Original Article

Affordable Acoustic Solutions: Enhancing Accessibility through Sustainable Soundproofing Materials

Piper Hutson¹, James Hutson²

^{1,2}Department of Art History, AI, and Visual Culture, Lindenwood University, MO, USA.

¹Corresponding Author : ejbarnes035@gmail.com

Received: 04 February 2025

Revised: 08 March 2025

Accepted: 22 March 2025

Published: 02 April 2025

Abstract - The prohibitive cost of traditional soundproofing materials, such as Mass Loaded Vinyl (MLV) and acoustic mineral wool, often limits their accessibility for smaller studios, community spaces, and individual users. This review investigates the potential of sustainable, low-cost materials to offer an alternative without compromising acoustic quality. Magnetic sound dampeners, recycled wool, egg cartons, and bottle caps, for example, provide effective sound management at a fraction of the cost of commercial products. By focusing on upcycled and readily available materials, this study presents strategies to reduce the financial barriers to soundproofing. It also examines the effectiveness of these alternatives in spaces where sound dampening, rather than full sound isolation, is necessary, such as artist studios, classrooms, and non-profit spaces. Case studies highlight the ease of installation, aesthetic flexibility, and environmental benefits of using sustainable materials. The results suggest that while these materials may not replace traditional solutions in professional-grade sound isolation, they offer a viable, accessible option for those seeking budget-conscious and eco-friendly sound management. This review provides valuable insights for individuals and organizations aiming to create acoustically balanced environments without the high cost, bridging the gap between functionality, sustainability, and affordability.

Keywords - Affordable soundproofing, Sustainable materials, Recycled sound dampeners, Accessible acoustic solutions, Ecofriendly design.

1. Introduction

Recent research in professional soundproofing technology has increasingly focused on optimizing both the materials used and the structural designs implemented to achieve maximum sound attenuation [1]. Traditionally, heavy materials like concrete and lead were employed for sound insulation due to their mass, following the mass law principle of soundproofing [2]. However, new developments have explored lighter alternatives that maintain effectiveness. Fiber-reinforced composite materials have emerged as a promising solution, leveraging carbon and glass fabrics with nano-silica hybrids [3]. These materials offer enhanced sound attenuation, as demonstrated in studies that report a significant increase in transmission loss even with reduced material thickness [4]. This innovation not only enhances soundproofing but also addresses the challenge of weight reduction, which is crucial for applications in architecture and construction, as noted by Kim, Choi and Jeon [5].

In addition to material advancements, structural designs are being optimized to enhance acoustic control further [6]. A recent study on multi-layer soundproof walls highlights the significance of incorporating various layers of soundproof materials, such as flax fiber, which can reduce noise by 21.2% at a thickness of just 1 cm [7]. This demonstrates that even sustainable, low-weight materials can be highly effective when integrated into multi-layered designs [8]. Such layered systems not only provide sound absorption but also manage reverberation, making them suitable for professional environments like recording studios and industrial workspaces. These advancements reflect the industry trend toward more lightweight, flexible, and cost-efficient soundproofing solutions that maintain high acoustic performance [9].

One of the key benefits of soundproofing beyond industrial applications is the improvement of acoustic comfort in educational environments, such as classrooms and community spaces [10]. Research shows that optimizing the acoustics of learning spaces is crucial for enhancing student's ability to focus and participate in lessons. Poor acoustics, particularly in noisy environments, can lead to reduced cognitive performance and increased stress levels for both students and teachers [11]. Studies have highlighted that reducing reverberation times and minimizing background noise significantly improves not only the overall comfort but also the learning outcomes in these settings [12]. Therefore, soundproofing plays a critical role in creating environments conducive to learning, reducing distractions, and improving communication between students and teachers.

Another significant benefit of soundproofing in nonindustrial settings is its potential to enhance creative processes, particularly in art studios and community spaces [13]. Incorporating soundproofing solutions helps reduce external noise distractions, allowing individuals to focus better on creative tasks. In art classrooms, for example, the use of sound-dampening materials can foster an atmosphere that encourages concentration and creativity [14].

Research suggests that natural soundscapes and controlled acoustic environments contribute to increased creative output, particularly in settings designed for artistic endeavors [15]. This highlights the importance of soundproofing not only for functional purposes but also for enhancing the psychological and creative experiences within these spaces.

Finally, soundproofing in community and non-profit spaces provides practical and economic benefits by reducing the need for expensive, specialized soundproofing materials [16]. Sustainable and upcycled materials, such as recycled wool, cardboard, and bottle caps, have proven to be effective at reducing noise levels in shared spaces. These materials offer a cost-effective solution for soundproofing, making it more accessible to smaller organizations and non-profits with limited budgets [17]. Additionally, these sustainable materials align with environmental goals, contributing to eco-friendly building practices while enhancing the acoustic quality of communal areas [18]. Thus, soundproofing in these contexts offers both economic and environmental advantages.

Given the substantial benefits of soundproofing in diverse environments, ranging from educational spaces to community centers and art studios, there is a pressing need for further research into accessible and sustainable solutions. This article will explore novel approaches to soundproofing, particularly focusing on cost-effective, eco-friendly materials and adaptable acoustic designs that meet the specific needs of nonindustrial users. By examining recent innovations in sounddampening techniques and sustainable materials, such as magnetic sound dampeners and upcycled insulation, this study aims to provide a comprehensive analysis of achievable soundproofing solutions for spaces where traditional methods may be either cost-prohibitive or unnecessarily complex.

The results of this investigation will offer practical insights into how these advancements can be implemented effectively, contributing to a broader discourse on making acoustic comfort more widely accessible. Thus, the significance of this research lies in its potential to bridge the gap between functionality, sustainability, and affordability in soundproofing, thereby empowering smaller institutions and creative spaces to optimize their environments without incurring prohibitive costs.

2. Soundproofing in Industrial Applications

In industrial environments, soundproofing plays a crucial role in controlling ambient noise, which can otherwise interfere with productivity, safety, and well-being [1]. In settings such as manufacturing plants or machinery-heavy facilities, effective sound control is essential not only to protect worker's hearing but also to reduce distractions and enhance communication. Traditional passive noise control methods, such as using sound barriers and dampeners, are highly effective in mitigating high-frequency noise but tend to struggle with low-frequency noise, a significant issue in industrial environments [19]. Active noise control techniques have been developed to address this gap, utilizing digital signal processors and adaptive algorithms to control noise in real-time, thus improving the overall acoustic environment [20-21]. These technologies are increasingly integrated into industrial settings where passive methods alone are insufficient.

Further advancements in active noise control have focused on more specialized applications, such as the use of sound encapsulations around noisy machinery like air compressors. These encapsulations, when enhanced with active control systems, offer improved sound transmission loss, particularly at low frequencies, which are typically difficult to manage [22]. Studies have shown that these systems, equipped with strategically placed control loudspeakers and error microphones, can significantly reduce noise within industrial environments, creating a safer and more comfortable workplace for employees [23-24]. These improvements in sound control, both active and passive, contribute to enhanced acoustic comfort and productivity in industrial settings, addressing the unique challenges posed by large-scale machinery and equipment.

Other advances include using different materials to improve soundproofing. For instance, magnetic sound dampeners offer significant flexibility in industrial applications where traditional methods may prove too rigid or invasive. These systems are particularly valued for their ability to provide adjustable damping solutions [25]. A prominent example is the use of magnetorheological (MR) dampers in vibration mitigation during the machining of complex components. MR dampers can adjust their damping characteristics in real-time through the application of a magnetic field, which modifies the viscosity of the fluid within the damper, thus allowing for dynamic adaptation to varying vibration levels [26]. This feature makes MR dampers particularly beneficial in industrial environments that require high precision, such as aerospace and automotive manufacturing. By offering adaptable damping, these systems enhance productivity and reduce machining errors [27].

In addition to their functional benefits, magnetic dampeners provide a more aesthetic and integrated approach to soundproofing in industrial settings, making them ideal for environments where both functionality and appearance are crucial [28]. For example, in certain industrial applications like high-speed rotor systems, magnetic dampeners are integrated not only to enhance performance but also to maintain overall system design coherence. These systems ensure that noise and vibrations are controlled without the need for large, obtrusive dampening mechanisms, which could detract from the overall industrial setup [29]. The integration of magnetic dampeners adds value not only in performance but also in maintaining a clean and organized operational environment [30]. This flexibility, combined with their aesthetic integration, makes magnetic dampeners a preferred choice in industries prioritizing both efficiency and design.

Furthermore, movable soundproofing panels offer a practical and cost-effective solution in industrial environments where permanent installation may not be feasible or necessary. These portable panels, which are lightweight and easy to relocate, provide flexibility in spaces requiring temporary noise reduction [31]. For instance, portable sound suppression panels have been developed for workshops, offering significant noise reduction while maintaining ease of installation, dismantling, and transportation. These panels, often made from organic and polymer materials, can be stored and moved as needed without compromising their noise suppression effectiveness [32]. The ease of mobility makes them particularly useful in multifunctional spaces such as repair shops or temporary construction sites where soundproofing requirements change frequently.

In addition to their practicality, movable panels provide an economical alternative to more permanent structures. For industries with limited budgets or where acoustic requirements vary, these panels offer a highly effective and flexible soundproofing option [33]. Vegetable fiber-based panels, for example, provide both cost-efficiency and sustainability by using renewable resources like coconut, palm, and sisal fibers. These natural materials have demonstrated competitive acoustic performance compared to conventional soundproofing materials while being more affordable and environmentally friendly [34, 3]. The use of such sustainable materials not only lowers costs but also aligns with broader environmental objectives in industrial applications, promoting the use of renewable resources while maintaining effective sound control.

3. Benefits of Soundproofing Beyond Industrial Applications

Poor acoustics in educational spaces have a significant impact on both student performance and teacher well-being. Studies indicate that excessive background noise and long reverberation times in classrooms can impair student's ability to comprehend speech, leading to decreased academic performance and increased cognitive load [35-36]. Younger children, particularly those in primary education, are especially vulnerable to poor acoustic conditions as they require clearer speech cues to process and understand lessons. In addition to speech intelligibility, poor acoustics can negatively affect student concentration, short-term memory, and social behavior in the classroom [37-38]. These findings underscore the importance of improving acoustic conditions in classrooms to facilitate a better learning environment.

For teachers, poor classroom acoustics can lead to increased stress and vocal strain. Teachers often raise their voices to overcome high noise levels, which can result in longterm vocal health problems [39]. Research shows that teachers working in classrooms with high reverberation times and significant background noise report lower job satisfaction and higher levels of fatigue after work [40]. Furthermore, teachers in noisy classrooms are more likely to experience burnout and consider leaving the profession. Addressing these issues through effective soundproofing measures, such as reducing reverberation and insulating against external noise, is essential not only for enhancing the learning environment but also for improving the well-being of educators [41].

Controlled acoustics play a significant role in fostering creativity, especially in artistic environments such as studios. Research highlights that noise and unregulated acoustics can significantly disrupt the creative process by introducing unwanted distractions and reducing focus [43]. In contrast, a well-regulated acoustic environment promotes better concentration and deeper engagement in creative tasks [44].

A study on the influence of natural sound in the art classroom showed that incorporating controlled natural sounds into the learning environment significantly enhanced students' creative output by providing a calm and stimulating atmosphere conducive to ideation and creative performance [15]. This demonstrates the profound impact that controlled sound environments can have on creative processes, particularly in spaces where focus and imaginative thinking are essential.

The benefits of soundproofing in reducing distractions are particularly relevant in environments where concentration is key to artistic expression. Distractions, such as background noise or reverberations, can hinder the ability of artists to enter a creative flow state, leading to reduced productivity. Soundproofing mitigates these disruptions by creating an acoustic environment where external noise is minimized, allowing for uninterrupted work [45]. Research supports the idea that reducing acoustic clutter in the workspace increases the likelihood of creative insights and original thinking by maintaining focus on the task at hand [46]. This suggests that artists, designers, and creators benefit from environments where the sound is carefully managed, ensuring that auditory distractions do not interfere with their creative processes. Furthermore, acoustic control has been linked to enhancing not only individual creativity but also collaborative artistic efforts. For instance, research on the role of controlled acoustics in collaborative virtual environments shows that well-managed soundscapes help participants focus on the creative task, facilitating better collaboration and the emergence of unique creative ideas [47]. In this way, soundproofing and acoustic control are not just beneficial for individual creators but also crucial for fostering creativity in group settings, where maintaining a conducive environment for focus and interaction is essential for innovative collaboration.

Moreover, research on the psychological effects of soundscapes and acoustic comfort in creative spaces underscores the importance of carefully managed acoustic environments for fostering mental well-being and creative performance [48]. Studies have shown that well-designed soundscapes, particularly those incorporating natural sounds, can significantly reduce stress and enhance relaxation, which in turn boosts creative output [49]. For instance, research on urban green spaces reveals that environments with higher levels of acoustic comfort, characterized by pleasant and natural sounds, promote positive psychological responses such as increased relaxation, cheerfulness, and energy [50]. Such findings suggest that artists and creators, when exposed to acoustically comfortable environments, are more likely to experience a calm state of mind, which facilitates the creative process. Furthermore, acoustic comfort has been linked to reduced cognitive fatigue and distraction in creative settings, helping individuals maintain focus over longer periods. A study examining acoustic environments in homes during the COVID-19 lockdown found that comfortable soundscapes are associated with better psychological well-being, particularly when engaging in tasks requiring high levels of concentration, such as working from home or creative work [51]. This demonstrates the crucial role that acoustic design plays not only in reducing stress but also in optimizing cognitive performance, making controlled sound environments a vital factor in enhancing both individual and collaborative creativity.

In conceptualizing an ideal artist studio with innovative sound management solutions, a few key acoustic elements can be integrated seamlessly into the design to optimize both functionality and aesthetics (Figure 1). Magnetic sound dampeners around the overhead lighting fixtures can serve dual purposes: reducing noise reflection from hard surfaces like ceilings while maintaining an unobtrusive, aesthetic appearance. These dampeners, being adjustable, allow the space to be easily reconfigured based on the artist's needs, ensuring the acoustic environment is as dynamic as the creative process itself. In addition, mineral wool insulation within the walls provides excellent sound absorption, particularly for low-frequency noise, creating a quieter, more focused work environment. Green Glue, a noise-dampening compound applied between layers of drywall, further reinforces soundproofing, ensuring that external noise is minimized and internal sound is better controlled. This combination of materials not only enhances the acoustics of the studio but also supports a visually clean and flexible design, ultimately creating a space where creativity can thrive free from acoustic distractions.



Fig. 1 Piper Hutson, Concept for Sound Proofing Studio with Green Glue and Magnetic Tiles, DALLE-3, 2024. Permission of the author

Likewise, several case studies have demonstrated the significant benefits of implementing soundproofing and acoustic treatments in classrooms. One study conducted in a New Zealand primary school classroom tested the efficacy of sound field systems and their impact on student performance. The study found that the use of soundfield systems significantly improved phonological discrimination, particularly in the presence of background noise. Both teachers and students reported overwhelmingly positive feedback regarding communication effectiveness, with improved student performance in noisy conditions being the most significant benefit [42]. This case highlights the importance of soundproofing in enhancing the learning environment, even in classrooms with relatively high acoustic standards.

Another notable field study conducted in Germany analyzed the effects of classroom reverberation on the performance and well-being of elementary school children. The study involved 487 students from 21 classrooms, with reverberation times ranging from 0.49 to 1.1 seconds. The findings revealed that classrooms with higher reverberation times negatively affected speech perception and short-term memory, leading to poorer performance in phonological tasks. Additionally, students from classrooms with better acoustic conditions reported stronger peer and teacher relationships and fewer complaints about indoor noise, underlining the importance of soundproofing not only for cognitive performance but also for overall student well-being [38]. These studies reinforce the critical role that soundproofing plays in fostering conducive learning environments.

The use of upcycled and sustainable materials in soundproofing community spaces offers significant practical and environmental benefits. Recycled materials, such as brick debris, rice straw, and cardboard, have been successfully utilized to create cost-effective soundproofing solutions. For example, research has demonstrated that brick debris, when processed into non-structural building materials, can effectively reduce noise levels, making it a sustainable option for community spaces that require moderate acoustic treatment [52]. Similarly, rice straw combined with recycled paper has shown high sound absorption properties, providing an eco-friendly alternative to traditional sound-absorbing materials without the need for chemical processing [53]. These examples highlight how community spaces can leverage waste materials to achieve acoustic comfort while contributing to environmental sustainability.

For non-profit organizations and smaller institutions, cost-effective soundproofing solutions are vital due to their limited budgets. The integration of recycled materials not only reduces costs but also aligns with the financial constraints faced by these organizations. For instance, the development of soundproofing elements from recycled cardboard has proven to be a cheaper alternative compared to conventional gypsum boards while providing better sound absorption at mid-to-high frequencies [54]. Such innovations offer smaller institutions the opportunity to enhance the acoustic quality of their spaces without resorting to expensive, commercially available materials, making it easier to maintain quiet, productive environments in community centers, libraries, and educational facilities.

In addition to economic benefits, the use of upcycled materials in soundproofing aligns with broader environmental goals and sustainable development initiatives. As the construction industry continues to grapple with its environmental impact, the shift towards sustainable materials can significantly reduce carbon footprints. Research shows that acoustic panels made from recycled cardboard or agricultural waste such as fruit stones or rice straw can reduce greenhouse gas emissions by up to 34% compared to traditional materials like gypsum and mineral wool [55]. This reduction in energy consumption and emissions contributes to sustainable building practices, offering a dual benefit of acoustic comfort and environmental responsibility. By adopting these materials, organizations not only reduce operational costs but also support a circular economy by repurposing waste materials. This approach aligns with global efforts toward sustainable development, promoting the creation of eco-friendly, acoustically optimized spaces that serve diverse community needs.

4. Neurological, Sensory Processing, and Neurodivergent Benefits

Excessive noise can have a particularly detrimental effect on individuals with sensory processing disorders or heightened sensitivity to auditory stimuli. Research shows that overstimulation of the auditory system can lead to increased anxiety, stress, and cognitive overload in individuals with sensory sensitivities, such as those with Autism Spectrum Condition (ASC) or Sensory Processing Disorder (SPD) [56]. In environments where noise levels are not properly controlled, these individuals may experience heightened stress, causing discomfort and reducing their ability to function effectively in their surroundings [57]. Studies involving fMRI data reveal that overstimulation from noise not only affects peripheral auditory systems but also impacts central auditory processing, leading to negative psychological effects such as increased anxiety and reduced focus [58-59]. This underscores the importance of creating controlled acoustic environments to mitigate overstimulation for those with sensory sensitivities.

Controlled acoustics play a critical role in reducing overstimulation and anxiety in environments designed for individuals with sensory processing issues. By managing sound levels and ensuring consistent noise reduction, acoustic control helps create calmer and more predictable environments [60]. This is particularly important in settings such as classrooms, therapeutic spaces, and community centers where individuals with neurodivergent conditions might be present [61]. Studies on hospital acoustics indicate that environments designed to control noise levels can significantly improve psychological well-being by reducing stress and anxiety, suggesting that similar benefits can be achieved in spaces catering to sensory-sensitive populations [62]. Through proper acoustic management, spaces can become more inclusive and conducive to the needs of individuals with sensory processing challenges.

In addition to reducing anxiety, controlled acoustic environments can enhance cognitive performance for individuals with sensory processing difficulties. In classrooms, for instance, proper soundproofing and acoustic treatments can help reduce background noise and reverberation, allowing students with ADHD or auditory processing issues to focus better. Excessive background noise has been shown to impair speech perception and concentration in individuals with these conditions, leading to increased cognitive strain and reduced learning outcomes. Research shows that implementing controlled soundscapes can help individuals maintain focus for longer periods, fostering an environment that supports cognitive function and learning [63]. Finally, the importance of controlled acoustics in reducing overstimulation extends to creative environments where focus and concentration are essential. For neurodivergent individuals engaged in creative work, a soundproofed, acoustically managed environment can help minimize distractions and allow for uninterrupted periods of deep concentration. This is particularly relevant for artists or creators with sensory processing sensitivities, where noise distractions can severely disrupt the creative process. By offering a stable and quiet environment, controlled acoustics not only reduce overstimulation but also support creativity and productivity, allowing for more inclusive artistic spaces [64].

Case studies have demonstrated that soundproofing provides significant benefits in reducing sensory overload for individuals with autism and other neurodivergent conditions. For individuals with ASC, sensory over-responsivity (SOR), particularly in the auditory domain, is a common and often overwhelming experience. Research demonstrates that individuals with ASD frequently experience heightened sensitivity to everyday sounds, such as environmental noise, leading to heightened anxiety, avoidance behaviors, and decreased social interaction [65]. A study found that participants with autism displayed stronger activation in primary sensory cortices when exposed to auditory stimuli, contributing to their heightened sensory response and difficulty in habituating to regular environmental sounds [66]. Moreover, soundproofing interventions, such as the use of auditory-friendly spaces or noise-reducing devices, have been found to improve emotional regulation and social interaction in individuals with ASC. Studies indicate that reducing background noise and controlling acoustic environments can decrease stress and anxiety, helping individuals with autism focus better on tasks and interact more comfortably with others [67]. For example, auditory integration therapies, including sound-based interventions, have been employed to reduce sound sensitivity, leading to improvements in selfregulation and behavior in children with ASD [68]. These findings support the use of soundproofing as an essential tool in managing auditory sensitivities for neurodivergent individuals, improving their overall quality of life by reducing sensory overload.

Soundproofing plays a critical role in creating inclusive spaces for neurodivergent individuals, particularly in settings such as classrooms, community centers, and art studios. For neurodivergent individuals, including those with ASC, sensory processing sensitivities often make everyday noise overwhelming, leading to anxiety and withdrawal from activities. Soundproofing these spaces not only reduces sensory overload but also fosters a more inclusive and accessible environment where neurodivergent individuals can participate fully. Research demonstrates that in learning environments, poor acoustics can severely impair concentration and increase stress, especially for students with sensory sensitivities. By reducing noise levels and controlling reverberation, soundproofing can mitigate these issues, allowing for improved focus and engagement in educational activities [69]. This highlights the importance of soundproofing not only as a functional necessity but also as a tool for fostering inclusivity in various communal spaces.

Acoustic adjustments are also essential in creating sensory-friendly spaces that encourage participation for individuals with neurodivergent conditions. In spaces such as community centers and studios, where individuals gather for social or creative activities, the implementation of soundproofing measures can help ensure that everyone feels comfortable and engaged. Studies have shown that soundabsorbing materials like carpets, thick curtains, and foam panels can significantly reduce background noise, which in turn lowers stress levels for those with auditory sensitivities [70]. These interventions not only improve the overall environment but also enable neurodivergent individuals to engage more meaningfully in creative and social settings without the risk of overstimulation. Such modifications can transform public spaces into welcoming environments that are supportive of all users, regardless of their sensory processing needs.

Finally, the integration of soundproofing in these spaces aligns with the principles of universal design, ensuring that environments are accessible to the widest possible range of individuals. By incorporating thoughtful acoustic design into classrooms, studios, and community spaces, institutions can create environments that accommodate diverse needs, thereby promoting participation and inclusion. Soundproofing measures that reduce reverberation, background noise, and other auditory distractions are increasingly being recognized as essential components of inclusive design. For example, in educational settings, studies have shown that well-designed acoustics not only benefit neurodivergent individuals but also enhance the overall learning experience for all students [12]. These findings underscore the value of soundproofing in creating spaces where everyone can thrive, further advancing the goals of inclusivity and accessibility.

To actualize the recommendations for creating sensoryfriendly, inclusive spaces in a concept design, one could envision an immersive soundproofing art installation that merges both functionality and aesthetic appeal (Figure 2). This design would incorporate intricate patchworks of high-quality recycled fabrics that not only absorb sound but also offer rich textures for sensory engagement. The inclusion of 3D egg carton structures and bottle cap mosaics arranged in organic, flowing patterns would serve as acoustic diffusers, breaking up sound waves while providing a visually stimulating environment. Seamlessly integrated vertical gardens, with lush greenery woven into the soundproofing panels, would further soften the acoustics while introducing a calming, natural element to the space. Overhead, large kinetic sculptures made from recycled glass and plastic would rotate gently, reflecting soft light across the room, adding to the serene, meditative atmosphere. The installation's LED lighting, strategically positioned to enhance the natural flow of the design, would maintain a sensory-friendly environment free from harsh, disruptive brightness. Together, these features create an acoustically balanced, inclusive space that promotes relaxation, creativity, and engagement for all users, particularly neurodivergent individuals who require sensorysensitive environments.



Fig. 2 Piper Hutson, Concept for Soundproofing Art Installation, DALLE-3, 2024. Permission of the author.

5. Novel Soundproofing Advances

Magnetic sound dampeners have emerged as an innovative and flexible solution in soundproofing applications, offering ease of installation and adaptability compared to traditional materials. These dampeners use magnetorheological properties to adjust their damping capabilities in real-time, responding to changes in the surrounding sound environment. Research into magnetic metasurfaces has demonstrated their ability to control sound insulation through non-contact adjustments effectively, making them ideal for environments where noise levels fluctuate frequently or where permanent installations are impractical. These materials are especially beneficial in industrial and creative spaces due to their lightweight and modifiable nature, which provides enhanced acoustic control without the need for bulky materials [71]. Such flexibility allows for the integration of these dampeners in environments that demand both high functionality and aesthetic cohesion.

In parallel, recycled and upcycled materials like wool, cardboard, and bottle caps are gaining recognition as effective soundproofing options. These materials not only provide ecofriendly alternatives to conventional solutions such as Mass Loaded Vinyl (MLV) but also offer cost benefits. For instance, wool has been found to possess excellent acoustic absorption qualities, while recycled cardboard panels can deliver mid-tohigh-frequency sound absorption, outperforming some traditional synthetic materials. Studies have shown that upcycled materials, while effective, may have limitations in high-noise environments due to their lighter mass, which is less effective in blocking low-frequency sounds compared to denser options like MLV [72]. Nonetheless, these materials present a sustainable and versatile solution for spaces where moderate noise control and environmental considerations are prioritized.

Movable and flexible soundproofing solutions have become increasingly important for multi-functional spaces that require adaptability. In environments such as art studios and classrooms, where acoustic needs can vary depending on the activity, temporary soundproofing solutions provide both flexibility and practicality. Modular acoustic panels are one such example, offering versatility in both absorption and diffusion of sound. A recent study introduced a parametric design of modular panels aimed at providing flexibility for recording spaces, allowing for easy adjustments in reverberation time and room clarity by swapping panel components. The design was shown to maintain acoustic performance similar to traditional, bulkier treatments while offering the advantage of a customizable setup based on specific acoustic needs [73]. These adaptable soundproofing designs can be extended to dynamic environments where temporary or modular configurations are required to support changing uses of space.

Temporary soundproofing panels, often made from sustainable materials, are particularly valuable in community spaces and educational settings where budgets may not allow for permanent installations. Lightweight and easy to assemble, these panels provide a cost-effective alternative to traditional soundproofing methods like MLV. Research on modular acoustic panel systems has highlighted their ability to meet varying acoustic demands while maintaining ease of transport and installation. For example, micro-perforated panels have been found to offer sound absorption across a wide range of frequencies. When combined with flexible panel designs, they allow for sound management that adapts to different room configurations or event requirements [74]F. This adaptability makes them an ideal solution for spaces that serve multiple enhancing both usability and functions, acoustic performance.

Eco-friendly materials are increasingly recognized for their benefits in soundproofing applications, offering both environmental sustainability and effective noise reduction. Green soundproofing materials, made from natural fibers such as jute, hemp, and recycled textile waste, present a viable alternative to traditional synthetic options like mineral wool and MLV. These materials are not only sustainable but also provide comparable acoustic properties, as seen in studies where their sound absorption and insulation performance matched or exceeded conventional solutions. For instance, jute and hemp fibers, when infused with resins, were shown to be as effective in sound insulation as plasterboards, commonly used in building acoustics [75]. These materials contribute to reducing the environmental footprint of soundproofing solutions, aligning with global sustainability efforts by minimizing the use of non-renewable resources and reducing waste.

The integration of eco-friendly materials into the aesthetic design of community and artistic spaces provides a dual benefit of acoustic improvement and environmental consciousness. For example, porous wood-based materials and recycled fabrics can be used creatively as both functional acoustic panels and decorative elements, creating visually appealing installations that also serve to manage noise. The incorporation of natural textures, such as vetiver grass or cork, has been shown to enhance both the acoustic and aesthetic quality of a space, making it ideal for environments like art studios and community centers [76]. Compared to more invasive technologies, such as MLV, these materials offer greater design flexibility while maintaining high levels of sound absorption, particularly in low- to mid-frequency ranges. This combination of sustainability, functionality, and design integration makes eco-friendly materials an increasingly popular choice in contemporary acoustic solutions.

In a CI/CD pipeline, code changes are automatically built, tested, and deployed to production environments. Microservices facilitate this automation by isolating changes to specific services, reducing the risk of conflicts and integration issues. Automated testing can be more targeted, focusing on the impacted services, which speeds up the validation process. For example, a team responsible for the user authentication service can deploy updates independently, ensuring that improvements reach users faster [22]. Companies like Amazon have leveraged microservices to achieve thousands of deployments per day. They adopt a "you build it, you run it" philosophy, where small, autonomous teams own the entire lifecycle of their services. This ownership model encourages accountability and accelerates problem-solving, as teams are directly responsible for their services in production [23].

The economic benefits of using recycled and accessible materials in soundproofing are considerable, especially in community and non-profit settings where budget constraints are often a limiting factor. Materials such as recycled wool, cardboard, and bottle caps can provide effective sound absorption at a fraction of the cost of traditional soundproofing materials like MLV. For example, recycled textiles have been demonstrated to offer competitive acoustic performance, particularly for mid-to-high frequencies, making them suitable for environments that do not require heavy-duty sound isolation. By sourcing locally available, low-cost materials, community projects can reduce initial expenses while achieving adequate acoustic treatment. Research on sustainable material applications in building construction highlights that incorporating recycled materials significantly reduces lifecycle costs due to lower material prices and reduced waste management fees [77].

Case studies of successful soundproofing projects in community and non-profit settings underscore the practicality of using sustainable materials. For instance, in a community center in New Zealand, a deconstruction and reuse project incorporated recycled materials such as wooden pallets and carpet tiles, leading to both cost savings and improved acoustics. The project demonstrated how upcycled materials could be creatively used to address both functional and environmental concerns without compromising performance or aesthetics. The cost-effectiveness of these materials allowed the project to meet its acoustic goals while staying within a limited budget, making it a model for other non-profit organizations seeking sustainable solutions [78]. These case studies highlight how sustainable soundproofing can be successfully implemented in various community projects.

When assessing the performance of novel soundproofing materials, two key metrics come into play: Sound Transmission Loss (STL) and Sound Absorption Coefficients (SAC). Recycled materials, such as wool and cardboard, have shown SAC values comparable to those of traditional acoustic mineral wool, making them suitable for applications requiring moderate sound absorption. However, when it comes to STL, materials like MLV outperform lightweight, sustainable options in low-frequency sound isolation due to their density. While sustainable materials may not fully replace traditional solutions in high-noise environments, they offer a viable alternative for projects where cost, sustainability, and aesthetic integration are more important than heavy-duty soundproofing performance [72].

The flexibility and customization benefits of lightweight, eco-friendly alternatives also contribute to their growing appeal in soundproofing projects. These materials are not only easier to install and transport but also offer more design flexibility than traditional options like MLV or acoustic foam. For example, modular panels made from recycled fabric can be rearranged or repurposed depending on the acoustic needs of the space, making them ideal for multi-functional environments such as art studios or classrooms.

Additionally, the aesthetic integration of natural textures, like recycled wood or cork, into soundproofing designs enhances the visual appeal of a space while maintaining its acoustic functionality. This adaptability allows for both practical and creative use, supporting the growing trend toward sustainable design solutions in architecture and interior design [74].

6. Challenges and Considerations

The limitations of sustainable soundproofing solutions become apparent in high-noise or professional-grade environments, where conventional materials like MLV still outperform lightweight, eco-friendly alternatives. Sustainable materials, such as recycled wool, cardboard, or bottle caps, are effective in moderate noise control but often struggle with low-frequency sounds that are common in industrial and highnoise settings. Their lighter mass reduces their capacity for sound insulation, especially in comparison to heavier, denser materials designed to block sound transmission. Research in sustainable acoustics indicates that while natural materials like hemp or jute offer high absorption rates for mid-to-high frequencies, their STL ratings fall short in professional environments requiring comprehensive sound isolation [75]. These findings suggest that while sustainable materials are useful in community settings, they may not yet serve as full substitutes in high-demand acoustic environments like recording studios or concert halls.

Another challenge of integrating upcycled materials in large-scale or professional settings lies in the variability of their acoustic properties. While recycled materials offer cost and environmental benefits, their acoustic performance is often inconsistent due to the non-standardized nature of the materials used. For example, recycled rubber, textiles, or foam may vary in density and composition, leading to unpredictable sound absorption or transmission rates. This presents challenges for designers and engineers when attempting to incorporate these materials into professional-grade soundproofing projects, where consistent performance is critical [77]. As a result, while these materials are valuable in smaller, community-oriented projects, their integration into professional environments remains limited by performance variability and lack of standardization.

Durability concerns also arise with the use of recycled and non-traditional materials, particularly in environments requiring long-term acoustic performance. While materials like wool or cardboard may offer sufficient noise control in the short term, their long-term resilience against wear, moisture, and environmental factors is less proven than traditional soundproofing materials like MLV or acoustic mineral wool. Studies have indicated that natural fibers, while eco-friendly, may degrade faster when exposed to high humidity or frequent handling, which limits their applicability in environments where durability is essential [79]. For spaces requiring frequent reconfiguration or exposure to varying conditions, the lower durability of some sustainable materials can pose significant challenges for maintenance and longevity.

Maintenance and replacement challenges also complicate the use of temporary or movable soundproofing solutions, especially when these materials are not designed for frequent reinstallation. Modular panels made from eco-friendly materials may require more frequent replacement due to wear and tear, increasing long-term costs despite their initial affordability. In contrast, conventional materials like acoustic foam or gypsum boards, while more expensive upfront, often provide greater longevity and less frequent maintenance. The trade-off between sustainability and durability must be carefully considered, particularly in dynamic spaces like art studios or community centers that require both flexible and durable acoustic solutions [80]. As such, balancing environmental goals with practical concerns of durability and maintenance remains a central challenge in the development of sustainable soundproofing solutions.

7. Conclusion

Despite the growing interest in sustainable soundproofing materials, significant gaps in knowledge remain regarding their long-term performance. While many eco-friendly materials, such as recycled wool, cardboard, and natural fibers, have demonstrated effective noise absorption in smaller, controlled environments, there is a lack of comprehensive, long-term empirical data on how these materials perform over extended periods and under varying conditions. Future research must focus on evaluating the durability, moisture resistance, and acoustic performance of these materials in real-world settings, particularly in environments with high humidity, frequent use, or exposure to fluctuating temperatures. Understanding the lifecycle and maintenance requirements of these materials is critical for their wider adoption in both professional and community settings.

Furthermore, exploring hybrid soundproofing solutions that combine traditional and novel materials may offer a promising pathway to address the limitations of sustainable alternatives. By integrating heavier, denser materials like Mass Loaded Vinyl (MLV) with lightweight, eco-friendly materials, researchers can develop hybrid systems that provide superior sound insulation without sacrificing environmental benefits. These solutions could balance the need for high performance in professional-grade settings with the growing demand for sustainability in building and construction. Research should investigate how these hybrid systems perform across different noise frequencies, with a particular focus on low-frequency sound attenuation, where sustainable materials often fall short.

Another area of future research lies in investigating the scalability of cost-effective soundproofing solutions for larger spaces and more complex environments. While sustainable materials have proven effective in smaller applications, such as community centers and art studios, questions remain about their scalability for larger spaces like theaters, concert halls, or multi-story buildings. Researchers must explore how these materials can be adapted to cover larger surface areas without compromising their acoustic properties or sustainability benefits. Additionally, the feasibility of using these materials in modular designs or temporary installations for large-scale events should be examined better to understand their potential flexibility and utility in diverse settings. Finally, there is immense potential for expanding the application of these sustainable soundproofing solutions into other fields, such as healthcare and public infrastructure. Hospitals, for example, require soundproofing for patient rooms and sensitive areas, while public infrastructure projects such as highways or public transportation systems could benefit from eco-friendly noise barriers. Future research should focus on how these materials can be tailored to meet the specific acoustic requirements of these fields, ensuring both functionality and sustainability. By addressing these research gaps, we can further advance the development of cost-effective, environmentally responsible soundproofing solutions that meet the acoustic needs of modern society.

References

- [1] Jonty Mago et al., *Sound Insulation: Key Concepts and Technologies*, Handbook of Vibroacoustics, Noise and Harshness, Springer, Singapore, pp. 1-44, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [2] Vijaya Laxmi et al., "An Innovative Approach for the Development of Sound-Absorbing Material Using Industrial Wastes," *Construction and Building Materials*, vol. 369, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [3] Majid Mohammadi et al., "Recent Progress in Natural Fiber Reinforced Composite as Sound Absorber Material," *Journal of Building Engineering*, vol. 84, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [4] Qing-Qing Ni et al., "Development of Insulation Sheet Materials and Their Sound Characterization," *Advanced Composite Materials*, vol. 17, no. 1, pp. 25-40, 2008. [CrossRef] [Google Scholar] [Publisher Link]
- [5] Jiwan Kim, Eunji Choi, and Wonju Jeon, "Lightweight Soundproofing Meta-Panel For Separate Wide Frequency Bands," *Mechanical Systems and Signal Processing*, vol. 184, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [6] Shoubo Dai et al., "Vibro-Acoustic Control of a Programmable Meta-Shell with Digital Piezoelectric Shunting," International Journal of Mechanical Sciences, vol. 255, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [7] Indrajit Wadgave et al., "A Comprehensive Review On: Mechanical and Acoustical Characterization of Natural Fiber-Reinforced Composite," *Materials Today: Proceedings*, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [8] Wahyu Tri Widiyanto, and Putri Sekar Hapsari, "The Interior Designing of Lawu Resort Hotel with Tirta Intanpari Batik Theme in Tawangmangu," *Pendhapa*, vol. 11, no. 2, pp. 85-90, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [9] Arun Arjunan et al., "Acoustic Metamaterials for Sound Absorption and Insulation in Buildings," *Building and Environment*, vol. 251, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [10] Antonio Laurìa, Simone Secchi, and Luigi Vessella, "Acoustic Comfort as a Salutogenic Resource in Learning Environments-A Proposal for the Design of a System to Improve the Acoustic Quality of Classrooms," *Sustainability*, vol. 12, no. 22, pp. 1-25, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [11] Amneh Hamida et al., "Indicators and Methods for Assessing Acoustical Preferences and Needs of Students in Educational Buildings: A Review," Applied Acoustics, vol. 202, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [12] Isabel Montiel et al., "Acoustic Comfort in Learning Spaces: Moving Towards Sustainable Development Goals," Sustainability, vol. 11, no. 13, pp. 1-18, 2019. [CrossRef] [Google Scholar] [Publisher Link]
- [13] Zaiton Haron et al., "Serene Classroom' Minimizes Noise for More Conducive Learning," ASEAN Journal of Community Engagement, vol. 5, no. 1, pp. 154-182, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [14] M. Herman, and J.F. Bobby Saragih, "Spatial Acoustic Approach: Sustainable Design Methods in Creative Centre Building," *IOP Conference Series: Earth and Environmental Science:* 7th International Conference on Eco Engineering Development, vol. 1324, no. 1, pp. 1-10, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [15] Abeer Alawad, "Can We Bring the Natural Environment into the Art Classroom? Can Natural Sound Foster Creativity?," *Educational Research Review*, vol. 7, no. 28, pp. 627-631, 2012. [Google Scholar] [Publisher Link]
- [16] Yoon Cha, "Non-Profit Real Estate: Financial Strategies for Mission and Impact," Theses, Massachusetts Institute of Technology, pp. 1-85, 2024. [Google Scholar] [Publisher Link]
- [17] Antonella Patti, Gianluca Cicala, and Domenico Acierno, "Eco-Sustainability of the Textile Production: Waste Recovery and Current Recycling in the Composites World," *Polymers*, vol. 13, no. 1, pp. 1-25, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [18] Sorin Simion et al., "Noise Level Reduction by Using Sound Insulation/ Sound Absorbent Materials," Proceedings of 22nd International Multidisciplinary Scientific GeoConference SGEM, vol. 22, no. 4.1, pp. 1-8, 2022. [CrossRef] [Google Scholar] [Publisher Link]
- [19] Philip Scranton, Production Practices-Manufacturing from the Inside Out, 1957-1967, Business Practice in Socialist Hungary, Palgrave Macmillan, Cham, vol. 2, pp. 273-321, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [20] C.R. Fuller, and A.H. von Flotow, "Active Control of Sound and Vibration," *IEEE Control Systems Magazine*, vol. 15, no. 6, pp. 9-19, 1990. [CrossRef] [Google Scholar] [Publisher Link]

- [21] Dongyuan Shi et al., "Active Noise Control in the New Century: The Role and Prospect of Signal Processing," INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise23, Chiba, Japan, pp. 4996-5995, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [22] Kevin M. Lee, Mark S. Wochner, and Preston S. Wilson, "Mitigation of Low-Frequency Underwater Anthropogenic Noise Using Stationary Encapsulated Gas Bubbles," *Proceedings of Meetings on Acoustics*, vol. 17, no. 1, pp. 1-9, 2012. [CrossRef] [Google Scholar] [Publisher Link]
- [23] Rajesh Babu Channamaneni, and M.R.Vikram, "Challenges in NVH Refinement of Electric Vehicle Built on ICE Platform 2024-26-0216," *Technical Paper*, SAE International, pp. 1-16, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [24] Paul Sas et al., "Active Control of Sound Transmission through an Industrial Sound Encapsulation," *Journal of the Acoustical Society of America*, vol. 103, no. 5, pp. 2964-2965, 1998. [CrossRef] [Google Scholar] [Publisher Link]
- [25] Ashish Kumar Sahu, Ali Emadi, and Berker Bilgin, "Noise And Vibration in Switched Reluctance Motors: A Review on Structural Materials, Vibration Dampers, Acoustic Impedance, and Noise Masking Methods," *IEEE Access*, vol. 11, pp. 27702-27718, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [26] Aji Masa'id et al., "A Review on Vibration Control Strategies Using Magnetorheological Materials Actuators: Application Perspective," Actuators, vol. 12, no. 3, pp. 1-34, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [27] S. Puma-Araujo et al., "Design and Characterization of a Magnetorheological Damper for Vibration Mitigation during Milling of Thin Components," *MRS Online Proceedings Library*, vol. 1812, pp. 65-70, 2016. [CrossRef] [Google Scholar] [Publisher Link]
- [28] Chao Wang et al., "Manufacturing of Membrane Acoustical Metamaterials for Low-Frequency Noise Reduction and Control: A Review," *Mechanics of Advanced Materials and Structures*, vol. 31, no. 25, pp. 7008-7023, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [29] M. Baloochi et al., "Analysis of a Passive Vibration Damper for High-Speed Superconducting Magnetic Bearings," *Engineering Research Express*, vol. 6, no. 3, pp. 1-14, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [30] Andreas Looser et al., "Active Magnetic Damper for Ultrahigh-Speed Permanent-Magnet Machines With Gas Bearings," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 4, pp. 2982-2991, 2017. [CrossRef] [Google Scholar] [Publisher Link]
- [31] Shubham Sharma et al., "Emerging Progressive Developments in the Fibrous Composites for Acoustic Applications," Journal of Manufacturing Processes, vol. 102, pp. 443-477, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [32] Asminin Viktor Fedorovich et al., "Development and Application of a Portable, Lightweight Sound Suppression Panel to Reduce Noise at Permanent and Temporary Workplaces in the Manufacturing and Repair Workshops," *Akustika*, vol. 34, pp. 18-21, 2019. [Google Scholar]
- [33] Fatima Alsakka et al., "Generative Design for More Economical and Environmentally Sustainable Reinforced Concrete Structures," *Journal of Cleaner Production*, vol. 387, pp. 1-12, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [34] Leopoldo Pacheco Bastos, Gustavo da Silva Vieira de Melo, and Newton Sure Soeiro, "Panels Manufactured from Vegetable Fibers: An Alternative Approach for Controlling Noises in Indoor Environments," *Advances in Acoustics and Vibration*, vol. 2012, pp. 1-9, 2012. [CrossRef] [Google Scholar] [Publisher Link]
- [35] Kiri Mealings, and Joerg M. Buchholz, "The Effect of Classroom Acoustics and Noise on High School Students' Listening, Learning ond Well-Being: A Scoping Review," *Facilities*, vol. 42, no. 5/6, pp. 485-503, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [36] Gerhart Tiesler, Rainer Machner, and Holger Brokmann, "Classroom Acoustics and Impact on Health and Social Behaviour," *Energy Proceedia*, vol. 78, pp. 3108-3113, 2015. [CrossRef] [Google Scholar] [Publisher Link]
- [37] Flavia Gheller et al., "Classroom Acoustics: Listening Problems in Children," Building Acoustics, vol. 27, no. 1, pp. 47-59, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [38] Maria Klatte et al., "Effects of Classroom Acoustics on Performance and Well-Being in Elementary School Children: A Field Study," *Environment and Behavior*, vol. 42, no. 5, pp. 659-692, 2010. [CrossRef] [Google Scholar] [Publisher Link]
- [39] Bianca L. Vieira, and Dhanashree Pillay, "Noise, Screaming and Shouting: Classroom Acoustics and Teachers' Perceptions of their Voice in a Developing Country," *South African Journal of Childhood Education*, vol. 10, no. 1, pp. 1-9, 2020. [Google Scholar] [Publisher Link]
- [40] Jesper Kristiansen et al., "Effects of Classroom Acoustics and Self-Reported Noise Exposure on Teachers' Well-Being," *Environment and Behavior*, vol. 45, no. 2, pp. 283-300, 2013. [CrossRef] [Google Scholar] [Publisher Link]
- [41] Suvi Karjalainen et al., "A Pilot Study on the Relationship Between Primary School Teachers' Well-Being and the Acoustics of their Classrooms," *International Journal of Environmental Research and Public Health*, vol. 17, no. 6, pp. 1-11, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [42] Stuart McLaren, and Steve Humphries, "A Pilot Study of a Soundfield System and Acoustical Quality in a New Zealand Primary School Classroom," New Zealand Journal of Educational Studies, vol. 44, no. 1, pp. 59-68, 2009. [Google Scholar] [Publisher Link]
- [43] Daniel Walzer, "Sonic Thinking is a Tool for Creativity, Communication, and Sensory Awareness in Music Production," *Thinking Skills and Creativity*, vol. 42, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [44] Jae Hwa Lee, and Soyeon Lee, "Relationships between Physical Environments and Creativity: A Scoping Review," Thinking Skills and

Creativity, vol. 48, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

- [45] Lisanne Bergefurt, Rianne Appel-Meulenbroek, and Theo Arentze, "Level-Adaptive Sound Masking in the Open-Plan Office: How does it Influence Noise Distraction, Coping, and Mental Health?," *Applied Acoustics*, vol. 217, pp. 1-11, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [46] Louise Suckley, and John Nicholson, *Enhancing Creativity Through Workspace Design*, The Palgrave Handbook of Creativity at Work, Palgrave Macmillan, Cham, pp. 245-263, 2018. [CrossRef] [Google Scholar] [Publisher Link]
- [47] Liang Men, and Nick Bryan-Kinns, *Supporting Sonic Interaction in Creative, Shared Virtual Environments*, Sonic Interactions in Virtual Environments, Springer, Cham, pp. 237-267, 2022. [CrossRef] [Google Scholar] [Publisher Link]
- [48] Pei-Rou Kong, and Ke-Tsung Han, "Psychological and Physiological Effects of Soundscapes: A Systematic Review," *Science of The Total Environment*, vol. 929, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [49] Timothy Onosahwo Iyendo, David Welch, and Patrick Chukwuemeke Uwajeh, "Soundscape and Natural Landscape as a Design Construct for Improving Psycho-Physiological Health in Cities: A Semi-Systematic Literature Review," *Cities and Health*, vol. 8, no. 3, pp. 447-485, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [50] Yuhan Shao et al., "Improving Soundscape Comfort in Urban Green Spaces based on Aural-Visual Interaction Attributes of Landscape Experience," *Forests*, vol. 13, no. 8, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]
- [51] Simone Torresin et al., "Indoor Soundscapes at Home during the COVID-19 Lockdown in London-Part I: Associations between the Perception of the Acoustic Environment, Occupantś Activity and Well-Being," *Applied Acoustics*, vol. 183, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [52] Hendrico Firzandy Latupeirissa, Gierlang Bhakti Putra, and Niki Prastomo, "Recycled Brick Soundproof Test as an Alternative Sustainable Material," *Ultimart: Jurnal Komunikasi Visual*, vol, 13, no. 2, pp. 44-54, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [53] Siwat Lawanwadeekul et al., "Development of Sound-Absorbing Materials from Rice Straw," INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise23, Chiba, Japan, pp. 995-1994, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [54] Simone Secchi et al., "Experimental and Environmental Analysis of New Sound-Absorbing and Insulating Elements in Recycled Cardboard," *Journal of Building Engineering*, vol. 5, pp. 1-12, 2016. [CrossRef] [Google Scholar] [Publisher Link]
- [55] Francesco Asdrubali, Francesco D'Alessandro, and Samuele Schiavoni, "A Review of Unconventional Sustainable Building Insulation Materials," *Sustainable Materials and Technologies*, vol. 4, pp. 1-17, 2015. [CrossRef] [Google Scholar] [Publisher Link]
- [56] Ben D.B. Willmore, and Andrew J. King, "Adaptation in Auditory Processing," *Physiological Reviews*, vol. 103, no. 2, pp. 1025-1058, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [57] Bouke de Vries, "Autism and the Right to a Hypersensitivity-Friendly Workspace," *Public Health Ethics*, vol. 14, no. 3, pp. 281-287, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [58] Paul D. McGeoch, and Romke Rouw, "How Everyday Sounds can Trigger Strong Emotions: ASMR, Misophonia and the Feeling of Wellbeing," *BioEssays*, vol. 42, no. 12, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [59] Tomasz Wolak et al., "Influence of Acoustic Overstimulation on the Central Auditory System: A Functional Magnetic Resonance Imaging (FMRI) Study," *Medical Science Monitor*, vol. 22, pp. 4623-4635, 2016. [CrossRef] [Google Scholar] [Publisher Link]
- [60] Vinh Le Quang, "Ease: A Cross-Platform Application for Supporting Individuals with Asd in Managing Overstimulation and Social Anxiety," Final Project, Boadilla del Monte, pp. 1-43, 2023. [Google Scholar] [Publisher Link]
- [61] Patrick Dwyer et al., "Building Neurodiversity-Inclusive Postsecondary Campuses: Recommendations for Leaders in Higher Education," *Autism in Adulthood*, vol. 5, no. 1, pp. 1-14, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [62] Tianfu Zhou et al., "Influence of the Acoustic Environment in Hospital Wards on Patient Physiological and Psychological Indices," *Frontiers in Psychology*, vol. 11, pp. 1-13, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [63] Anders Fridberger, Josephus Th.P.W. Van Maarseveen, and Mats Ulfendahl, "An In Vitro Model for Acoustic Overstimulation," *Acta Oto-Laryngologica*, vol. 118, no. 3, pp. 352-361, 1998. [CrossRef] [Google Scholar] [Publisher Link]
- [64] Ben Warren et al., "Physiological Basis of Noise-Induced Hearing Loss in a Tympanal Ear," *The Journal of Neuroscience*, vol. 40, no. 15, pp. 3130-3140, 2019. [CrossRef] [Google Scholar] [Publisher Link]
- [65] Peter Bang et al., "Sensory Symptoms Associated with Autistic Traits and Anxiety Levels in Children Aged 6-11 Years," *Journal of Neurodevelopmental Disorders*, vol.16, no. 1, pp. 1-10, 2024. [CrossRef] [Google Scholar] [Publisher Link]
- [66] Elena V. Orekhova et al., "Auditory Cortex Responses to Clicks and Sensory Modulation Difficulties in Children with Autism Spectrum Disorders (ASD)," *PLOS One*, vol. 7, no. 6, pp. 1-10, 2012. [CrossRef] [Google Scholar] [Publisher Link]
- [67] Marcelo Rocha et al., "Towards Enhancing the Multimodal Interaction of a Social Robot to Assist Children with Autism in Emotion Regulation," *International Conference on Pervasive Computing Technologies for Healthcare*, pp. 398-415, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [68] Bryan M. Gee, Kelly Thompson, and Holly St John, "Efficacy of a Sound-Based Intervention with a Child with an Autism Spectrum Disorder And Auditory Sensory Over-Responsivity," *Occupational Therapy International*, vol. 21, no. 1, pp. 12-20, 2014. [CrossRef]

[Google Scholar] [Publisher Link]

- [69] Fernanda Caldas et al., "Measurements of Classroom Acoustic Conditions in which Young Neurodiverse Persons Learn in São Paulo and Nebraska," *The Journal of the Acoustical Society of America*, vol 153, no. 3 (supplement), 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [70] Kanako Ueno, Saki Noguchi, and Hidetoshi Takahashi, "A Field Study on the Acoustic Environment of Special-Needs Education Classrooms," *Building Acoustics*, vol. 26, no. 4, pp. 263-274, 2019. [CrossRef] [Google Scholar] [Publisher Link]
- [71] Pu Xia, Yun Lai, and Xiaozhou Liu, "Adjustable Magnetic-Control Design of a Metasurface for Sound Insulation," *Frontiers in Mechanical Engineering*, vol. 7, pp. 1-8, 2022. [CrossRef] [Google Scholar] [Publisher Link]
- [72] Olga M. Smirnova et al., "Sound-Absorbing Composites with Rubber Crumb from Used Tyres," *Applied Sciences*, vol. 11, no. 16, pp. 1-12, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [73] Stavros Tagios, and Luis Gomez Agustina, "Parametric Design of a Modular Acoustic Panel for Sound Recording Space Versatility," INTER-NOISE and NOISE-CON Congress and Conference Proceedings, InterNoise22, Glasgow, Scotland, pp. 999-1999, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [74] Ela Fasllija, Semiha Yilmazer, and Cengiz Yilmazer, "Equivalent Circuit Method Based Double Layer Micro-Perforated Panel (MPP) Design to Widen the Sound Absorption Bandwidth," *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*, *InterNoise22*, Glasgow, Scotland, pp. 2000-2998, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [75] J. Fontoba-Ferrándiz et al., "Panels of Eco-Friendly Materials for Architectural Acoustics," *Journal of Composite Materials*, vol. 54, no. 25, pp. 3743-3753, 2020. [CrossRef] [Google Scholar] [Publisher Link]
- [76] Nishant Kumar, Kirti Soni, and Mahavir Singh, "Exploring Sound Absorption Properties of Porous Wood-Based Eco-Friendly Materials for Noise Reduction on Buildings," *The Journal of the Acoustical Society of America*, vol. 154, no. 4, 2023. [CrossRef] [Google Scholar] [Publisher Link]
- [77] Ahmed Ali Khatatbeh, and Yazan Alzubi, "Role of Materials and Labor Allocation in Cost-Effective Soundproof House Construction Projects," *Journal of Civil Engineering and Architecture*, vol. 14, pp. 668-675, 2020. [Google Scholar]
- [78] Atiq U. Zaman et al., "Resource Harvesting through a Systematic Deconstruction of the Residential House: A Case Study of the 'Whole House Reuse' Project in Christchurch, New Zealand," *Sustainability*, vol. 10, no. 10, pp. 1-21, 2018. [CrossRef] [Google Scholar] [Publisher Link]
- [79] J. Lavrentjev, "Green, Eco-Friendly Acoustic Materials," *IOP Conference Series: Materials Science and Engineering*, vol. 1140, no. 1, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]
- [80] Sunita Doddamani, Bhavna Shrivastava, and Nand Kumar, "A Comprehensive Review on Noise Reducing Materials for Habitable Spaces," *Applied Science and Engineering Progress*, vol. 15, no. 2, pp. 1-16, 2022. [CrossRef] [Google Scholar] [Publisher Link]