Review

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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

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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 are systemic challenges that influence 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: “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.

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The inclusion criteria were peer-reviewed publications between 2014 and 2025, full-text availability (open access or PMCID), 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: 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 through structured searches in four major academic databases: PubMed, Scopus, Web of Science, and Google Scholar, using Boolean combinations of keywords such as “dental acoustics,” “sound environment in healthcare,” and “biophilic acoustic design.” 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. 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 [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. Table 1.

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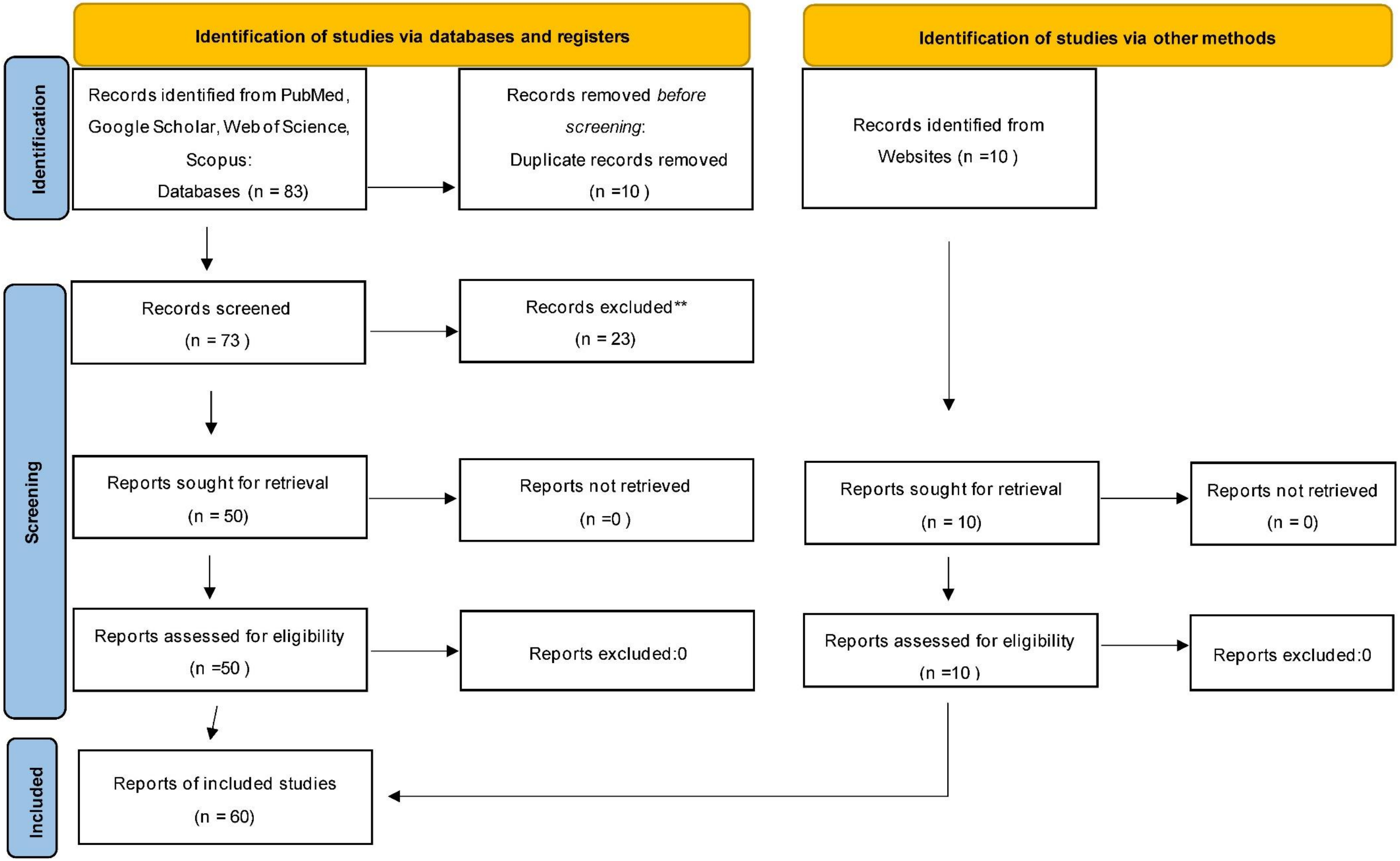

Figure 1.

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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	Measured ICU noise at 87 dBA	Confirmed excessive noise, often over threshold	General Environmental Improvement
2	Zhang et al. (2024)[19].	Meta-analysis	NICU	Review of RCTs assessing 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	Sensory mapping and soundscape assessment	Water and greenery reduce anxiety	Biophilic and Acoustic Comfort Design
5	Zhang (2024)[20].	Conceptual Paper	Healthcare	Design review & emotional mapping	Biophilic design enhances perception through acoustics	Biophilic and Acoustic Comfort Design
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
8	Engineer et al. (2024)[28].	Book Chapter	Healthcare	Review and applied 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	Study protocol for improved ICU environment	Focus on the environment (noise, light) to optimize recovery	Architectural Redesign (e.g., sound-absorbing materials, spatial layout changes)
10	Kurniawati et al. (2024)[30].	Survey	ICU	Nurses' knowledge and needs for detecting Sick Building Syndrome	Knowledge gaps found; suggested educational programs	General Environmental Improvement
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

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12	Rodriguez-Nogueiras (2024)[32].	Observational Study	Neuroscience Unit	Perception of hospital noise	Highlighted high perceived noise among patients	General Environmental Improvement
13	Tziovara et al. (2024)[4].	Survey	Dental Clinic	Patients' perceptions of dental clinic soundscape	Described sound as potentially stressful	General Environmental Improvement
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	Noise level evaluation at the university dental clinic	Documented excessive noise levels and suggested solutions	General Environmental Improvement
17	Deng et al. (2023)[9].	Experimental Study	Healthcare	Water sound interventions	Calming water sounds reduce physiological stress, improve comfort	Healing Environment Design (e.g., sleep-supportive design, family zones)
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
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	Assessed noise and staff cortisol levels	Identified link between noise and staff burnout	General Environmental Improvement
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	Sound impact in dental clinics	Outlined practices and recommendations for sound control	General Environmental Improvement

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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)
25	Lo Castro et al. (2022)[41].	Survey	Hospital	Measured noise in wards; staff reactions	Revealed stress and annoyance among healthcare workers	General Environmental Improvement
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	Music therapy intervention with stress measures	Music therapy significantly reduces stress and heart rate in dental patients	Healing Environment Design (e.g., sleep-supportive design, family zones)
29	Souza et al. (2022)[45].	Implementation Project	ICU	Best practice implementation for noise control	Successful noise reduction and sleep improvement	Soundproofing and Noise Mitigation (e.g., insulation, barriers, quiet zones)
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 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	Building soundscape perceptions during lockdown	Access to natural sounds improved well-being and acoustic comfort	Biophilic and Acoustic Comfort Design
33	de Lima Andrade et al. (2021)[49].	Systematic Review	Hospital	Reviewed noise levels in hospital settings	Noise impacts both patients' health and staff performance	General Environmental Improvement
34	Patil (2021)[50].	Survey	Hospital	Patients and visitors' perceptions of noise	Identified the need for real-time noise monitoring	Real-time Noise Monitoring Systems

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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
36	Fu et al. (2021)[52].	Systematic Review	Operating Room	Review of attitudes toward noise/music in OR	Mixed attitudes on the effects of music and noise on performance	General Environmental Improvement
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	Healing Environment Design (e.g., sleep-supportive design, family zones)
39	Dabrowska (2020)[55].	Literature Review	Healthcare	Design stimuli (art, sound, nature)	Nature sounds support healing as a positive distraction	Biophilic and Acoustic Comfort Design
40	Schmidt et al. (2020)[56].	Survey and Experiment	ICU	Survey and experimental exposure to ICU noise	Identified noise as a stressor for healthcare professionals	General Environmental Improvement
41	Jiang (2020)[57].	Qualitative Study	Hospital	User perspectives on hospital design	Biophilic design, including nature sounds, enhances recovery	Biophilic and Acoustic Comfort Design
42	Ma KW et al. (2020)[58].	Observational Study	Dental Clinic	Practitioners surveyed about noise effects	Noise is linked to fatigue, impaired focus, and long-term hearing risks	Real-time Noise Monitoring Systems
43	Khan et al. (2020)[13].	Randomized Pilot Trial	ICU	Delirium reduction via personalized music in ICU	Music reduced delirium severity, promising for stress environments like dental offices	Healing Environment Design (e.g., sleep-supportive design, familyes)
44	Mohammed et al. (2020)[59].	Observational Study	Surgical Suite	Noise exposure in surgeries under regional anesthesia	Proposed real-time noise monitoring during anesthesia	Real-time Noise Monitoring Systems
45	Zhou et al. (2020)[8].	Experimental Study	Hospital Ward	Studied acoustic impact on physiological/psychological indices	Reported significant influence of acoustic environment	Architectural Redesign (e.g., sound-absorbing materials, spatial layout changes)

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46	Zijlstra et al. (2019)[60].	Experimental Study	Outpatient	Tested non-talking rule for sound level impact	Reduced sound and improved patient experience	General Environmental Improvement
47	Benzies et al. (2019)[61].	Qualitative Study	NICU	Interviews with healthcare providers and administrators	Highlighted barriers to family-centered care due to noise	General Environmental Improvement
48	Johansson et al. (2018)[62].	Feasibility Study	ICU	Intervention to improve 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	Meta-analysis of nature sound exposure	Natural acoustic stimuli reduce stress more than mechanical soundscapes	Biophilic and Acoustic Comfort Design
50	Lin et al. (2017)[25].	Mixed-Methods Study	Healthcare	Waterscape preferences for anxiety	Water and greenscape elements significantly reduced anxiety	Biophilic and Acoustic Comfort Design
51	Mittelmark et al. (2017)[64].	Book	Healthcare	Focus groups on design elements	Green materials and natural lighting are perceived as most healing	Biophilic and Acoustic Comfort Design
52	Williams (2017)[65].	Book	General	Science communication	Auditory connection to nature reduces stress	Biophilic and Acoustic Comfort Design
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	Cross-disciplinary city planning insights	Biophilic city elements improve mental health and reduce stress	Biophilic and Acoustic Comfort Design
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	Analyzed noise and air pollution correlations in London	Found spatial-temporal patterns affecting epidemiological results	Architectural Redesign (e.g., sound-absorbing materials, spatial layout changes)
57	Kaur et al. (2016)[70].	Survey	PICU	Staff and family survey on noise sources and strategies	Identified key sources of noise and suggested interventions	General Environmental Improvement
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

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59	Nieto-Sanjuanero et al. (2015)[72].	Observational Study	Neonatal Care	Noise measurement and strategy evaluation	Proposed effective noise-reduction strategies	Real-time Noise Monitoring Systems
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

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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 9 studies), the AMSTAR 2 (A Measurement Tool to Assess Systematic Reviews) instrument was basically 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 (Table S1).

3. Results

3.1. Distribution of Study Types

Of the 60 studies analyzed, the most prominent category is original and empirical research, comprising 32 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 9 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]. Also, there are 5 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) discussing restorative design in urban health planning [67]. Additionally, 6 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 Tziovara et al. (2024) on thematic sound analysis in dental clinical soundscapes [4]. Lastly, a small but impactful set of design frameworks and evaluation studies (2–3 studies)

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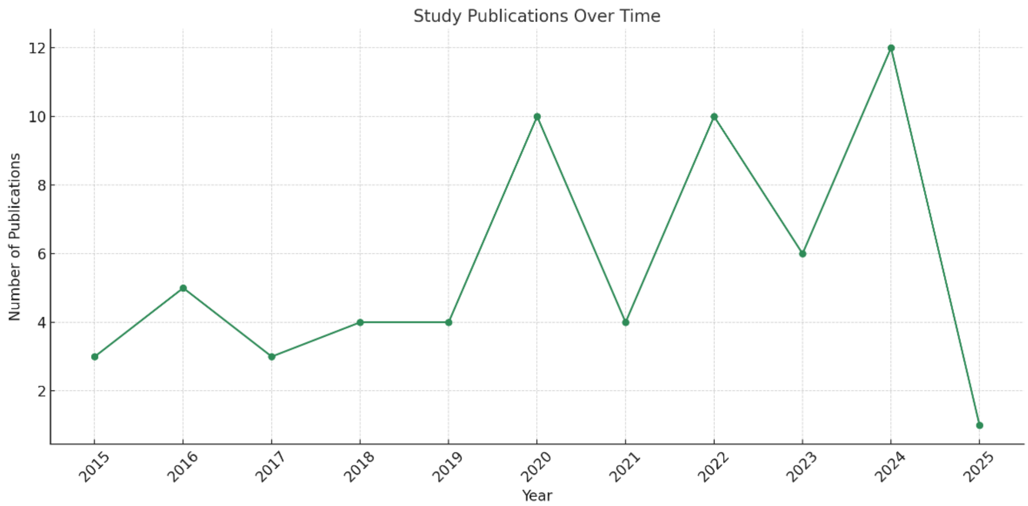
explores design methods more directly. For example, Zhang and Tzortzopoulos (2016) provide a framework that connects the acoustic environment with occupant health outcomes [66].

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.



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 [61,45]. 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) [44,5]. 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 [40,32], 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 rigor and reliability. The majority of 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, assessed using the AMSTAR 2 tool, 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 not only reduced 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 [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].

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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 birdsong 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 fosters well-being, while sustainable materials and design layouts improve long-term health and operational efficiency [26,81,82].

In this study and based on the WELL Building Standard (v1 with May 2016 Addenda, https://standard.wellcertified.com/well), 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. 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.

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	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 & 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.
	Beauty and Design (Feature 87)	Aesthetic and multisensory enhancements are covered in patient journey mapping.
Innovation	Custom Features	Adaptive AI-driven soundscapes and plant acoustics meet innovation criteria.

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.

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 [38], 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

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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, are 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 [58].

Crucially, 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

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overload for neurodivergent individuals, providing calming background tones for anxious adults, or incorporating gamified, interactive cues to ease pediatric procedures [85,93]. These intelligent sound environments 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. 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].

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]. 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 [85,93]. This makes it difficult to assess their real-world effectiveness in clinical dental settings.

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 [94-96]. Practical tools, such as tables, checklists, and a multi-sensory patient journey map, enhance their translational value for clinicians, designers, and policymakers [97-99]. Importantly, this review reframes 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 [96]. 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, 99-101].

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. Given that dental patients remain conscious and psychologically engaged throughout treatment, managing acoustic conditions becomes critical for both therapeutic outcomes and overall patient experience. Overall, the 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. 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 person-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 the website of this paper posted on Preprints.org.

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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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