise transmission and improved acoustic outcomes	Architectural redesign (e.g., sound-absorbing materials, spatial layout changes)
7	Elf, et al. (2024) [27].	Systematic Review	Inpatient Healthcare Settings	Comprehensive literature review of peer-reviewed studies on built environments in inpatient care	Identified major research gaps, including the lack of evidence on spatial design and environmental factors (like acoustics) affecting outcomes	Call for interdisciplinary research; emphasized patient-centered architectural design, incorporating flexible, adaptable, and sensory-sensitive spaces

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
8	Engineer et al. (2024) [28].	Book Chapter	Healthcare	Review and apply examples	Built environment influences pain perception and emotional state	Healing environment design (e.g., sleep-supportive design, family zones)
9	Tronstad et al. (2024) [29].	Protocol	ICU	Proposed a study protocol to evaluate an improved ICU environment, focusing on sensory factors.	Focus on the environment (noise, light) to optimize recovery	Suggested architectural redesign, including sound-absorbing materials and strategic spatial layout changes to optimize acoustic and visual comfort.
10	Kurniawati et al. (2024) [30].	Survey	ICU	Conducted a questionnaire-based survey among ICU nurses to assess their knowledge, awareness, and perceived needs regarding the detection of Sick Building Syndrome (SBS) in their work environment.	Identified significant knowledge gaps and a lack of training on recognizing and managing SBS symptoms, indicating risks to staff health and performance.	Recommended general environmental improvements, such as better ventilation, monitoring of indoor air quality, and incorporation of educational programs to raise awareness and support healthier workspaces.
11	Raghuwanshi et al. (2024) [31].	Review	Hospital	Review of noise effects and control strategies in hospitals	Summarized impacts and control methods	General environmental improvement
12	Rodriguez-Nogueiras (2024) [32].	Observational Study	Neuroscience Unit	Observed and recorded patient feedback on their experience of noise levels within a neuroscience hospital ward.	Patients reported high levels of perceived noise, which negatively affected their comfort, rest, and overall care experience.	Proposed general environmental improvements, including noise reduction strategies, the use of sound-absorbing materials, and spatial reorganization to create quieter, more patient-friendly environments.

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
13	Tziovara et al. (2024) [4].	Survey	Dental Clinic	Collected patient-reported perceptions of the dental clinic's soundscape, focusing on how specific sounds (e.g., drills, suction devices, conversations) were experienced emotionally and physically during visits.	High-frequency mechanical sounds were perceived as particularly stressful and anxiety-inducing, with patients reporting discomfort and reduced overall satisfaction with their care experience.	Suggested general environmental improvements such as installing sound-absorbing materials, creating quieter zones, and incorporating calming auditory elements (e.g., background music, nature sounds) to improve the patient experience.
14	Al Khatib et al. (2024) [33].	Review	Healthcare	Environmental comfort synthesis	Comfort includes biophilic sounds and views	Biophilic and acoustic comfort design
15	Armbruster et al. (2023) [34].	Longitudinal Study	ICU	Prospective study of noise levels and noise management	Interventions reduced noise, but levels remained above WHO limits	General environmental improvement
16	Antoniadou et al. (2023) [5].	Observational Study	Dental Clinic	Measured and analyzed noise levels at various locations within a university dental clinic, identifying peak noise sources and comparing results to recommended standards.	Recorded excessive noise levels exceeding comfort and safety thresholds, especially during the use of high-speed instruments, and highlighted potential impacts on both patients and staff.	General environmental improvements, including the use of sound-absorbing materials, spatial zoning to separate noisy functions, and maintenance of equipment to reduce noise at the source.
17	Deng et al. (2023) [9].	Experimental Study	Healthcare	Tested the effects of water sound interventions on stress by exposing participants to controlled water soundscapes in a clinical setting.	Found that calming water sounds reduced physiological stress markers and enhanced perceived comfort.	Recommended incorporating water features or soundscapes into healing environment designs, especially in areas intended for rest and recovery, such as sleep-supportive zones and family-friendly spaces.
18	Kumar et al. (2023) [35].	Perspective/Review	Smart Buildings	Ten principles review	Acoustic comfort is essential in smart healthcare environments	Multi-sensory and comfort-oriented design

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
19	Bergefurt et al. (2023) [36].	Systematic Review	Workspaces	Mental health metrics	Noise, privacy, and green views affect mental health	Healing environment design (e.g., sleep-supportive design, family zones)
20	Bringel et al. (2023) [37].	Observational Study	NICU	Measured ambient noise levels and correlated them with healthcare staff's cortisol levels and self-reported stress.	Found that higher noise levels were associated with increased staff stress and signs of burnout.	Suggested general environmental improvements to reduce noise exposure and support staff well-being.
21	Verderber et al. (2023) [38].	Comprehensive Literature Review	Residential Environments for Older Adults	Reviewed 17 years of interdisciplinary literature (2005–2022) on residential design for older populations	Identified key environmental factors influencing physical health, emotional well-being, and social engagement in aging	Design of age-friendly, sensory-sensitive spaces with biophilic elements, acoustic zoning, and adaptable layouts
22	Nicoletta et al. (2022) [39].	Mixed-Methods Study	Maternity Unit	Combined spatial analysis and user perception	Contributed to design knowledge for maternity care	Architectural redesign (e.g., sound-absorbing materials, spatial layout changes)
23	Antoniadou et al. (2022) [2].	Narrative Review	Dental Clinic	Reviewed existing literature and case studies on the impact of sound in dental clinics, synthesizing findings into actionable insights.	Highlighted the detrimental effects of noise on both patients and staff, emphasizing the psychological and operational challenges posed by poor acoustic environments.	Provided recommendations for general environmental improvement, including the use of sound-absorbing materials, better spatial planning to separate noisy and quiet areas, and introducing calming auditory elements to improve the overall soundscape.
24	Meng et al. (2022) [40].	Editorial	Vulnerable Groups	Overview on sound perception	Emphasized its role in well-being	Healing environment design (e.g., sleep-supportive design, family zones)

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
25	Lo Castro et al. (2022) [41].	Survey	Hospital	Conducted a survey measuring noise levels in hospital wards and collecting healthcare workers' subjective reactions to the noise environment.	Found that staff reported significant stress, annoyance, and reduced well-being associated with high noise levels in the wards.	Recommended general environmental improvements, such as reducing noise through spatial planning, adding sound-absorbing materials, and monitoring sound levels to improve staff comfort and productivity.
26	Khowaja et al. (2022) [42].	Observational Study	NICU	Sound level measurements in NICU, Karachi	Increased noise is linked to more procedures and staff presence	Real-time noise monitoring systems
27	Ruettgers et al. (2022) [43].	Survey	ICU	Online survey of ICU professionals about noise disturbances	Perceived noise negatively impacted well-being	Healing environment design (e.g., sleep-supportive design, family zones)
28	Wazzan et al. (2022) [44].	Clinical Trial	Dental Clinic	Conducted a clinical trial in a dental clinic using music therapy as an intervention; measured patients' stress and heart rate before and after the intervention.	Demonstrated that music therapy significantly reduced both perceived stress and physiological stress markers (heart rate) in dental patients during treatment.	Healing environment design principles, such as integrating music systems in treatment areas, creating calm and supportive zones (e.g., sleep-supportive design, family-friendly spaces), and using soundscapes as a therapeutic element of the environment.
29	Souza et al. (2022) [45].	Implementation Project	ICU	Best practice implementation for noise control	Successful noise reduction and sleep improvement	Soundproofing strategies, such as insulation, physical barriers, and the creation of quiet zones, to sustain a restful and controlled acoustic environment.

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
30	Seyffert et al. (2022) [46].	Randomized Clinical Trial	ICU (Intensive Care Unit), Older Adults	Two-arm, parallel-group RCT testing individualized music listening in mechanically ventilated patients	Music listening significantly reduced the incidence and duration of delirium in ICU patients	Integration of music delivery systems in patient rooms; sound-zoned ICU design for non-pharmacological interventions
31	Huntsman & Bulaj (2022) [47].	Conceptual/Design Study	Residential and clinical interiors	Proposed a framework combining biophilic design with self-care strategies for individuals with chronic conditions	Biophilic interiors promote relaxation, reduce pain perception, and support emotional well-being in chronic patients	Integration of natural elements (plants, natural light, textures, sensory zones) into care-oriented interiors
32	Torresin et al. (2021) [48].	Survey + Acoustic Assessment	Residential/Urban	Survey and acoustic measurements of residential buildings during the COVID-19 lockdown.	Access to natural sounds improved well-being and acoustic comfort	Integration of biophilic elements and enhancing access to natural soundscapes.
33	de Lima Andrade et al. (2021) [49].	Systematic Review	Hospital	Comprehensive review of published studies measuring and analyzing noise levels in various hospital settings, assessing their effects on occupants.	Found that excessive hospital noise negatively affects both patients' health by increasing stress, disrupting sleep, and delaying recovery and staff performance, leading to fatigue and reduced efficiency.	Recommended general environmental improvements, such as incorporating sound-absorbing surfaces, optimizing layout to reduce noise transmission, and implementing noise monitoring and control strategies to maintain acceptable sound levels.
34	Patil (2021) [50].	Survey	Hospital	Patients' and visitors' perceptions of noise	Identified the need for real-time noise monitoring	Implement real-time noise monitoring systems to manage and control noise effectively.
35	Dzhambov et al. (2021) [51].	Cross-sectional Study	Educational	Student survey on acoustic discomfort	Mental health moderated by perception of indoor soundscapes	Multi-sensory and comfort-oriented design

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
36	Fu et al. (2021) [52].	Systematic Review	Operating Room	Review of attitudes toward noise/music in OR	Reported mixed attitudes toward noise and music in the operating room: some staff found music beneficial for concentration and stress reduction, while others considered it distracting or interfering with communication and task performance.	Suggested general environmental improvements, such as implementing controlled sound environments and establishing guidelines to balance beneficial auditory stimuli (like music) with the need for clear communication and reduced disruptive noise.
37	Allahyar & Kazemi (2021) [53].	Experimental Study	Urban healthcare and educational settings	Evaluated the psychological and neurophysiological effects of different landscape design elements on children through structured observation and assessment tools	Found that natural landscape features such as vegetation, sensory gardens, and organic materials positively influenced neuropsychological well-being, attention, and stress reduction in children	Integration of green zones, sensory gardens, and nature-based play or waiting areas into dental and pediatric clinic architecture.
38	Noble (2020) [54].	Qualitative Study	Psychotherapy	Psychotherapy waiting room evaluation	Sound and lighting influence the perception of care	Incorporation of soft lighting and quiet, soothing sound environments in waiting areas to support emotional well-being.
39	Dabrowska (2020) [55].	Literature Review	Healthcare	Literature review of studies exploring the impact of environmental stimuli (art, sound, nature) on healing processes in healthcare spaces.	Found that natural sounds, in particular, act as positive distractions, lowering stress and improving patient experience and recovery.	Incorporation of biophilic elements and soundscapes, e.g., integrating calming nature sounds and visual stimuli into healthcare environments to create restorative, multi-sensory spaces.

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
40	Schmidt et al. (2020) [56].	Survey and Experiment	ICU	Combined survey of ICU staff and experimental exposure of participants to typical ICU noise levels to assess perceptions and physiological/psychological responses.	Identified noise as a stressor for healthcare professionals	General environmental improvement: reduction of noise through better acoustic materials, spatial planning, and staff awareness measures.
41	Jiang (2020) [57].	Qualitative Study	Hospital	Qualitative interviews and analysis of user (patients and staff) perspectives on hospital environments and design features.	Incorporating biophilic elements, such as nature-inspired soundscapes and visual connections to greenery, contributes to psychological recovery and a sense of calm.	Integrate biophilic features in both patient rooms and transitional spaces, emphasizing not just nature sounds but also views, textures, and materials that create a restorative and comforting atmosphere tailored to different user needs.
42	Ma KW et al. (2020) [58].	Observational Study	Dental Clinic	Survey of dental practitioners assessing their perceptions and experiences of noise exposure in dental clinics.	Identified that persistent noise in dental settings contributes to practitioner fatigue, reduced concentration, and potential long-term hearing damage.	Proposed implementing real-time noise monitoring systems to track and control sound levels, along with design changes to reduce occupational noise exposure.
43	Khan et al. (2020) [13].	Randomized Pilot Trial	ICU	Delirium reduction via personalized music in the ICU	Music reduced delirium severity, promising for stress environments like dental offices	Healing environment design, incorporating music-friendly, sleep-supportive spaces and family-centered zones.
44	Mohammed et al. (2020) [59].	Observational Study	Surgical Suite	Measured noise levels during surgeries under regional anesthesia and observed their effects on patients and staff	Noise levels were high enough to potentially affect communication, concentration, and patient experience	Recommended to implement real-time noise monitoring systems during procedures to manage and control disruptive noise effectively

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
45	Zhou et al. (2020) [8].	Experimental Study	Hospital Ward	Studied the acoustic impact on physiological/ psychological indices	Reported significant influence of the acoustic environment	Architectural Redesign (e.g., sound-absorbing materials, spatial layout changes)
46	Zijlstra et al. (2019) [60].	Experimental Study	Outpatient	Conducted an experimental study in an outpatient setting by implementing and testing a “non-talking” rule to assess its effect on sound levels	Demonstrated that enforcing the rule significantly reduced noise and enhanced patient comfort and experience	Suggested incorporating behavioral guidelines and spatial signage to support quieter environments and improve overall acoustic conditions
47	Benzies et al. (2019) [61].	Qualitative Study	NICU	Interviews with healthcare providers and administrators	Identified that high ambient noise levels in NICUs created barriers to effective family-centered care, including communication challenges, reduced parental involvement, and increased stress for both families and staff.	Recommended general environmental improvements, such as reducing mechanical and human-generated noise through better spatial layout, sound-absorbing materials, and staff training to support a quieter, more supportive care environment.
48	Johansson et al. (2018) [62].	Feasibility Study	ICU	Intervention to improve the ICU sound environment	Design changes were feasible and reduced noise levels	Architectural redesign (e.g., sound-absorbing materials, spatial layout changes)
49	Fan & Baharum (2018) [63].	Systematic Review	Healthcare	Systematic review and meta-analysis of studies examining the effects of natural versus mechanical sound exposure in healthcare settings	Found that natural acoustic stimuli (like water and birdsong) significantly reduce stress and promote psychological recovery more effectively than mechanical sounds	Recommended integrating natural soundscapes into design, such as water features, nature-inspired audio systems, and biophilic materials, to enhance healing environments
50	Lin et al. (2017) [25].	Mixed-Methods Study	Healthcare	Assessed patient preferences and responses to waterscape and greenscape elements in care environments.	Water and greenscape elements significantly reduced anxiety	Biophilic and acoustic comfort design, incorporating water elements and natural greenery into healthcare spaces.

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
51	Mittelmark et al. (2017) [64].	Book	Healthcare	Report of focus group discussions and expert contributions on healthcare design elements.	Identified that the presence of green materials and access to natural daylight significantly enhance perceived healing and comfort.	Integrate green materials (e.g., wood, plants) and maximize natural lighting through windows, skylights, and reflective surfaces to support a biophilic and healing environment.
52	Williams (2017) [65].	Book	General	Science communication synthesizing interdisciplinary research on sound, nature, and well-being.	Demonstrated that auditory connections to natural environments (like water, birdsong) reduce stress and enhance emotional regulation.	Incorporate biophilic and acoustic comfort design by integrating natural soundscapes into built environments to support mental health.
53	Zhang & Tzortzopoulos (2016) [66].	Framework Analysis	Healthcare	Environment and occupants' health linkage	Multi-sensory comfort is critical to healthcare performance	Multi-sensory and comfort-oriented design
54	Roe & McCay (2016) [67].	Urban Design Theory	Urban	Theoretical and conceptual exploration of urban design principles with a cross-disciplinary lens.	Demonstrated that incorporating biophilic elements (green spaces, water, natural soundscapes) in urban environments enhances mental health and reduces stress.	Incorporate natural elements and soundscapes systematically into urban and healthcare settings to promote psychological well-being and acoustic comfort.
55	MacAllister & Zimring (2016) [68].	Literature Review	Healthcare	Environmental psychology in design	Noise directly impacts satisfaction and perceived quality of care	Architectural redesign (e.g., sound-absorbing materials, spatial layout changes)
56	Fecht et al. (2016) [69].	Observational Study	Urban	Observational study analyzing spatial and temporal correlations between noise and air pollution in London.	Identified distinct spatial-temporal patterns of noise and air pollution that can influence epidemiological outcomes and health risk assessments.	Redesign urban layouts and building envelopes using sound-absorbing materials and strategic spatial configurations to reduce combined exposure to noise and pollution.

Table 1. Cont.

No	Study (Authors, Year)	Study Type	Setting	Methodology	Outcomes	Suggested Architectural Intervention
57	Kaur et al. (2016) [70].	Survey	PICU	Collected staff and family perceptions of noise sources and potential controlling strategies through questionnaires.	Identified primary noise contributors (equipment alarms, conversations, procedures) and raised awareness of their impact on care quality and stress.	General environmental improvements, including better layout planning, staff education, and use of quieter equipment.
58	Iyendo (2016) [71].	Narrative Review	Hospital Environments	Synthesized evidence from interdisciplinary studies on the impact of music and sound in hospitals	Sound and music reduce patient anxiety, improve mood, aid healing, and enhance satisfaction	Incorporation of curated soundscapes and therapeutic music zones in hospital design
59	Nieto-Sanjuanero et al. (2015) [72].	Observational Study	Neonatal Care	Measured noise levels in different neonatal care areas and evaluated implemented reduction strategies.	Identified high noise levels above recommended limits; demonstrated that targeted interventions reduced noise effectively.	Implementation of real-time noise monitoring combined with structural and operational changes to maintain acceptable levels.
60	Mazer (2014) [73].	Conceptual/Theoretical Paper	Healthcare Environments	Narrative exploration integrating environmental psychology, music therapy, and person-environment theory	Demonstrated how music, when used as part of environmental design, reduces anxiety, masks unpleasant noise, improves patient experience, and enhances healing. Emphasizes music's role as a positive auditory stimulus in therapeutic contexts	Integration of curated music into ambient design; use of person-environment auditory alignment; incorporation of music therapy as part of spatial and sensory planning in hospitals and clinics

2.3. Assessment of Study Validity

To ensure the methodological strength and internal validity of the included literature, a structured critical appraisal was conducted using validated tools. For primary empirical studies, the Cochrane Risk of Bias 2.0 (RoB 2.0) tool was applied [74]. This tool evaluates risk across five key domains: the randomization process, deviations from intended interventions, missing outcome data, outcome measurement, and selective reporting of results. Each domain is assessed and rated as “low risk,” “some concerns,” or “high risk.” An overall risk of bias score was then derived for each study (Cochrane Methods Bias). This assessment was particularly relevant for the 32 original and empirical studies, many of which employed randomized, quasi-experimental, or observational designs.

For systematic and scoping reviews (a total of nine studies), the AMSTAR 2 2025 (A Measurement Tool to Assess Systematic Reviews) instrument was used. This tool comprises 16 items and assesses the methodological quality of reviews based on criteria such as the comprehensiveness of the literature search, the presence of duplicate screening and data extraction, and whether a risk of bias was considered when interpreting the results. Each review was categorized based on the overall confidence in its findings: “high,” “moderate,” “low,” or “critically low.” [75]. For studies not amenable to these frameworks, such as narrative reviews, conceptual papers, book chapters, and design studies, a qualitative evaluation was performed [76]. These were assessed based on theoretical clarity, citation use, methodological transparency, and relevance to acoustic design in healthcare environments.

3. Results

3.1. Distribution of Study Types

Of the 60 studies analyzed, the most prominent category is original and empirical research, comprising 37 studies. These include experimental trials, observational assessments, and mixed-methods investigations conducted in real healthcare environments, such as ICUs, NICUs, dental clinics, and psychotherapy settings. They provide insights into how acoustic interventions affect patient stress, recovery, cognitive focus, and staff well-being. Beyond these, systematic and scoping reviews appear in nine studies, providing structured syntheses of current evidence. These include Fan & Baharum (2018) on the effects of nature sounds on stress [63], Bergefurt et al. (2023) on how environmental conditions affect mental health [36], Guidolin et al. (2024) on inpatient exposure to nature [15], Raghuwanshi et al. (2024) summarizing hospital noise impacts [31], Verderber et al. (2021) focusing on ICU soundscapes [38], Elf et al. (2024) investigating existing research gaps in the design of inpatient healthcare environments, highlighting the need for more evidence-based, interdisciplinary approaches to architectural features, such as acoustics, lighting, and spatial layout, that directly impact patient outcomes and staff performance [27] and Kumar et al. (2023) reviewing principles of acoustic comfort in smart healthcare environments [35]. Narrative reviews and conceptual papers, represented in 10 studies, offer theoretical perspectives and reflective syntheses. Notable examples include Zhang (2024), who maps the emotional role of acoustics in biophilic design [20], Antoniadou et al. (2022) calling for sustainable acoustic protocols in dental offices [2], and Dabrowska (2020) discussing natural sound as positive distraction [55]. Additionally, there are five studies classified as book chapters or full-length books. These include Engineer et al. (2024), who explore how architectural features impact emotional and pain responses [28], Williams (2017) on the stress-reducing power of auditory nature [65], Jiang (2020) examining soundscapes and views in healing [57], Mittelmark [64], and Roe & McCay (2021) discuss restorative design in urban health planning [67]. Additionally, six studies are literature or applied reviews. These include MacAllister & Zimring (2016) on noise and care satisfaction [68], Al Khatib et al. (2024) on environmental comfort elements like biophilic acoustics [33], Zhang &

Tzortzopoulos (2016) proposing a health-focused design framework [66], and Tziovra et al. (2024) on thematic sound analysis in dental clinical soundscapes [4]. Lastly, a small but impactful set of design frameworks and evaluation studies (two to three studies) explores design methods more directly. For example, Zhang and Tzortzopoulos (2016) provide a framework that connects the acoustic environment with occupant health outcomes [66].

In Figure 2, we present a pie chart illustrating the distribution of study types among the 60 reviewed articles.

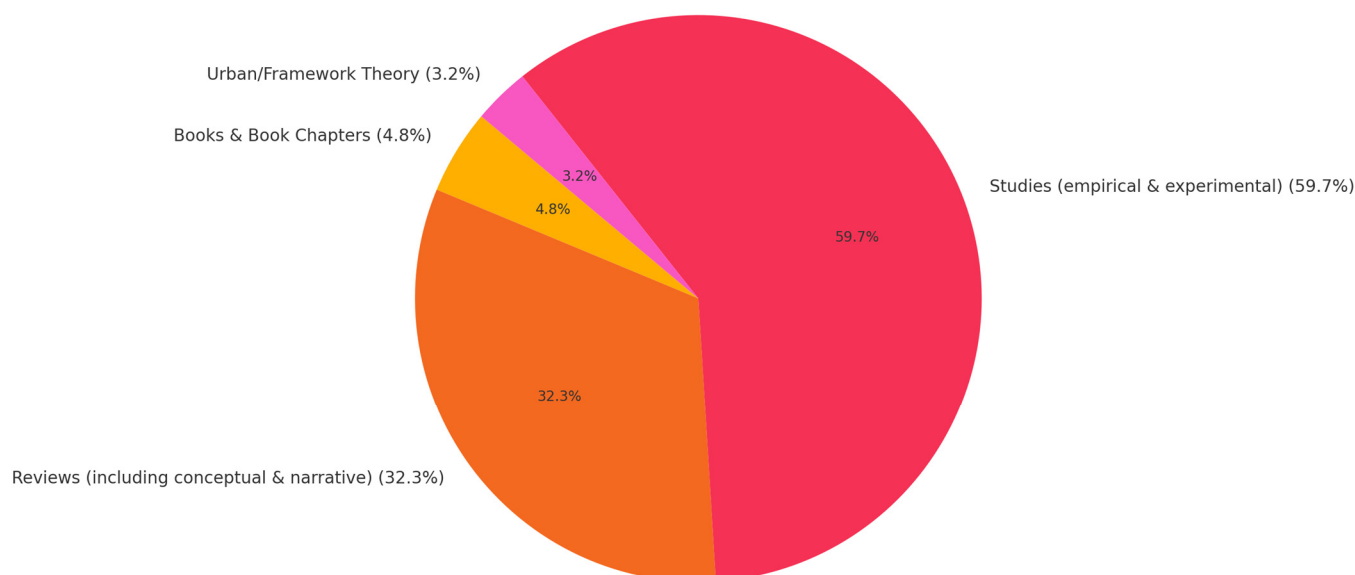


Figure 2. Distribution of summarized study types in the reviewed literature on acoustic design in healthcare and dental settings.

3.2. Publication Trends over Time

The timeline of publication shows a clear upward trend, particularly from 2020 onwards. This surge likely correlates with heightened awareness around environmental stressors in healthcare, partly catalyzed by the COVID-19 pandemic [77]. The years 2023 and 2024 especially stand out, featuring a concentration of studies exploring biophilic acoustics, nature-based sound interventions, and sensory mapping in both clinical and residential care contexts. These trends suggest a growing recognition of sound not just as a nuisance, but as a powerful therapeutic and architectural element (Figure 3).



Figure 3. Timeline of publications highlighting trends in acoustic design research (2015–2025).

3.3. Most Studied Healthcare Settings

When we examine where these studies are set, Intensive Care Units (ICUs) and Neonatal Intensive Care Units (NICUs) emerge as the most researched environments. This is expected, given these spaces' high noise sensitivity and their critical impact on vulnerable patient populations, such as the elderly or pre-term infants. Examples include Tahvili et al. (2025), who documented ICU noise levels reaching 87 dBA [24], Jonescu et al. (2024), who implemented modeling strategies for acoustic optimization [26], Armbruster et al. (2023), who observed noise reduction through lean management interventions [34], and Bringel et al. (2023), who linked NICU noise to staff burnout [37]. Studies like Zhang et al. (2024) and Khowaja et al. (2022) confirmed the physiological impact of noise on preterm infants [19,42], while Benzies et al. (2019) and Souza et al. (2022) highlighted the systemic and architectural challenges in noise control and sleep promotion [45,61]. Dental clinics also represent a significant portion of the studies, demonstrating increasing awareness of acoustics in outpatient environments. Research in this domain often centers around stress reduction through curated music or sound design, such as in Wazzan et al. (2022) and Antoniadou et al. (2023) [5,44]. Other studies, like Tziovara et al. (2024) and Ma et al. (2020), explore patient and practitioner perspectives, highlighting stress, anxiety, and hearing concerns [4,58]. Interventions include real-time monitoring systems and personalized soundscapes to mitigate negative effects. Additionally, general hospital wards, psychotherapy spaces, and healthcare environments such as smart buildings also receive attention. For example, Guidolin et al. (2024) and Lin et al. (2024) propose biophilic soundscapes using natural elements like water or birdsong to improve recovery [15,25]. Similarly, Meng et al. (2022) and Rodriguez-Nogueiras (2024) examine sound perception in vulnerable groups [32,40], while Elf et al. (2024) offer a meta-perspective on architectural design gaps in inpatient healthcare settings [7]. Deng et al. (2023) and Jiang (2020) illustrate how sensory design, particularly through water features and greenery, can reduce stress and promote healing [9,57]. Overall, these studies emphasize sound's role in mental health, perceived quality of care, and patient experience in both clinical and transitional care spaces, reinforcing the need for acoustic optimization as part of sustainable and patient-centered design.

3.4. Quality Assessment

The quality assessment of the 60 studies included in this review revealed a diverse methodological landscape with varying degrees of strength and reliability. Most empirical studies, comprising experimental, observational, and mixed-methods research, were judged as suitable for appraisal using the Cochrane RoB 2.0 tool. Most demonstrated low to moderate risk of bias, contributing valuable real-world insights despite occasional limitations in reporting transparency or measurement standardization. For example, Zhang et al. (2024) conducted a meta-analysis on white noise in NICUs [19], while Tahvili et al. (2025) and Armbruster et al. (2023) offered good observational assessments of ICU noise levels [24,34]. Wazzan et al. (2022) used clinical trial methodology to measure stress reduction via music therapy in dental clinics, showcasing strong experimental validity [44]. Further, systematic and scoping reviews, generally demonstrated moderate confidence. These included comprehensive literature syntheses, such as Elf et al. (2024), which identified architectural research gaps in inpatient environments [7], and Fan & Baharum (2018), which summarized evidence on natural soundscapes and stress reduction [63]. While structured and insightful, some of these lacked formal risk-of-bias evaluations for included studies, slightly limiting their generalizability. Moreover, narrative reviews, conceptual papers, and book chapters, appraised through qualitative tools, were found to offer strong theoretical contributions, especially in areas like biophilic design and acoustic psychology [40,46,47].

These sources enriched the review by framing the role of sound beyond mere decibel measurements, though their lack of empirical data constrains their direct applicability to clinical design contexts.

In general, the assessment confirms a solid foundation of evidence, with a balanced mix of empirical investigations and theory-driven contributions. This blend affirms the growing maturity and interdisciplinary richness of research in healthcare and dental acoustic environments. In Table S1, the detailed quality appraisal results for each included study are summarized.

3.5. Sources of Sound in Dental Settings

The dental clinic is an acoustically complex environment where various sound sources intersect, often creating high levels of auditory stimulation [2,5]. The soundscape can be categorized into four broad typologies: mechanical, environmental, human, and ambient [78]. Mechanical sounds derive predominantly from dental instruments, including air turbines, ultrasonic scalers, suction devices, and polishing tools [4,5]. Among these, the high-frequency and tonal noise generated by air turbines is the most prominent and has been measured at levels exceeding 85 dB [5]. These instruments contribute significantly to both patient discomfort and occupational hearing risks [5,58]. Also, environmental sounds are often byproducts of the building's infrastructure, such as HVAC systems, water pipes, and electrical equipment [31,32]. Although less intense than mechanical sounds, their continuous and low-frequency nature raises the general noise floor, affecting background stress and reducing the clarity of verbal communication [34,43]. In addition, human-generated sounds, including patient speech, staff communication, and procedural dialogue, also shape the clinic's acoustic environment. These can become especially disruptive in open-plan or poorly insulated layouts [5,58]. Excessive conversational noise has been found to interfere with staff concentration, reduce team performance, and elevate fatigue [52]. Finally, ambient sound refers to the cumulative reverberations and overlaps of mechanical, environmental, and human noise within the physical space [8,60]. Inadequate use of sound-absorbing materials, reflective surfaces, and poor zoning can result in increased echo and suboptimal auditory ergonomics [19,26]. This has negative consequences on both patient perception and professional effectiveness [4,5]. Together, these sound typologies underline the multifaceted nature of dental acoustics and the pressing need for integrated architectural and technological solutions. According to the reviewed literature, studies consistently emphasize that sound in healthcare environments, including dental settings, is not incidental but central to both environmental quality and care outcomes [27,40,63].

3.6. Patients' Perceptions of Dental Soundscapes

Patients' perceptions of dental soundscapes are shaped by more than just volume; they are deeply influenced by associations with pain, anxiety, and prior traumatic experiences [2,5]. High-frequency sounds from dental drills and suction devices are consistently reported as among the most distressing elements in the clinical environment [5]. These sounds have been directly linked to anticipatory fear, particularly among those with previous negative dental experiences or high auditory sensitivity [52]. Importantly, perceptual responses to sound are not uniform. Certain populations, including children, elderly patients, and individuals with neurodevelopmental conditions such as autism spectrum disorder, exhibit heightened reactivity to unpredictable or high-pitched stimuli [27,40]. This can result in increased distress, avoidance behaviors, or non-compliance during treatment. Such findings support the need for inclusive acoustic design, tailored to accommodate diverse sensory thresholds [39,51].

The psychophysiological impact of dental noise is also measurable. Exposure to sharp or sudden clinical sounds can activate the sympathetic nervous system, leading to elevated heart rate, blood pressure, and cortisol levels, as seen in both patient and staff populations [5,37,44]. In this context, non-invasive interventions such as music therapy have gained clinical attention. Wazzan et al. (2022) demonstrated that customized music sessions reduced not only subjective anxiety but also lowered objective stress markers in patients undergoing dental treatment [44]. Moreover, carefully curated background music has been shown to mask aversive clinical sounds, creating a more calming and supportive environment [2,4]. This strategy aligns with broader healing environment design principles, which emphasize multisensory comfort as a pillar of care quality [31,63]. Together, these findings affirm that dental soundscapes are not merely a technical concern but a central element of the patient's experience. Perception of sound operates as a complex interplay of physical stimuli, emotional interpretation, and environmental context, one that can and should be actively shaped through architectural, technological, and psychological design strategies [5,19,27].

3.7. Designing for Acoustic Wellness

Designing for acoustic wellness in dental settings requires adapting proven strategies from broader healthcare environments to address the unique psychological and spatial dynamics of outpatient dentistry. Hospital-based research shows that poor acoustic environments contribute to sleep disruption, physiological stress, and delayed recovery, supporting the need to extend similar design principles to dental clinics [8,19,62]. To be more specific, dental clinics often evoke anticipatory anxiety, making sound control not only a matter of comfort but of clinical importance. Tziovara et al. (2024) found that chaotic soundscapes in clinics intensify stress-related responses [4], while Antoniadou et al. (2023) quantitatively recorded noise levels surpassing comfort thresholds, urging the application of sound-absorbing ceiling tiles, wall panels, and spatial zoning [5]. Similarly, Dzhambov et al. (2021) linked poor acoustic design to decreased well-being in healthcare learning spaces, reinforcing its importance in academic and pediatric clinics [5,51].

Furthermore, strategic spatial zoning is essential: high-noise areas such as sterilization rooms should be acoustically separated from quiet zones like recovery or consultation rooms [29,39]. In open-plan clinics, sound-dampening dividers and directional barriers can reduce sound spillover, though private operatories offer the greatest control over the auditory environment [26,43].

Emerging research also supports biomedical acoustics, a concept that uses evidence-based layout planning and sound modulation to enhance healing [10]. These principles align with biophilic strategies, where natural acoustic stimuli, like water sounds or birdsong, create calming environments [25,57,63]. These can be particularly effective in waiting or reception areas, where patients experience peak anticipatory anxiety [19].

Best practices include specifying materials with high NRC and CAC ratings, using insulated doors, noise-controlling HVAC, and rubber flooring in non-clinical areas [27,50,68]. Real-time noise monitoring can further optimize these spaces dynamically [10,58]. Additionally, incorporating feedback from dental professionals is key to ensuring both functionality and sensory comfort [28]. Guidelines from industry sources discuss early-stage acoustic planning to minimize retrofitting costs and disruptions. Ultimately, as dentistry transitions toward a more holistic, preventive model, acoustic wellness must be considered a core design parameter, benefiting not only patient experience but also staff retention, workflow efficiency, and environmental sustainability [2,13,36].

3.8. Sustainability and Biophilic Integration

The integration of sustainability and biophilic design in dental settings reflects a growing shift toward holistic and patient-centered care that acknowledges both environmental responsibility and psychological well-being [78]. Biophilic design, defined as the incorporation of nature-inspired elements into architectural planning, has demonstrated measurable impacts on patient outcomes [79]. Research has shown that incorporating biophilic elements such as green walls, indoor plants, natural wood finishes, and organic textures can significantly reduce patient anxiety in healthcare environments [15]. These design features have also been associated with higher levels of user satisfaction and enhanced physiological comfort, supporting both psychological restoration and sensory well-being [79]. Evidence indicates that even modest plant-based interventions, such as dish gardens, can lead to measurable improvements in neuropsychological outcomes among pediatric patients and patients in psychotherapy offices, supporting their integration into dental operatories and waiting rooms too [53]. In addition to visual biophilia, natural soundscapes, such as bird-song or flowing water, can mask mechanical noise and reduce physiological stress. Studies by Fan & Baharum (2018), Jiang (2020), and Dabrowska (2020) confirm the anxiolytic effects of these sounds in healthcare settings, promoting calmness and enhancing cognitive clarity [55,57,63]. These findings justify the integration of nature-inspired audio environments in reception and treatment zones of dental clinics.

Furthermore, designing for sustainability extends beyond aesthetics. Environmentally friendly material choices, such as bamboo wall panels, low-VOC (volatile organic compound) paints, and rubber flooring, enhance indoor air quality and support compliance with LEED and WELL Building Standards [13,27]. Fenestration strategies that maximize daylight also reduce energy consumption while contributing to mood regulation and circadian alignment [65,66,80]. Research highlights that transitional areas such as corridors and lobbies are critical zones where patient stress often peaks, underlining the importance of targeted design interventions in these spaces [8,81]. Here, biophilic elements serve not only as visual reprieve but as sensory anchors that aid orientation and reduce anxiety, especially for neurodivergent individuals. Incorporating acoustic panels made from recycled fibers, green wall systems, and multisensory zoning strengthens the link between comfort and sustainability [10,65,66,80]. Importantly, as highlighted in the Routledge Handbook of High-Performance Workplaces (2023) and supported by Antoniadou (2024), acoustic performance and environmental sustainability are not competing priorities but are synergistic goals [82]. Acoustic comfort reduces cognitive load and supports well-being, while sustainable materials and design layouts improve long-term health and operational efficiency [26,81,82].

In this study, based on the WELL Building Standard (v1 with May 2016 Addenda, <https://standard.wellcertified.com/well>, accessed on 10 May 2025), we present a list of relevant WELL features that intersect with our themes of soundscapes, patient well-being, environmental sustainability, and dental settings (Table 2).

In summary, the convergence of biophilic and sustainable architectural strategies in dental settings contributes not only to reduced stress and better care experiences but also supports broader goals of resource efficiency, equity, and environmental responsibility [78,82–84]. These innovations redefine the dental office as a healing space, actively designed to promote calm, resilience, and ecological stewardship.

Table 2. WELL Building Standard checklist for dental spaces.

WELL Concept	Feature Name	Article Relevance
Air	VOC Reduction (Feature 4)	Use of low-emission materials in green dentistry clinics.
	Air Quality Standards (Feature 1)	Sustainable ventilation impacts perceived environmental quality.
Water	Fundamental Water Quality (Feature 30)	Indirect relevance, biophilic use of water elements as calming features.
Nourishment	N/A	Not applicable.
Light	Circadian Lighting Design (Feature 54)	Integration of lighting systems to reduce stress in dental clinics.
Fitness	Active Furnishings (Feature 71)	Less directly relevant, but could tie into ergonomic design in staff areas.
Comfort	Acoustic Comfort (Feature 80)	Central to the article, acoustic design in dental settings, noise mitigation, and stress relief.
	Sound Masking (Feature 81)	Use of music therapy and nature soundscapes.
	Individual Thermal Comfort (Feature 76)	Peripheral relevance; supports holistic sensory environments.
Mind	Biophilic Design I and II (Features 88, 100)	Directly addressed through green elements, natural soundscapes, and visual comfort.
	Stress Support (Feature 84)	Interventions like music therapy reduce dental anxiety.
	Adaptable Spaces (Feature 89)	Encourages responsive, user-centered design in dental clinics.
Innovation	Beauty and Design (Feature 87)	Aesthetic and multisensory enhancements are covered in patient journey mapping.
	Custom Features	Adaptive AI-driven soundscapes and plant acoustics meet innovation criteria.

4. Emerging Research and Novel Ideas

As acoustic awareness continues to evolve within healthcare design, novel interdisciplinary innovations are beginning to shape the future of soundscapes in dental spaces. One of the most intriguing developments is the exploration of plant acoustics, the notion that plants not only react to sound but may also emit sound frequencies in response to stress or environmental changes [65,66,81,82]. Hussain et al. (2023) explored this concept in “Plants Can Talk,” suggesting that integrating responsive greenery in healthcare settings could open pathways to dynamic, biofeedback-driven environments that are more attuned to natural rhythms and patient needs [85].

Beyond biological responses, advancements in artificial intelligence (AI) and adaptive sound technologies are paving the way for personalized sound environments. AI-

enabled systems can monitor noise patterns in real time and adjust ambient soundscapes accordingly, lowering volume during periods of peak stress or tailoring auditory stimuli based on patient profiles [86]. This concept has been trialed in dementia care and neonatal units, showing promise in modulating agitation and enhancing therapeutic outcomes [38,39,46,47,56]. Such adaptive technologies could be seamlessly integrated into dental settings to create individualized sound profiles. For instance, neurodivergent patients or those with PTSD could benefit from pre-set calming sound environments, while pediatric dental spaces might use gamified auditory cues to reduce procedural fear. Personalized acoustic zoning could also be employed through smart headphones or directional speakers embedded in dental chairs, too [4]. These approaches do not sound like a fixed background condition, but as an active therapeutic modality, programmable, customizable, and aligned with the user's sensory and emotional state [19,20]. As acoustic science intersects with biomimicry, data-driven systems, and sensory design, the potential for acoustic innovation in dental care is substantial [87].

5. Discussion

The growing convergence of acoustics, healthcare design, and sustainability reflects a marked shift from function-driven to experience-driven clinical environments, signaling a more human-centered approach to care. This transformation is particularly salient in dental settings where patients are conscious during procedures and highly sensitive to environmental stimuli [4,5]. As discussed by multiple studies, dental clinics must no longer be viewed solely as procedural spaces but as sensory landscapes that influence trust, compliance, and health outcomes [2,4,5,58].

One of the most compelling innovations explored across recent literature is the multisensory optimization of clinical settings through biophilic design. Exposure to natural stimuli, such as daylight, vegetation, and nature-inspired acoustics, has been shown to reduce stress, improve mood, and enhance overall patient experience [15,79–87]. These effects are not only physiologically significant, lowering heart rate, anxiety, and cortisol, but also contribute to a positive emotional climate in the clinic. Importantly, the presence of biophilic elements can offer patients a subconscious signal of care and safety even before the clinical encounter begins [57,58,84]. Additionally, plant-based design interventions have been linked to improvements in spatial legibility and user comfort, supporting psychological orientation and well-being in both pediatric and general dental settings [54]. Water features, used strategically, have also demonstrated calming effects, particularly in high-stimulus zones like waiting areas and corridors, and are especially effective for neurodivergent individuals or those with heightened sensory sensitivities [25,40]. Mapped against the dental patient journey, from arrival to procedure and post-treatment recovery, these principles contribute to what Devetziadou & Antoniadou (2021) describe as the “environmental scaffolding” of emotional resilience [88]. The infusion of greenery, scent, and tailored soundscapes at critical touchpoints supports the so-called “wow effect,” which strengthens perception of care quality and long-term loyalty [88].

Moreover, the use of curated auditory environments, such as music therapy, ambient soundscapes, and nature-based acoustic masking, has emerged as a non-invasive, patient-centered strategy for emotional regulation in dental and pediatric clinics. These interventions have been shown to lower anxiety, modulate physiological stress responses, and enhance perceived quality of care [10,13,44,45,60]. Integrating such auditory tools into clinical workflows supports a more calming and predictable sensory experience, particularly beneficial for vulnerable populations, including children, neurodivergent patients, and individuals with prior dental trauma [40,51]. As patients transition into treatment zones, the focus increases to green dentistry, a growing field that fuses environmental

responsibility with architectural innovation. Research highlights that elements such as energy-efficient lighting systems, low-VOC (volatile organic compound) materials, and the use of recycled acoustic panels are not only ecologically sound but also elevate the professional image of dental practices [89]. This alignment with green building standards is becoming a differentiating factor in dental clinic branding, influencing patient choice and contributing to long-term cost efficiency [90,91]. In tandem, quieter dental equipment, including low-noise air turbines and ultrasonic scalers, is recommended to reduce background stress, improve communication clarity, and protect the auditory health of staff and patients alike [2,5]. Additionally, spatial zoning, strategically separating high-noise procedures from quieter consultative or recovery areas, has emerged as a key intervention to manage cumulative sound exposure and optimize workflow within eco-conscious clinic layouts [20,58,78,92–99].

The following table summarizes practical soundproofing options, indicating where they can be applied within the dental office, their relative cost implications, and suggested priority based on their impact on noise reduction and patient experience (Table 3).

When planning acoustic interventions in dental clinics, priority should be given to areas where noise most affects patient and staff experience, like operatories, waiting rooms, and staff areas [100,101]. High-impact surfaces such as walls and ceilings benefit from sound-absorbing materials like acoustic panels, ceiling tiles, and specialized gypsum boards to reduce reverberation [5]. Flooring options like rubberized vinyl or carpet tiles help reduce impact noise, while doors and windows should be sealed or upgraded to acoustic-rated models to prevent sound leakage [93,102,103]. Additionally, zoning noisy functions (e.g., sterilization, equipment rooms) away from quiet zones and implementing sound-masking systems are cost-effective strategies that enhance speech privacy and comfort [101,103]. Low-cost solutions, such as soft furnishings and portable absorbers, can complement higher-cost interventions like structural wall insulation, which provide long-term benefits [94,101]. Moreover, biophilic and sustainable materials, including natural fiber panels and 3D-printed porous absorbers, further support these goals while aligning with ecological and patient-centered principles [92]. Collectively, these strategies reinforce the role of holistic acoustic planning in modern, therapeutic, and environmentally responsible dental architecture [92,94].

In addition, we should mention that dental noise levels typically range from 47.5 to 80.8 dB(A), with high-speed handpieces, ultrasonic scalers, and suction devices being the primary sources of discomfort for patients and staff [5,93]. Although newer equipment has reduced noise from earlier peaks over 90 dB(A), exposure above 70 dB(A) remains common and problematic [102]. Adopting recommended acoustic standards, such as reverberation times (RT60) of 0.4–0.6 s and background sound levels below 45 dB(A) in treatment areas, can improve communication, comfort, and perceived care quality [94,101,103].

Crucially, as we can report from the findings in this study, the emerging frontier in healthcare and dental design lies in adaptive and personalized soundscapes [92]. Recent research highlights how AI-integrated acoustic systems can dynamically adjust the auditory environment in response to patient-specific needs, reducing sensory overload for neurodivergent individuals, providing calming background tones for anxious adults, or incorporating gamified, interactive cues to ease pediatric procedures [85,93,104]. These intelligent sound environments will not only enhance patient comfort but also improve communication, reduce staff fatigue, and support procedural efficiency. They align with broader biomimetic and responsive design movements that draw inspiration from nature's feedback systems, aiming to create "healing ecosystems" where architecture, sound, light, and user behavior are in continuous dialogue [85,105,106]. Such innovations represent a

paradigm shift from static clinical settings to dynamic, emotionally attuned environments that actively support health and well-being [38,71,85,93].

Table 3. Soundproof materials and applications in the dental office.

Soundproof Material/ Technique	Application in Office Part	Priority Level (High/Med/Low)	Approximate Cost (Low/Med/High)	Additional Notes
Acoustic ceiling tiles (e.g., mineral fiber, recycled PET)	All treatment rooms, open-plan areas	High	Medium	Effective at reducing RT60 and noise spread; WELL recommended.
Wall-mounted acoustic panels (fabric-wrapped, perforated wood)	Operatory walls, waiting room	High	Medium	Enhances speech intelligibility and patient comfort.
Sound-insulated doors with perimeter seals	Operatories, sterilization room doors	High	Medium	Controls noise leakage between rooms.
Carpeting or area rugs (where hygienically acceptable)	Waiting area, consultation rooms	Medium	Low	Adds comfort and noise absorption but consider cleaning.
Double-glazed (laminated) windows	Exterior walls, partitions	Medium	High	Reduces external and internal sound transmission.
Spatial zoning and layout planning	Separating noisy (sterilization, lab) from quiet areas	High	Low	Critical to reduce cumulative stress; low-cost if planned early.
Sound masking systems (e.g., low-pitch, speech-shaped noise)	Open-plan areas, waiting rooms	Medium	Medium	It improves privacy and comfort.
Biophilic elements (plants, green walls)	Waiting areas, corridors	Medium	Medium	Adds psychological calmness and some diffusion of sound.
Heavy draperies or acoustic blinds	Consultation rooms, windows	Low	Low	Minor improvement but aesthetic and economical.
Floating floors (with underlay)	Operatories, corridors	Low	High	Major construction effort; reduces impact noise.

At the systems level, interdisciplinarity is not merely encouraged; it is essential. Collaboration among architects, clinicians, environmental psychologists, and engineers must guide both the design of new dental facilities and the retrofitting of existing ones to meet contemporary standards of sensory and psychological care [19,27,106]. Such collaborative efforts ensure that acoustic strategies are not treated as afterthoughts but are integrated from the earliest planning stages. Furthermore, design frameworks must evolve to treat acoustic quality as a core determinant of health, aligning with hygiene, lighting, and ergonomic principles [43,68]. These perspectives reinforce the need for regulatory bodies and institutional stakeholders to adopt acoustic benchmarks in dental and healthcare facility guidelines, thereby institutionalizing sound as an element of therapeutic infrastructure.

Overall, the dental clinic is evolving from a space of sterile procedural function into an experiential care hub, capable of supporting emotional health, staff performance, and environmental responsibility. Acoustic wellness is no longer an optional amenity; it is integral to therapeutic outcomes and patient trust. As this field matures, it must continue to push boundaries through research, design innovation, and policy advocacy to redefine what dental care environments can be.

Ultimately, this review proposes a critical redefinition: the dental clinic is no longer a neutral shell for technical delivery, but a carefully orchestrated sensorial environment that amplifies healing, professionalism, and sustainability. Through evidence-based design and visionary collaboration, acoustic and biophilic excellence can become signature hallmarks of 21st-century dental care. Future dental environments may feature intelligent ecosystems where walls adapt to noise, plants interact acoustically, and soundscapes are personalized in real time, ushering in a new era of responsive, human-centered, and ecologically informed clinic design.

6. Limitations and Strengths of the Study

This review presents several limitations. Most notably, there is a scarcity of randomized controlled trials specifically evaluating acoustic interventions in dental settings. Much of the evidence is extrapolated from broader healthcare environments like ICUs, NICUs, and inpatient wards (e.g., [15,24,27]), which, while relevant, limits direct applicability to dentistry. Additionally, the geographic focus of the included studies skews toward high-income regions, underrepresenting dental environments in low- and middle-income countries [41,58]. Another constraint is the emerging nature of innovations like AI-driven soundscapes and plant acoustics, which are still largely conceptual but suggested in the literature [85,93,104–106]. This makes it difficult to assess their real-world effectiveness in clinical dental settings. Finally, a notable limitation of this review is the lack of empirical data on the quantitative acoustic performance (e.g., RT60, dB(A), frequency spectra) of specific design interventions, as the included literature primarily focused on conceptual frameworks and subjective outcomes rather than technical measurements.

Despite these limitations, the review's strength lies in its interdisciplinary synthesis. It is among the first to systematically link sustainable acoustics, lean practice, and patient-centered care in dentistry, drawing from 60 screened studies across environmental psychology, healthcare design, and clinical acoustics [78,94,95]. Practical tools, such as tables, checklists, and a multi-sensory patient journey map, enhance their translational value for clinicians, designers, and policymakers [20,96,97]. Importantly, this review re-frames acoustics as a core component of dental care quality and sustainability. Integrating sound design with the principles of green dentistry and the circular economy promotes the transformation of dental clinics from purely utilitarian settings into spaces that actively support healing, emotional well-being, and sustainable operations [78]. Future research should prioritize participatory design methods, especially engaging vulnerable populations such as children and neurodivergent individuals, to ensure inclusive and adaptive dental environments. Empirical trials should evaluate the impact of real-time sound modulation, acoustic zoning, and biophilic design strategies tailored to clinical dentistry. Additionally, alignment with frameworks such as the WELL Building Standard, particularly its provisions on Comfort (Feature 80: Sound Reducing Surfaces), Mind (Feature 89: Adaptable Spaces), and Nourishment of Sensory Health, can guide the development of acoustically resilient, psychologically supportive, and environmentally responsive dental care spaces [82,97–99,106].

7. Conclusions

Acoustic design is a fundamental element of effective, empathetic, and sustainable dental care, not a secondary concern. This review has shown that soundscapes profoundly affect emotional regulation, physiological stress responses, communication, and clinical performance in healthcare units and dental settings. Given that dental patients remain conscious and psychologically engaged throughout treatment, managing acoustic conditions becomes critical for both therapeutic outcomes and overall patient experience. The modern complexity of dental acoustics calls for a truly interdisciplinary approach. Collaboration between dental professionals, architects, acoustic engineers, and behavioral scientists is essential to develop environments that are not only technically proficient but also psychologically supportive and environmentally responsible for all stakeholders. Finally, this review proposes the integration of acoustic benchmarks within dental facility guidelines and regulatory standards. It also underlines the need for future empirical studies, particularly randomized trials, real-time soundscape monitoring, and participatory co-design, to validate and refine current design strategies.

As dentistry evolves toward more patient-centered, digitally enhanced, and ecologically conscious models, acoustics must be embraced as a core design principle. Doing so will transform dental clinics from purely clinical spaces into restorative, intelligent environments that support the well-being of patients, staff, and the planet alike.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/app15158167/s1>, Table S1: Full Quality Assessment Table for All 60 Studies.

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Abbreviations

Intensive Care Units (ICUs), Neonatal Intensive Care Units (NICUs), Leadership in energy and environmental design (LEED), Performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and well-being, through air, water, nourishment, light, fitness, comfort and mind (WELL).

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