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REVIEW

Neuroarchitecture and Mental Health: The Role of Sustainable Building Materials in Cognitive and Emotional Well-Being

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ABSTRACT

Growing interest in sustainable architecture has highlighted not only ecological benefits but also potential impacts on mental and neurological health. This review explores the emerging field of neuroarchitecture, focusing on how environmentally friendly building materials influence cognitive function, stress regulation, and emotional well-being. A narrative review was conducted across interdisciplinary literature in neuroscience, environmental psychology, biophilic design, and sustainable architecture. The review analyzed peer-reviewed studies on eco-friendly materials—including wood, bamboo, cork, and stone—and their influence on neurological biomarkers, sensory engagement, and psychological health. Preliminary evidence suggests that exposure to natural, non-toxic materials is associated with reduced stress markers (e.g., lower cortisol), improved mood, and enhanced cognitive clarity. Some studies indicate potential links to increased neuroplasticity, greater hippocampal activity, and reduced neuroinflammation; however, these findings are largely derived from animal models or short-term human studies. Materials such as untreated wood and cork provide multisensory stimuli (visual, tactile, olfactory) that may activate brain regions involved in emotional regulation and attention. Sustainable materials may offer neuropsychological benefits that extend beyond aesthetics and environmental responsibility. While early evidence is promising, more longitudinal and mechanistic research is needed to confirm their impact on mental health. Integrating biophilic principles with evidence-informed material selection could transform how architects and designers support well-being through the built environment.

Keywords: Neuroarchitecture; Biophilic; Sustainable Materials; Cognitive; Environmental Psychology

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1. Introduction

The intersection of sustainable architecture and mental health is an emerging yet underexplored domain. While early studies suggest that eco-friendly materials may positively influence emotional well-being and cognitive performance, the existing literature is fragmented and often lacks longitudinal depth. Few reviews critically assess the quality, consistency, and limitations of this evidence. Additionally, some studies report null or negligible effects of natural materials on stress or cognition, indicating the need for cautious interpretation [1]. This review addresses these gaps by evaluating how specific eco materials affect neurological and psychological outcomes through sensory engagement and air quality improvements. Key design frameworks such as biophilic design which emphasizes human affinity for nature and salutogenic design which focuses on health promotion rather than disease avoidance offer promising but distinct perspectives. Biophilia centers on emotional connection and visual cues from nature, while salutogenic design emphasizes physical and psychological resilience through built environments. Both approaches contrast with more traditional frameworks like the Attention Restoration Theory, which focuses on cognitive fatigue recovery in natural settings [2]. Despite overlapping goals, these theories vary in how they define and measure psychological benefit. Furthermore, the rationale behind material selection remains inconsistent across studies. While bamboo, cork, and untreated wood are frequently cited, materials like hemp, straw bale, or recycled metals are less commonly evaluated despite potential sensory or ecological benefits. This review focuses on materials with both robust evidence and broad architectural application, while also acknowledging studies that challenge the assumed psychological benefits of natural design elements.

In recent years, the growing emphasis on sustainability has led to major innovations across various industries, especially in architecture and materials science. With pressing global challenges like climate change, resource depletion, and environmental degradation, there is a widespread shift toward more eco-conscious practices. In architecture, this shift is reflected in the increased adoption of green materials, energy-saving technologies, and low-impact construction methods. Simultaneously, rising awareness of mental health has prompted greater examination of how our built environments affect emotional and cognitive well-being. This dual focus is reshaping the concept of sustainable design to include not only environmental responsibility but also psychological wellness [1].

This manuscript explores the emerging connection between sustainable building materials and mental health. It examines how environmentally friendly materials influence brain function and emotional balance. Sustainable architecture now emphasizes materials that are renewable, non-toxic, energy efficient, and recyclable, aiming to reduce a building's ecological impact from construction through to demolition (**Table 1**). Traditional materials like bamboo, adobe, rammed earth, and untreated wood are being revived for their low environmental costs and minimal processing [1]. Meanwhile, newer innovations such as biodegradable insulation, green roofing, non-toxic paints with low VOCs, and recycled composites are becoming standard in eco-conscious design. These materials offer benefits beyond environmental sustainability. By improving indoor air quality, reducing harmful chemical exposure, and engaging the senses in nature-like ways, they contribute to mental clarity, emotional stability, and cognitive performance. Overall, the research suggests that using sustainable materials not only protects the planet but also fosters environments that support psychological health and well-being [2].

Table 1. Environmental Characteristics of Eco-Friendly Materials and Their Neurophysiological Effects.

Material	Neurosensory Stimuli	Associated Brain Region Activation
Bamboo	Tactile warmth, light scent	Prefrontal cortex
Stone	Visual grounding, cool texture	Amygdala
Cork	Acoustic absorption, tactile softness	Hippocampus
Wood	Earthy scent, rich grain, visual appeal	PFC, limbic system
Clay	Warm tones, tactile graininess	Hippocampus

While **Table 1** summarizes likely associations between natural materials and corresponding brain region activation, it is intended as a conceptual overview rather than a deterministic mapping. The relationships between sensory input and neural activity are highly complex and influenced by numerous variables including individual neurodiversity, prior experiences, and cultural context. For instance, the calming effect of stone surfaces may be experienced differently across populations depending on

familiarity, environmental associations, or symbolic meanings. Additionally, observed neural activations (e.g., in the amygdala or prefrontal cortex) often involve overlapping cognitive and emotional processes that cannot be attributed to a single sensory input. Therefore, the table should be interpreted as a simplified model that highlights general trends rather than definitive cause-effect pathways.

Sustainable building materials not only reduce environmental harm but also contribute significantly to healthier indoor environments. Unlike many conventional materials that emit harmful substances over time a process known as off-gassing eco-friendly alternatives are typically made with non-toxic, low-emission components that improve air quality and minimize health risks [2]. As public understanding of the link between architecture and mental well-being grows, elements such as lighting, acoustics, spatial design, and especially material selection are increasingly recognized for their influence on stress levels, cognitive function, and emotional stability. Central to this idea is biophilic design, which integrates natural elements to foster a connection with nature an approach shown to alleviate anxiety, elevate mood, and boost concentration [3].

Closely related is the concept of salutogenic design, which focuses on promoting well-being rather than merely avoiding illness. Here, building materials play a central role in shaping psychological outcomes. Natural substances like wood and stone have been shown to reduce stress responses, with studies noting that wooden interiors can lower heart rates and activate calming neural pathways [3]. These effects are deeply connected to the sensory qualities of natural materials visual textures, tactile warmth, and even subtle scents all work to trigger relaxation and emotional comfort. Moreover, sustainable materials enhance indoor air quality by limiting volatile organic compounds (VOCs), which are associated with symptoms such as headaches, irritability, and anxiety (**Figure 1**). Beyond their physical benefits, these materials also offer psychological rewards by providing a sense of purpose and eco-alignment, especially for younger generations grappling with climate concerns. Spaces built with such materials often feature calming, minimalist aesthetics that support mental clarity and emotional balance [4].

Architects worldwide are adopting this dual-purpose approach. Notable examples like Maggie's Centers in the UK show how sustainable, biophilic design supports healing and mental well-being. This growing movement underscores the potential for architecture to simultaneously nurture the planet and the human mind [5].

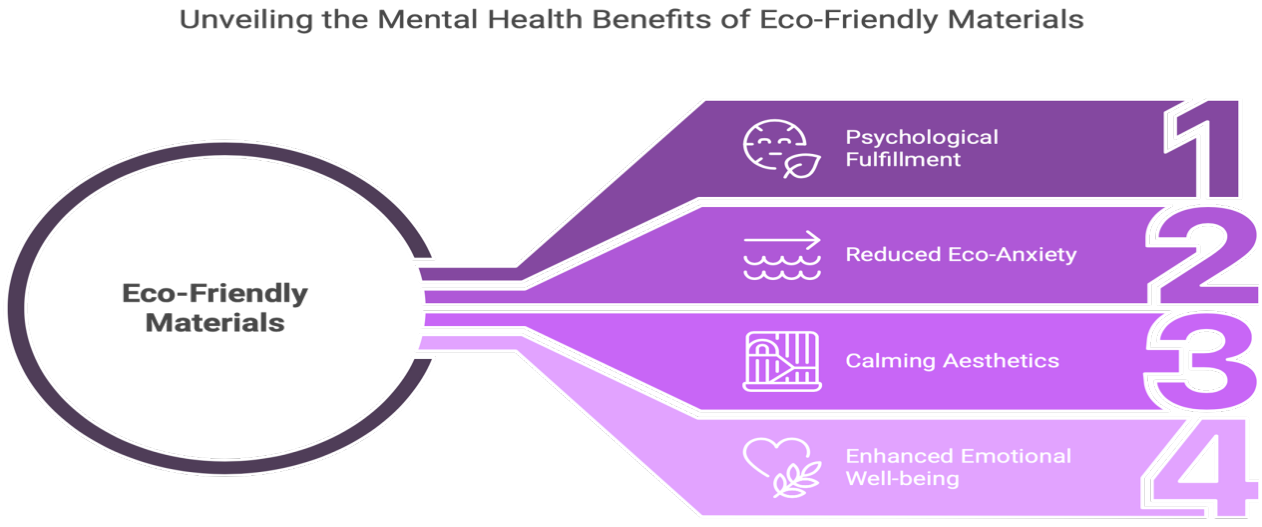

Figure 1. Environmentally Friendly Materials Boost Mental Health by Fostering Fulfillment, Environmental Responsibility, and Reducing Eco-Anxiety. Their Natural Aesthetics Create Calming, Minimalist Spaces That Lower Cognitive Load, Enhance Emotional Well-Being, and Offer a Sense of Agency in Combating Environmental Degradation.

Although integrating sustainability and mental health in architectural design holds significant potential, several challenges hinder widespread adoption. High costs and limited availability of certain eco-friendly materials can make them less practical for many builders and clients. Additionally, there is still a general lack of awareness among industry professionals and the public regarding the psychological benefits of sustainable materials [3]. Compounding this is the absence of standardized tools to measure the mental health effects of different materials, making it difficult to compare and select options based on psychological outcomes [2]. Despite these challenges, growing research is steadily uncovering the link between sustainable materials and mental well-being, signaling increased investment and interest in this area [4]. As the field evolves, we can expect improvements in education, innovation, and policy. Future building codes and green certifications may begin to include mental health considerations alongside environmental standards, encouraging more balanced and human-centered design approaches [6].

The use of environmentally conscious materials is not merely an ecological choice; it represents a meaningful opportunity to support mental wellness through intentional design. By reducing exposure to harmful substances, enhancing sensory engagement, and deepening connections to nature, these materials contribute to emotional stability and psychological resilience. As our understanding of environmental psychology and neuroarchitecture grows, the relationship between sustainable design and mental health is set to become a foundational principle in modern architecture, shaping spaces that benefit both the planet and the people who inhabit them [7].

2. Defining Environmentally Friendly Materials

Eco-friendly materials are essential to sustainable development, helping to reduce the environmental impact of construction and manufacturing as global population growth and urbanization place increasing strain on natural resources [1]. By shifting to materials that are less harmful throughout their entire life cycle from sourcing and production to use and disposal industries can lower pollution, conserve resources, and reduce greenhouse gas emissions. This transition also supports the creation of healthier indoor environments and more sustainable communities [8].

These materials are selected based on their ability to minimize environmental damage across each stage of their existence, including extraction, processing, transport, and end-of-life outcomes like recycling or biodegradation. Renewable resources such as bamboo, which grows rapidly and can be harvested within a few years, serve as ideal alternatives to traditional hardwoods that take decades to mature [7]. This fast regeneration helps ease pressure on limited natural resources and supports circular economy practices [3]. In addition to being sustainable, these materials contribute to improved human health. Unlike conventional products that often release volatile organic compounds (VOCs) and other toxins into indoor air, eco-friendly alternatives are typically low-emission or non-toxic, enhancing indoor air quality (**Table 2**) [2,9–12]. Materials like cork, straw, and rammed earth are biodegradable, while recycled composites can be transformed into new products, reducing landfill waste and easing the burden on disposal systems [13].

Table 2. Comparative Impact of Conventional vs. Sustainable Materials on Mental Health. Biomarker Associations Derived from Studies on Environmental Exposure and Brain Health [2,9–12]. Cortisol and BDNF Data Supported by Environmental Enrichment and Biophilic Design Literature.

Property	Conventional Materials	Sustainable Materials
VOC Emissions	High (e.g., formaldehyde, phthalates)	Low or none (e.g., plant-based finishes)
Psychological Symptoms	Irritability, anxiety, cognitive fatigue	Mental clarity, emotional balance
Neurological Biomarkers	Elevated cortisol, inflammation markers	Lower cortisol, improved BDNF expression
Mental Health Impact	Risk of neuroinflammation, depression	Cognitive resilience, enhanced neuroplasticity

Sustainable materials also tend to require less energy for production and maintenance. For instance, using locally sourced stone or adobe cuts down on emissions from transportation and industrial processing. Others, like wool or cellulose insulation, improve a building's thermal efficiency, promoting energy conservation. Ultimately, the use of eco-friendly materials not only protects the environment

but also contributes to healthier, more energy-efficient living and working spaces [14].

Sustainable materials often feature natural textures, colors, and patterns that enhance both visual appeal and psychological wellness [4]. Materials like wood, cork, and bamboo not only create aesthetically pleasing spaces but also evoke calmness and a connection to nature key principles in biophilic design [2]. Bamboo, a fast-growing, renewable resource, is used in flooring, furniture, and structural components. Cork, harvested without damaging trees, is hypoallergenic, fire-resistant, and sound-absorbing. Reclaimed wood offers character and sustainability, while rammed earth provides thermal regulation through its dense, natural structure [15].

In addition, recycled composites created from waste like plastics or metals combined with natural fibers offer durable, low-emission solutions for decking, countertops, and more. These innovative materials are increasingly favored in construction for their performance and eco-benefits. Though initial costs may be higher, their energy efficiency, longevity, and minimal maintenance typically yield long-term economic advantages [3]. Many such materials, like adobe or straw bales, can also be sourced locally, cutting emissions and boosting regional economies. Despite these advantages, challenges remain. Limited availability, supply chain issues, and a lack of awareness among professionals can hinder adoption. Some stakeholders remain skeptical about the performance and reliability of natural materials, and the lack of standardized certifications can make it difficult to validate sustainability claims. Nonetheless, these hurdles can be addressed through education, investment in supply infrastructure, and supportive policies [16].

As climate and resource concerns grow, eco-materials are shifting from niche to norm. Advances in material science and rising consumer demand are driving development in bio-based materials and low-carbon manufacturing [7]. Government incentives and certifications like LEED are promoting adoption. Ultimately, eco-friendly materials are becoming essential in sustainable design, combining ecological responsibility with human health benefits and playing a central role in building a resilient, healthier future [17].

3. Mental Health and the Built Environment

In recent years, the relationship between architecture and mental health has gained increasing attention among professionals across disciplines. With mental health issues like anxiety, depression, and chronic stress on the rise, there's growing awareness that our built environments significantly influence emotional and cognitive well-being [3]. Modern architecture is evolving to address not just form and function, but also the psychological needs of occupants. Research highlights how elements such as natural light, ventilation, and sound control can reduce mental strain and support emotional balance. Additionally, using sustainable, non-toxic materials enhances indoor air quality and sensory comfort, further promoting mental wellness. By combining smart spatial planning with eco-friendly material choices, designers can create holistic environments that nurture human health [18].

A key architectural element for mental well-being is access to natural daylight. Sunlight regulates the body's circadian rhythm, influencing sleep, hormones, and mood [4]. Insufficient exposure to daylight has been linked to mood disorders like seasonal affective disorder (SAD) and reduced cognitive performance (**Table 3**). Incorporating design features such as large windows, skylights, open spaces, and reflective surfaces can significantly brighten interiors, boosting mood and productivity. Research by the Center for Health Design shows that hospital patients in sunlit rooms report less pain and require fewer medications, while employees in well-lit offices sleep better and feel more satisfied at work [19].

Table 3. Biophilic Design Strategies and Their Neurological Mechanisms of Action.

Element	Brain Regions Engaged	Outcome
Indoor Plants	Hippocampus, PFC	Improved memory, lowered anxiety
Natural Light	Circadian system, limbic	Better sleep, elevated mood
Water Features	Amygdala, brainstem	Reduces arousal, enhances tranquility
Organic Patterns	Visual cortex, DMN	Improved focus, reduced visual fatigue
Tactile Surfaces	Somatosensory cortex, PFC	Psychological safety

This passage explores how sustainable architectural practices can enhance mental health by improving indoor environmental quality. It emphasizes that daylight's psychological benefits are amplified through eco-conscious design [3]. Techniques like low-emissivity glazing and light-colored, non-toxic finishes enhance natural brightness without overheating or overusing artificial lighting (**Figure 2**). Proper ventilation also plays a key role; inadequate airflow can cause symptoms such as fatigue, headaches, and impaired concentration, potentially leading to "sick building syndrome" [1]. Incorporating natural ventilation methods like operable windows and passive airflow systems improves air quality and strengthens a connection to the outdoors. Sustainable materials further support this by reducing indoor toxins [7]. Items free from formaldehyde, VOCs, and phthalates like natural insulation and eco-certified finishes promote better respiratory health, cognitive clarity, and emotional balance. Acoustic comfort is another important yet often overlooked factor. Excessive noise can elevate stress and hinder focus, especially in sensitive groups like children or the elderly [20].

Using sound-absorbing, sustainable materials such as cork and wool reduces auditory stress while aligning with eco-design values. The sensory experience of a space its textures, colors, and materials also impact emotional well-being [4]. Natural surfaces like wood, stone, and fibers foster calm and connection through biophilic design. These elements have been shown to lower stress and elevate mood. Additionally, knowing that a space is environmentally responsible can increase feelings of satisfaction and purpose [2]. Ultimately, the overall perception of a space through its air, light, sound, and materials shapes how people think, feel, and function. Sustainable, health-focused architecture creates environments that feel cleaner, safer, and more nurturing. This is especially crucial in settings like schools, hospitals, and shelters. The text argues that architecture should promote not only ecological balance but also mental wellness, merging ethics with design for the benefit of both people and the planet [21].

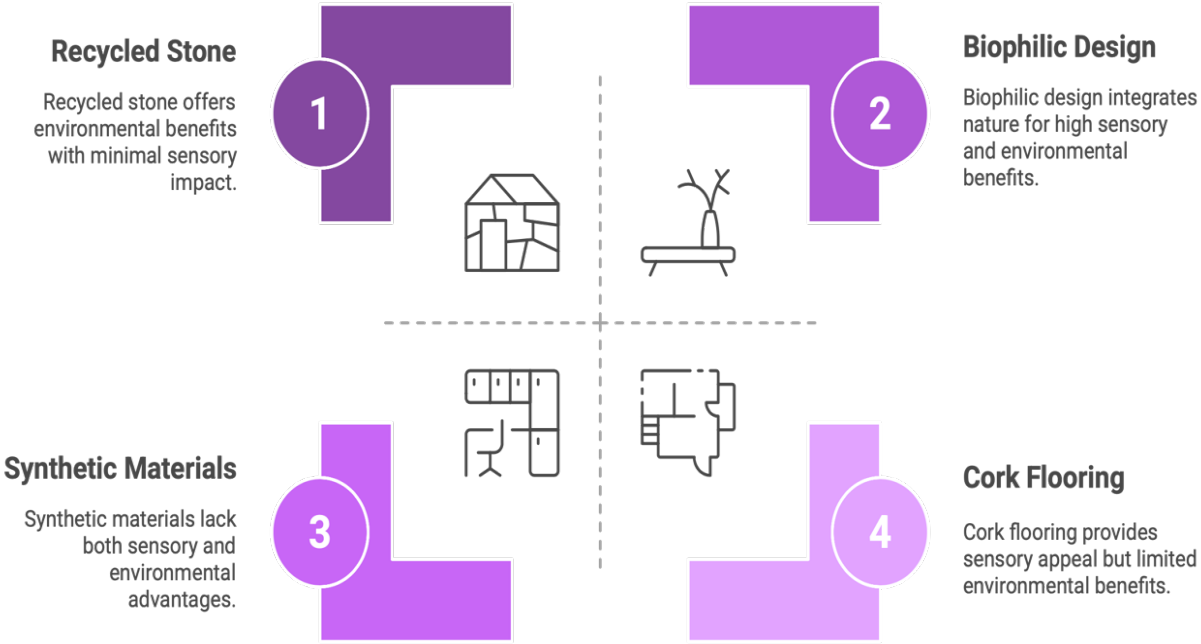

Figure 2. Sustainable Materials Enhance Well-Being by Reducing Noise, Offering Calming Sensory Experiences, and Supporting Biophilic Design. Natural Textures and Ethical Sourcing Promote Focus, Stress Relief, and Emotional Balance, While Reinforcing a Sense of Purpose and Alignment with Environmental Values.

4. Biophilic Design and Emotional Regulation

This passage explores biophilic design as a critical intersection of sustainable architecture and environmental psychology, aiming to restore the human-nature connection within built environments [19]. Rooted in the theory of biophilia our innate tendency to affiliate with nature this approach introduces natural elements into urban and interior spaces, enhancing both ecological responsibility and mental well-being [3]. Biophilic design uses eco-conscious materials that preserve natural qualities like texture, color, and scent [7]. These materials such as wood, stone, and wool engage the senses and create calming, restorative environments. Inspired by Edward O. Wilson's work, this design philosophy emphasizes the psychological benefits of nature exposure, including reduced stress and improved cognitive performance, even when direct access to outdoor greenery is limited [22].

Two primary strategies define biophilic spaces: direct engagement with nature (e.g., indoor gardens, water features, natural light) and indirect simulation through materials and design motifs. When direct features are impractical, tactile and visual elements like raw wood or fractal patterns emulate nature's presence [4]. Organic shapes, earthy tones, and familiar textures foster a sense of comfort and grounding. Additionally, eco materials emit subtle natural scents that enhance emotional and sensory richness, unlike synthetic alternatives. Research highlights multiple psychological benefits: lower cortisol levels, sharper focus, reduced anxiety, and elevated mood. These outcomes are especially valuable in environments like schools, hospitals, homes, and offices, where mental well-being is crucial. Eco-friendly design also strengthens individuals' ethical connection to sustainability, reinforcing a sense of purpose and psychological alignment [23].

Ultimately, biophilic design transcends aesthetics. It addresses a deep psychological need for nature amid growing urbanization and digital immersion. Sustainable materials play a vital role by offering immersive, sensory experiences that promote calm, clarity, and emotional resilience. This holistic design approach supports both planetary health and human flourishing, offering a path to more restorative and meaningful environments.

5. Gross Neuroanatomy and Environmental Influence

The human brain's response to environmental stimuli is mediated by various structures. The prefrontal cortex (PFC) is a vital region of the brain located at the front of the cerebral cortex. It plays a central role in a wide array of higher order cognitive functions, often referred to as executive functions, including decision making, attention regulation, working memory, and emotional control [3]. Additionally, the PFC is closely linked with mood regulation, as it helps manage stress responses and moderates the activity of the brain's limbic system, which governs emotional reactions. Although several studies associate natural materials with activation in brain regions such as the prefrontal cortex, hippocampus, and amygdala, the underlying mechanisms are not always well delineated. These claims often rest on indirect inferences rather than direct causal mapping. In most cases, material-induced brain activity is hypothesized to occur through multisensory pathways including tactile, visual, and olfactory inputs that interact with neural circuits involved in attention, emotion regulation, and memory. For example, tactile engagement with wood grain or the scent of natural oils may stimulate somatosensory and olfactory cortices, which in turn modulate activity in the prefrontal cortex through top-down cognitive appraisal processes. However, the exact neurobiological routes remain insufficiently studied, and more empirical work using standardized stimuli and mechanistic modelling is needed to clarify how specific materials engage these brain regions. Modern neuroscience has shown that prolonged stress, anxiety, and depression are often associated with overactivity in the default mode network (DMN) a network that includes parts of the PFC and is responsible for introspective thoughts and self-referential processing (**Figure 3**). This state, often characterized by rumination, leads to repetitive negative thinking and diminished mental clarity [24].

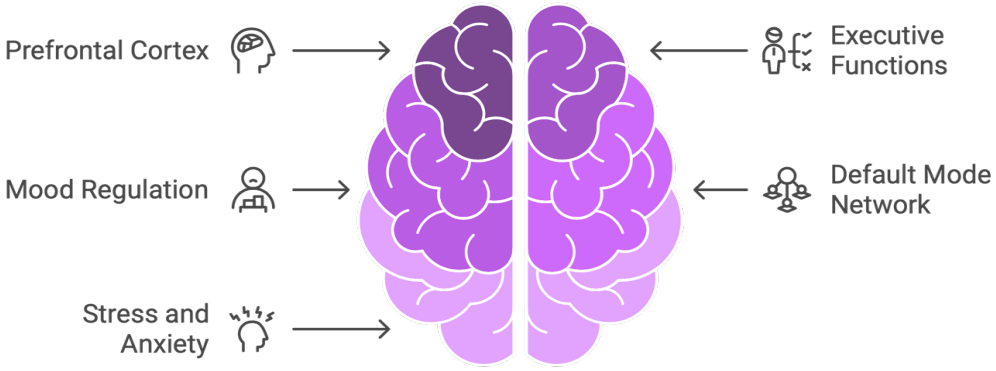

Figure 3. The Prefrontal Cortex Regulates Decision-Making, Attention, Emotions, and Stress. Overactivity in Its Default Mode Network Links to Anxiety, Depression, and Rumination. This Disrupts Mental Clarity, Highlighting How Environmental Stimuli Influence Cognitive and Emotional Well-Being Through Brain Function.

This text explores how interaction with natural environments and the incorporation of biophilic design elements can positively influence brain function particularly in the prefrontal cortex (PFC) and amygdala leading to enhanced emotional and cognitive health [4]. Neuroscientific studies using fMRI and EEG have shown that time spent in nature stimulates beneficial brain activity, particularly in the PFC, which governs attention, emotion regulation, and decision-making [1]. For example, research from Stanford revealed that individuals who walked in natural settings showed decreased activity in a part of the PFC linked to depressive rumination, alongside improved mood and reduced negative thoughts. These findings underscore that even brief exposure to nature can promote psychological calm and improve mental clarity [25]. While the reviewed studies generally suggest a positive correlation between sustainable materials and mental well-being, it is important to recognize the methodological limitations within this body of research. Many cited findings particularly those involving fMRI or EEG neuroimaging are based on small sample sizes, limiting generalizability and statistical power. In addition, most studies measure short-term psychological or physiological responses, making it difficult to assess long-term or cumulative effects of material exposure. Variability in study design, such as inconsistent definitions of "natural" materials or non-standardized sensory conditions, further complicates comparisons across research [9]. The lack of replication studies and the underreporting of null or contradictory results also present significant gaps. These limitations highlight the need for more rigorous, longitudinal research to validate and expand upon the initial findings in this field.

Biophilic design replicates these effects by using natural textures, colors, and materials like wood, stone, and organic fibers in indoor spaces [19]. These eco materials provide sensory stimuli that reduce mental fatigue and promote mindfulness, mimicking the calming impact of real nature [2]. Such design choices are especially beneficial in settings like schools, offices, and healthcare environments, where enhanced focus, emotional stability, and reduced stress are vital [9].

The amygdala, which regulates fear and stress responses, also reacts strongly to environmental stimuli [3]. Chronic exposure to urban stressors noise, crowding, and lack of green space has been linked to overactivation of the amygdala, increasing the risk of anxiety and mood disorders (**Figure 4**). However, nature exposure and biophilic elements help counteract this by reducing physiological stress markers like heart rate and cortisol levels [26]. Natural materials like cork, bamboo, and untreated wood not only improve air quality but also offer calming sensory experiences that help regulate amygdala activity. When integrated into high-stress environments, they help create safer, emotionally balanced spaces. Overall, sustainable design enhances brain function and well-being, offering a science-backed strategy for supporting mental health through thoughtful environmental choices [26].

The hippocampus is a crucial part of the brain located within the medial temporal lobe, best known for its role in memory formation, spatial navigation, and emotional regulation [19]. It is a key structure in consolidating short term memories into long term ones and plays a vital role in how

we process and respond to emotional experiences [2]. Additionally, the hippocampus works in close conjunction with the amygdala and prefrontal cortex to regulate the body's stress response [4]. One of the most significant findings in neuroscience over the past two decades is the plasticity of the hippocampus its ability to generate new neurons in a process called neurogenesis (**Figure 5**). This plasticity is highly sensitive to environmental influences [7]. Chronic stress, lack of stimulation, and exposure to urban stressors like noise and pollution have been shown to shrink hippocampal volume, impair memory function, and increase susceptibility to mood disorders such as depression and anxiety [27].

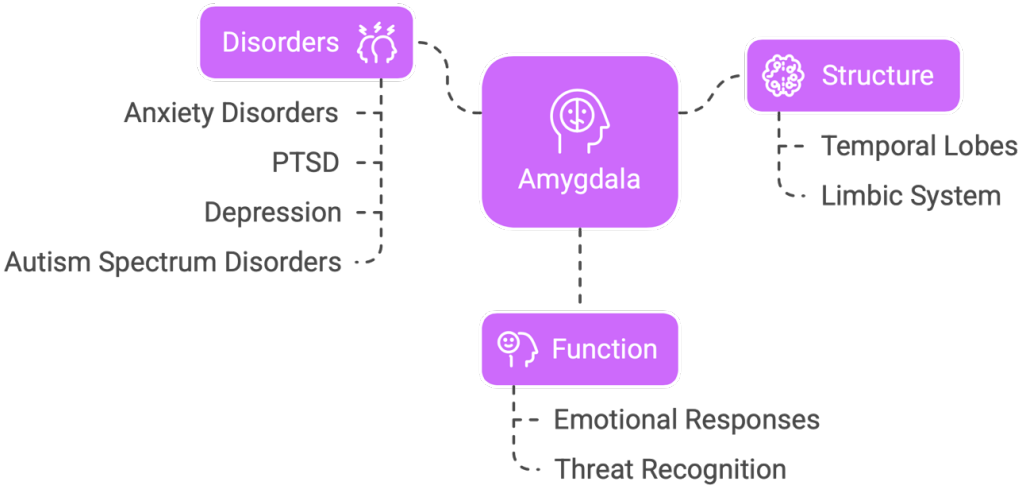

Figure 4. The Amygdala, Located in the Temporal Lobe, Is Crucial for Processing Emotions, Especially Fear and Pleasure, and Forming Emotional Memories. It Influences Behavior and Threat Response, and Its Dysfunction Is Linked to Anxiety, PTSD, Depression, and Autism Spectrum Disorders.

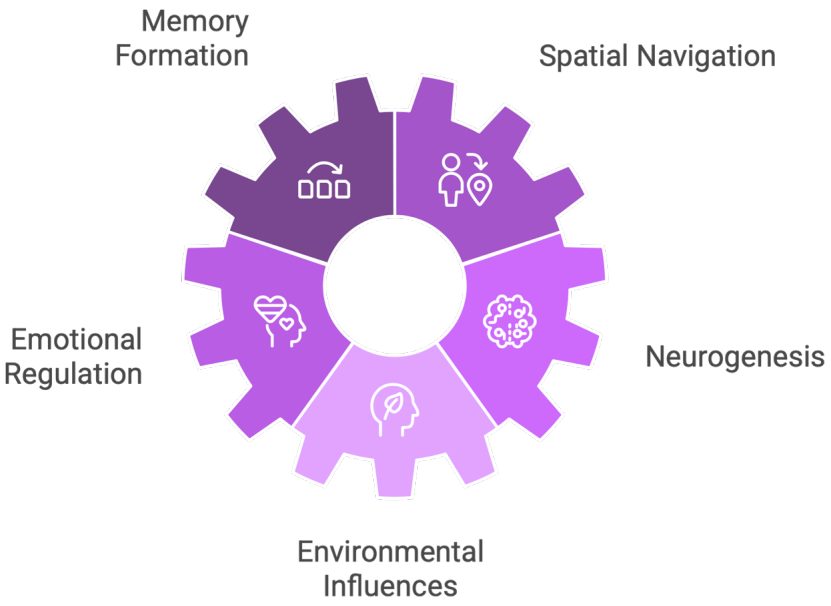

Figure 5. The Hippocampus Supports Memory, Emotion, and Stress Regulation, and Can Grow New Neurons Through Neurogenesis. Its Plasticity Is Affected by Environment, Chronic Stress, and Urban Noise, Which Can Reduce Its Size, Harming Memory and Increasing the Risk of Anxiety and Depression.

Natural stimuli, whether experienced in outdoor environments or through biophilic design and eco-friendly materials, have been linked to increased hippocampal activity and volume [9]. Neuroimaging research shows that individuals who spend time in green spaces or interact with natural textures often have healthier, more active hippocampi [1]. These individuals tend to exhibit better memory, improved emotional regulation, and reduced stress. Natural environments offer rich multisensory experiences, like navigating through a forest or garden, that engage spatial memory and complex sensory processing, activating and strengthening the hippocampus [28].

Even when people aren't directly in nature, eco materials such as reclaimed wood, bamboo, stone, and cork can provide similar benefits. These materials mimic the sensory qualities of nature, offering tactile and visual stimulation that engages the hippocampus through texture, pattern recognition, and color variation [3]. Additionally, the scent of natural wood or the warmth of sunlight passing through wooden slats can activate sensory networks that promote emotional calm and cognitive clarity [19]. As eco materials tend to be low in toxins and volatile organic compounds (VOCs), they improve indoor air quality, which further supports brain health by reducing irritants that could hinder hippocampal function [10].

The importance of memory-enhancing environments is particularly evident in educational and healthcare settings. Schools designed with natural materials and access to green spaces show improved student focus and memory retention [4]. Likewise, environments for individuals with dementia or cognitive decline benefit from familiar, nature-based materials, which help reduce memory loss and enhance comfort [3]. Since the hippocampus is highly responsive to its environment, eco materials that engage the senses and reduce stress can help preserve its function, supporting memory, learning, and overall well-being. Thus, integrating nature-based design elements is not just aesthetically pleasing it's a scientifically supported strategy for enhancing cognitive resilience and emotional health [29].

6. Molecular Pathways Influenced by Environmental Stimuli

Exposure to natural and sustainable environments has a significant impact on cortisol production at the cellular level [9]. Cortisol, a hormone produced by the adrenal glands in response to stress, plays a vital role in regulating metabolism, immune function, blood pressure, and the sleep-wake cycle [3]. While cortisol is helpful in short-term stress responses, chronic elevation, common in fast-paced and overstimulating environments, can lead to negative health effects such as anxiety, depression, cardiovascular problems, weakened immunity, and impaired memory [2]. Urban environments, characterized by noise, crowding, pollution, and limited greenery, tend to promote continuous stress activation, leading to prolonged high cortisol levels [7]. Research shows that individuals in such environments experience elevated heart rates, higher blood pressure, and increased cortisol, even at rest [30].

In contrast, environments designed with natural elements and eco-friendly materials help reduce cortisol levels significantly [19]. This concept is supported by environmental psychology and biophilic design, which emphasize integrating nature into built spaces for physical and psychological health [4]. A study in Japan on "forest bathing" (Shinrin-yoku) found that spending time in a forest reduced cortisol levels, lowered pulse rates, and decreased sympathetic nervous system activity compared to urban settings. This inspired architects to bring the calming benefits of nature indoors by using sustainable materials and design strategies [31].

Materials like natural wood, bamboo, stone, clay, wool, and cork are not only renewable and non-toxic but also trigger calming sensory responses. Their soft textures, earthy tones, and organic patterns promote relaxation and signal safety to the brain. When paired with natural light, good ventilation, greenery, and acoustic comfort, these materials create environments that help lower stress levels, reducing the body's reliance on cortisol [19]. The absence of volatile organic compounds (VOCs) in eco materials further supports health by improving air quality and brain function. Sustainable design with low VOC finishes, plant-based textiles, and recycled materials aligns with ecological and stress-reducing goals [3]. These benefits are especially valuable in high-stress environments like hospitals, offices, and schools. In healthcare settings, reduced cortisol is associated with faster recovery and better patient satisfaction. In offices, stress reduction boosts focus, creativity, and productivity, while in schools, calming materials

and nature-inspired spaces enhance emotional stability and learning readiness. By incorporating eco materials, designers can create spaces that regulate stress naturally, promoting both mental and physical resilience [32].

Brain Derived Neurotrophic Factor (BDNF) is a vital protein that supports the growth, maintenance, and survival of neurons. It plays a central role in neurogenesis (the creation of new neurons), synaptic plasticity (the brain's ability to adapt and reorganize connections), and cognitive functions such as learning and memory [2]. BDNF is considered one of the most important molecules for brain health and mental resilience, and its levels are closely influenced by environmental and lifestyle factors. Low levels of BDNF are strongly associated with a range of neuropsychiatric disorders, including depression, anxiety, schizophrenia, and Alzheimer's disease [1]. Conversely, increased BDNF expression is linked to improved cognitive function, mood regulation, and neural recovery (**Table 4**). This makes BDNF a key target for interventions aimed at enhancing mental and neurological well-being [19]. Recent research suggests that natural environments may significantly enhance BDNF expression, offering powerful support for brain function through environmental design [9]. Studies have shown that exposure to green spaces, physical activity in natural settings, and interaction with nature-based materials can all boost BDNF levels. These findings align closely with the principles of biophilic and sustainable design, which aim to recreate the benefits of nature within built environments [33].

Table 4. Brain-Based Biomarkers Modulated by Eco-Friendly Design.

Biomarker	Function	Effect of Eco Materials
Cortisol	Stress hormone	Reduced through sensory and air quality improvements
BDNF	Neurogenesis, cognitive plasticity	Increased by natural stimuli and physical movement
IL-6	Pro-inflammatory cytokine	Lowered in toxin-free, calming environments
TNF-α	Inflammatory response	Reduced in clean air/natural-material spaces
Melatonin	Sleep-wake regulation	Enhanced by daylight access and organic surroundings

Spending time in natural environments or in indoor spaces designed with natural elements stimulates the sensory systems, promoting neurological engagement and cognitive enrichment. Eco-friendly materials like wood, cork, stone, and plant-based fibers provide sensory inputs similar to those found in nature [3]. This multisensory stimulation is believed to boost neural activity and growth, potentially by enhancing the production of Brain-Derived Neurotrophic Factor (BDNF), a key protein involved in brain health. Animal studies have shown that enriched environments offering varied sensory input, physical movement, and social interaction can significantly increase BDNF levels in the hippocampus, a brain region essential for memory and emotional regulation [34].

When applied to human design, eco materials and sustainable architecture offering warmth, variation, and organic complexity can replicate this effect. This is especially true when combined with access to daylight, vegetation, and opportunities for movement. Physical activity is a known promoter of BDNF, so environments that encourage natural movement, such as walking paths or garden spaces, can complement the effects of eco materials, promoting cognitive and emotional benefits [4]. Spaces designed with nature-inspired materials and layouts, such as schools, offices, and healthcare facilities, are more likely to encourage these behaviors, leading to higher BDNF expression and improved cognitive and emotional well-being [7]. Additionally, clean air quality, reduced noise, and the absence of chemical pollutants in sustainably built environments help reduce oxidative stress and inflammation both of which suppress BDNF production [19]. By creating calming, non-toxic spaces, eco-design supports a physiological state conducive to brain repair and growth. BDNF is a powerful pathway for improving brain health, and natural stimuli from eco materials play a critical role in increasing its expression. This helps foster environments that support neuroplasticity, learning, and overall psychological health [35].

Inflammatory cytokines, like interleukin 6 (IL-6) and tumor necrosis factor alpha (TNF-α), play a key role in the body's inflammatory response. Chronic inflammation, especially in the brain, can lead to conditions like depression, anxiety, cognitive decline, and neurodegenerative diseases such as Alzheimer's. Neuroinflammation, which refers to

inflammation within the central nervous system, is linked to psychiatric and neurological disorders. Elevated levels of IL-6 and TNF-α are associated with disrupted neurotransmitter function, impaired neurogenesis, and heightened stress vulnerability [2]. Environmental factors, such as synthetic materials, poor air quality, and pollutants, can trigger or worsen the release of these pro-inflammatory cytokines. Conventional building materials, including vinyl flooring, plastic composites, and particleboard, often emit volatile organic compounds (VOCs) and other airborne toxins. Prolonged exposure to these substances can result in low-grade systemic inflammation, including neuroinflammation. Research shows that individuals in poorly ventilated, chemically laden environments exhibit higher levels of inflammatory cytokines and symptoms like fatigue, brain fog, irritability, and mood disturbances [36]. Inflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-alpha (TNF-α) play a critical role in neuroimmune signaling and are increasingly implicated in the pathophysiology of mental health conditions, including depression, anxiety, and cognitive impairment. Chronic exposure to environmental stressors—such as air pollution, synthetic off-gassing materials, and poor indoor air quality—can upregulate these cytokines, leading to a state of low-grade systemic inflammation that may extend to the brain [35]. Elevated IL-6 and TNF-α have been shown to impair neurogenesis, disrupt synaptic plasticity, and contribute to oxidative stress within the central nervous system. In contrast, eco-friendly materials that are low in volatile organic compounds (VOCs) and promote clean indoor environments may help reduce systemic inflammatory load. Preliminary human studies and animal models suggest that environments incorporating natural materials like untreated wood, wool, or clay are associated with lower circulating levels of pro-inflammatory markers, potentially by reducing both chemical exposure and stress-induced sympathetic nervous system activity [34]. Future research should explore these mechanisms longitudinally to determine whether sustained exposure to such materials yields clinically meaningful reductions in neuroinflammation.

In contrast, natural and eco-friendly materials have the opposite effect. Materials like untreated wood, bamboo, cork, wool, and stone are low in emissions or VOC-free, making them more compatible with the body's systems [9]. These materials help maintain clean indoor air, reducing exposure to airborne irritants that provoke inflammatory responses [36]. Additionally, some natural materials, like certain types of wood and wool, contain antimicrobial and hypoallergenic properties that further support immune system balance [11].

Clean, low-toxin environments have been linked to lower levels of IL-6 and TNF-α, suggesting that using natural materials in architecture may help prevent inflammation-related disorders [3]. Moreover, exposure to natural materials and nature-based settings has been shown to calm the nervous system, reduce sympathetic nervous activity, and modulate inflammatory processes. This effect occurs both directly through chemical-free exposure and indirectly by reducing stress levels that drive up cytokine production [1]. By lowering exposure to inflammatory triggers and supporting a more balanced immune response, eco-friendly materials promote mental clarity, emotional stability, and long-term brain health [37].

7. Sustainable Materials and Sensory Integration

Natural materials engage multiple senses, which supports the brain's sensory integration processes. Among the various senses, touch plays a vital role in human interaction with the environment [4]. Tactile stimuli, such as the texture of materials, provide sensory feedback that influences emotional and psychological states [19]. In architectural design and material science, the texture of surfaces whether rough, smooth, soft, or hard can significantly affect an individual's emotional response, comfort, and cognitive functioning [7]. Materials like raw wood, stone, cork, or clay are especially effective in engaging our tactile senses. Their inherent irregularities, grains, and patterns offer rich sensory input that can evoke a range of emotional responses, from calm and relaxation to excitement and curiosity [38].

The tactile experience of touching materials such as raw wood or stone often triggers deep-rooted psychological associations with nature, stability, and authenticity. This connection has been explored in environmental psychology and biophilic design, where natural textures are used to promote mental well-being and reduce stress [36]. Research

has shown that interacting with textured surfaces can lead to increased feelings of safety and comfort, making spaces feel more grounded and welcoming. For instance, the rough texture of stone or the smooth feel of polished wood can create a soothing sensory experience, helping reduce anxiety and enhancing emotional regulation [39].

Tactile engagement not only calms the body but also supports cognitive functions such as attention and focus. Textured surfaces anchor the mind in the present moment, promoting mindfulness and improving cognitive processing. Studies suggest that when individuals engage with tangible, textured objects, they are more likely to remember them and experience heightened cognitive clarity [2]. The sensory stimulation from these textures activates neural pathways related to memory, learning, and emotional processing. In spaces designed with eco materials like wood, stone, or bamboo, the interaction with these surfaces provides a gentle cognitive workout, reinforcing mental flexibility and resilience [3]. Textured surfaces are particularly beneficial in spaces where concentration or focus is essential. In offices, for example, the presence of tactile materials like wood panels, stone floors, or woven fabrics can foster a more productive atmosphere by reducing mental fatigue [36]. These textures create a stimulating yet non-overwhelming environment that encourages creativity and sustained attention [4]. In contrast, sterile or overly smooth surfaces, often found in spaces designed with synthetic materials, can have a flattening or disengaging effect on cognitive and emotional states [40].

Additionally, eco materials such as cork, wool, and natural fabrics are often low in toxicity and VOCs, further enhancing the overall sensory experience [19]. Clean air, combined with the tactile stimulation provided by these materials, contributes to a more positive sensory environment, with long-term benefits for mental health. By reducing environmental stressors like chemical exposure or poor air quality, the use of natural materials provides a holistic approach to improving the sensory and emotional experience of a space [7]. Textured surfaces made from natural materials like wood, stone, and other eco materials play a critical role in enhancing sensory feedback, which positively impacts emotional well-being and cognitive function [9]. The tactile interaction with these materials encourages mindfulness, reduces anxiety, and improves focus, while also fostering a deeper connection to the natural world. Incorporating such surfaces in architectural design and interior spaces can contribute to restorative and stimulating environments, aligning both physical and mental health benefits with sustainable material choices [12].

The visual environment plays an integral role in shaping our perception, emotional state, and cognitive abilities. The way we perceive, and process visual stimuli can directly influence our levels of stress, focus, and overall mental well-being. One of the most significant findings in the field of environmental psychology and biophilic design is the positive impact of organic patterns such as those found in nature on attention restoration, visual comfort, and psychological rejuvenation (**Figure 6**). In modern, urban settings, individuals are often exposed to monotonous, sharp edged, or artificial patterns that can lead to visual fatigue. This fatigue is a form of cognitive overload, where the brain becomes strained from processing too much stark, repetitive, or highly artificial visual input [2]. Over time, this constant exposure can contribute to stress, mental exhaustion, and a decline in focus and productivity. This is especially true in settings such as offices, schools, or hospitals, where individuals are required to maintain high levels of concentration for extended periods [41].

In contrast, organic patterns, which mimic the irregular forms found in nature such as the veins in leaves, the grain of wood, or the undulating lines of a stone surface have been shown to reduce visual fatigue and enhance mental clarity [3]. These naturally occurring patterns are inherently more restorative and soothing for the brain, offering visual diversity without overwhelming the senses. This aligns with the attention restoration theory (ART), which suggests that exposure to natural patterns helps restore the brain's cognitive capacity, particularly after extended periods of focused attention or mental effort. Organic patterns offer a gentle variation in form and texture that engages the brain without overstimulating it [42].

Unlike artificial, highly structured patterns often found in urban spaces, these natural patterns allow for more fluid, harmonious visual processing, which fosters a sense of calm and ease [36]. For example, the grain of wood or the mottled surface of stone can help guide the eye in a way that feels comfortable and natural, reducing the mental strain typically caused by more rigid or repetitive designs [43].

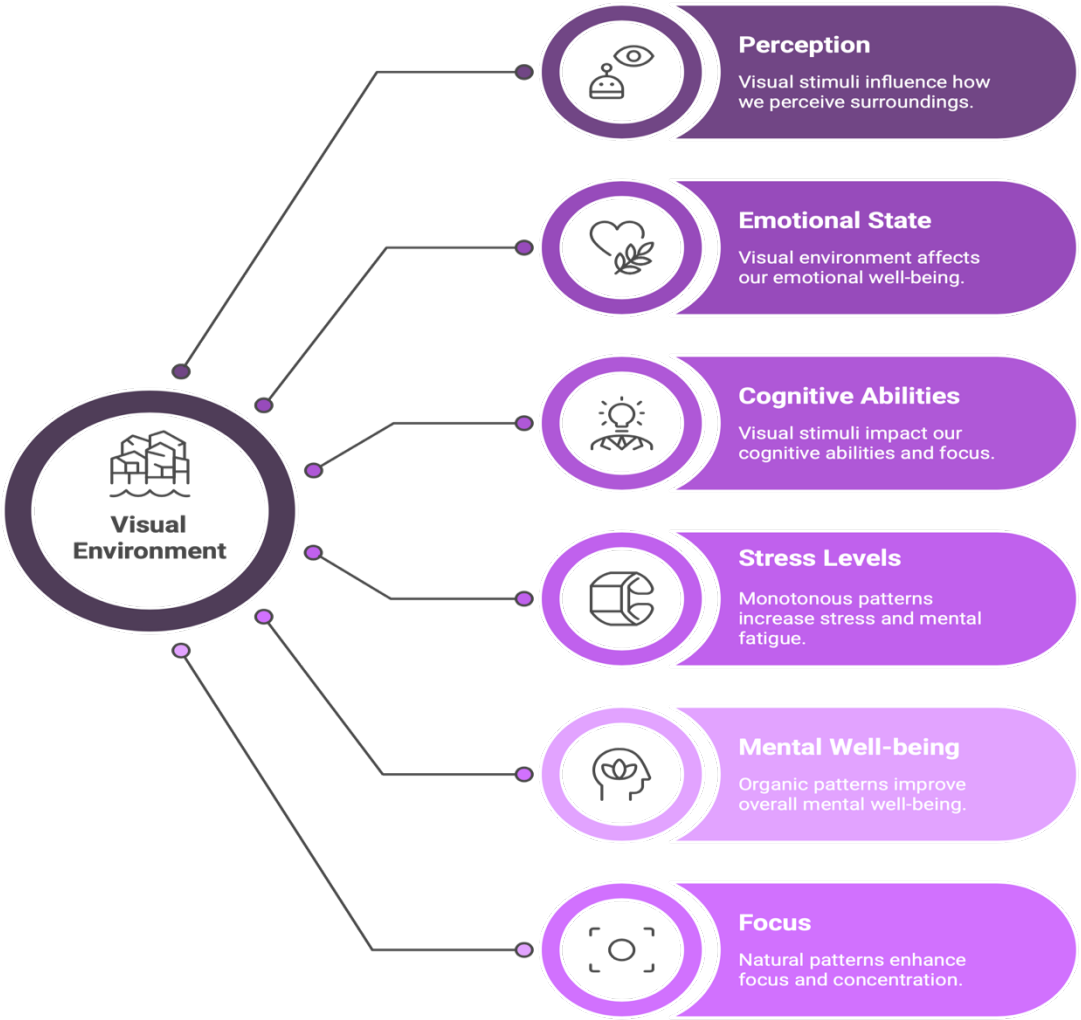

Figure 6. Visual Environments Greatly Influence Stress, Focus, and Mental Well-Being. Natural Patterns Enhance Attention and Relaxation, While Artificial, Harsh Visuals in Urban Spaces Can Cause Fatigue and Cognitive Overload, Reducing Focus and Increasing Stress, Especially in High-Demand Settings Like Offices or Schools.

The presence of natural patterns in interior design whether through the grain of wooden furniture, the veining in marble, or the gentle flow of fabric textures encourages the brain's relaxation response. This is especially important in environments where individuals need to maintain focus, such as workspaces or learning environments [1]. Studies have shown that people who work in spaces with biophilic design elements including natural patterns, natural light, and plant life are more likely to experience increased productivity, reduced mental fatigue, and improved overall mental well-being. Furthermore, organic patterns can also aid in attention restoration by providing a visual break from the monotonous or overstimulating stimuli that characterize most urban environments [3]. These visual pauses allow the brain to recover from cognitive fatigue, which improves the ability to sustain attention and focus for longer periods [9]. By integrating natural textures, curved lines, and organic forms into architectural and interior design, it is possible to foster environments that support cognitive restoration and reduce the mental strain that typically accompanies the use of technology or the demands of modern life [44].

In addition to their calming effects, organic patterns also provide a deeper sense of connection to the natural world [7]. This biophilic connection has been shown to foster a sense of well-being, reduce anxiety, and enhance mood, further contributing to mental health. The use of such patterns in built environments creates a more harmonious and nurturing space one that promotes both mental clarity and emotional resilience [2]. Organic patterns in in-

terior and architectural design offer significant benefits for mental health and cognitive function [19]. By reducing visual fatigue, enhancing attention restoration, and promoting a sense of calm, these patterns play a crucial role in creating mentally supportive environments [4]. Integrating natural patterns whether in materials like wood, stone, or textiles helps create spaces that reduce cognitive overload, support focus, and provide a sense of comfort and relaxation, ultimately fostering a healthier, more productive environment for individuals [45].

The olfactory sense (sense of smell) is one of the most direct and powerful ways our brain interacts with the environment. Unlike the other senses, which typically pass through several neural relays, the olfactory signals travel straight to the limbic system, the part of the brain involved in emotion, memory, and behavior. This unique connection between the olfactory system and the brain's emotional and memory centers gives scents the remarkable ability to influence our mood, cognitive function, and mental well-being. Among the most beneficial and therapeutic scents are those derived from natural sources, such as wood oils and other plant-based aromas. Natural scents like cedarwood, sandalwood, pine, and lavender have been used for centuries not only for their pleasant qualities but also for their impact on psychological and neurological health. When incorporated into architectural design and materials, these scents provide a sensory experience that can improve both memory retention and emotional balance [46].

Research has demonstrated that natural scents, especially those derived from wood and plants, have a significant effect on the hippocampus the brain region responsible for memory formation and emotional processing [46]. For example, cedarwood and pine oils have been shown to activate areas of the brain that are involved in memory recall and cognitive clarity, enhancing the brain's ability to retain information and improve learning [4]. These scents not only trigger memories of natural environments but also help reinforce neural pathways associated with attention and focus [36]. Natural wood scents can also have a calming effect on the nervous system, which directly influences mood regulation. Studies have found that exposure to wood-based scents helps reduce feelings of anxiety, stress, and irritability. The scent of cedarwood has been linked to lower cortisol levels, suggesting that it may help reduce stress and promote relaxation. By influencing brain regions responsible for emotional balance, natural scents can contribute to a sense of well-being and calm in stressful or stimulating environments, such as workplaces or homes [47].

The therapeutic effects of olfactory stimuli are widely acknowledged in aromatherapy, where essential oils like lavender, rosemary, and sandalwood are used to promote relaxation, reduce anxiety, and improve overall mental health [2]. In built environments, incorporating wood-based materials or essential oils into spaces like offices, healthcare facilities, and living spaces can harness these olfactory benefits to support mental clarity, emotional stability, and a positive mood [46]. Additionally, natural scents can serve as cues for memory retrieval and emotional regulation [1]. The brain's ability to form associations between specific smells and memories is well documented in studies of olfactory triggered recollection [4]. A pleasant scent, such as that of wood or fresh herbs, can trigger positive memories and emotional states, which enhances the overall experience of a space. By designing environments with natural scents embedded in materials or diffusers, it's possible to support both cognitive function and emotional resilience [48].

Wood based scents such as cedar, pine, and oak are also thought to be especially effective because they carry a sense of natural authenticity and warmth, which may promote a sense of safety and comfort. These scents can transport individuals to natural, peaceful environments, offering a mental escape from the pressures of urban life [7]. This sense of connection to nature (known as biophilia) is crucial for mental health, as it helps reduce mental fatigue and promotes emotional recovery [3]. The olfactory sense plays a critical role in our mental and emotional well-being [19]. Natural scents such as wood oils have a profound effect on the brain's memory, emotional regulation, and stress response. By activating brain regions involved in mood and memory, natural scents can enhance cognitive function and emotional balance, offering a natural remedy for mental fatigue and stress. Integrating these scents into architectural design and everyday environments can create spaces that are not only physically comfortable but also mentally restorative, promoting overall health and resilience [49].

8. Implications for Neuroarchitecture

Neuroarchitecture is an emerging interdisciplinary field that examines the relationship between architecture and the brain. This discipline focuses on how built environments the spaces we inhabit affect our cognitive function, emotions, and overall psychological health [36]. As scientific understanding of the brain's response to physical environments deepens, neuroarchitecture offers profound insights into how architecture can be used to improve mental well-being, enhance cognitive performance, and foster emotional stability [9]. One of the key aspects of neuroarchitecture is the recognition that the design and materials used in architectural spaces are not neutral but have a significant impact on how our brains and bodies respond [46]. With increasing awareness of the importance of mental health, there is a growing interest in creating environments that support psychological resilience and emotional well-being. This is where the integration of eco materials sustainable, non-toxic, and natural materials becomes particularly relevant [50].

Eco materials such as wood, stone, bamboo, cork, and natural fibers are not only environmentally friendly but also provide a multitude of benefits that support the brain and emotional regulation [2]. These materials have inherent aesthetic, tactile, and olfactory qualities that engage the senses in ways that promote cognitive restoration and emotional balance. The natural textures, colors, and smells associated with eco materials evoke a sense of connection to nature, which has been shown to reduce stress, enhance attention, and support mental clarity [7,47]. One of the key mechanisms through which eco materials affect brain function is by promoting a sense of calm and well-being [4]. For instance, wooden surfaces have been shown to induce feelings of comfort and safety, reducing anxiety and promoting a sense of stability [46]. The natural patterns in wood, stone, and other materials also have a restorative effect on the brain, which can reduce mental fatigue and improve focus and productivity [51]. These effects are especially important in spaces like offices, schools, or hospitals, where cognitive performance and emotional regulation are critical (**Table 5**).

Table 5. Sector-Based Implementation of Sustainable Neuroarchitecture.

Sector	Design Strategies	Cognitive/Emotional Outcomes
Healthcare	Use of wood, natural light, garden access	Reduced patient anxiety, faster recovery
Education	Biophilic classrooms, non-toxic paints, cork flooring	Increased focus, reduced behavioral issues
Workplace	Open layout with natural textures, acoustic cork, light stone	Greater productivity, lower stress
Residential	Clay walls, bamboo flooring, untreated wood interiors	Enhanced mood, improved sleep quality
Public Spaces	Green roofs, recycled composites, sensory paths	Social connectedness, environmental awareness

In terms of emotional stability, eco materials are particularly effective in creating environments that reduce stress and promote psychological resilience. The use of natural materials has been linked to reduced levels of cortisol, the stress hormone, which in turn helps to lower anxiety and promote calmness [36]. When integrated into spaces designed for rest or recovery, such as homes, spas, or therapy rooms, these materials can help foster a healing environment that nurtures both the body and mind [1]. Another significant benefit of eco materials in neuroarchitecture is their contribution to psychological resilience. Exposure to natural environments, or even environments designed to mimic nature, has been shown to increase neuroplasticity the brain's ability to adapt and rewire itself in response to new experiences. By incorporating materials like bamboo or cork, which have a connection to natural cycles and growth, built environments may encourage a sense of renewal and flexibility in mental health [3]. This aligns with the principles of biophilic design, which promotes the idea that a connection to nature is crucial for emotional healing and mental well-being [52].

Additionally, eco materials can significantly improve indoor air quality, which directly impacts brain function [46]. Low VOC (volatile organic compound) materials such as natural wood, clay, and wool contribute to healthier indoor air, thereby reducing exposure to harmful chemicals that can impair cognitive performance and increase neuroinflammation [7]. Healthy air quality has been shown to enhance focus, reduce fatigue, and improve overall mental health, all of which are vital for long term cognitive perfor-

mance and emotional stability [4]. Incorporating eco materials within neuroarchitecture also serves a social purpose by promoting sustainability and fostering a sense of ethical responsibility in building design [9]. People often report feeling more emotionally engaged and fulfilled when they are in spaces made from materials that have a positive impact on the environment [36]. This sense of ethical alignment can further contribute to emotional well-being and a sense of purpose, which are important components of psychological resilience [53].

Neuroarchitecture offers a promising framework for designing spaces that support cognitive performance, emotional stability, and psychological resilience [19]. By integrating eco materials, architects and designers can create environments that foster mental clarity, reduce stress, and enhance overall well-being [2]. As the field of neuroarchitecture continues to grow, it will be essential to prioritize both environmental sustainability and human health, creating built spaces that support a holistic approach to mental and emotional wellness [54].

9. Future Directions and Research Gaps

While current research into the relationship between eco materials and mental health provides promising insights, there is still much to learn about the long-term effects of these materials on cognitive function, emotional well-being, and psychological resilience [3]. As interest in neuroarchitecture and biophilic design grows, several key areas of research are emerging that could deepen our understanding of how sustainable materials influence the human brain and overall mental health [7,47]. Longitudinal studies, research into the epigenetic effects of environment-based interventions, and the development of neuro supportive materials represent critical avenues for future exploration [55].

One of the primary limitations in the current body of research on eco materials and mental health is the lack of long-term studies [46]. While many studies have shown immediate or short-term benefits of natural materials on cognitive performance, emotional regulation, and stress reduction, longitudinal studies are necessary to isolate the enduring effects of these materials on mental health [19]. Long term research would allow researchers to examine whether the benefits of eco materials such as wood, stone, or bamboo persist over extended periods of exposure and whether these materials contribute to long term improvements in psychological health and resilience [56].

Longitudinal studies are essential for understanding the sustainability of these effects over time [2,46]. For example, do the cognitive benefits of exposure to natural textures or the reduction in stress levels from using non-toxic, eco-friendly materials last for months or years? Do these materials continue to improve mental health in environments where individuals spend a significant amount of time, such as homes, offices, or schools? By tracking participants' mental health and cognitive performance over extended periods, researchers could better understand the duration of eco materials' positive impact and refine the design of spaces to optimize their long-term mental health benefits [57].

Another promising area of research lies in the field of epigenetics, which studies how environmental factors influence gene expression and the way our genes respond to external stimuli [3]. As the science of neurobiology progresses, more attention is being paid to how environmental exposures can impact mental health through epigenetic mechanisms altering the way genes involved in stress, emotional regulation, and neuroplasticity are expressed [19]. This research could provide groundbreaking insights into the long-term benefits of eco materials in supporting mental health [58].

For instance, exposure to eco-friendly materials like wood oils, natural fibers, and low VOC materials may influence gene expression related to stress response [36]. By integrating natural materials into living and working spaces, it is possible that epigenetic changes could occur that contribute to enhanced emotional stability, cognitive performance, and resilience to mental health challenges (**Figure 7**). These changes could potentially make individuals more resilient to stress and improve neuroplasticity, which is the brain's ability to adapt and form new connections [1]. Future research into the epigenetic effects of environment-based interventions would deepen our understanding of how natural spaces and materials influence gene expression over time, potentially offering new avenues for preventive mental health strategies [59].

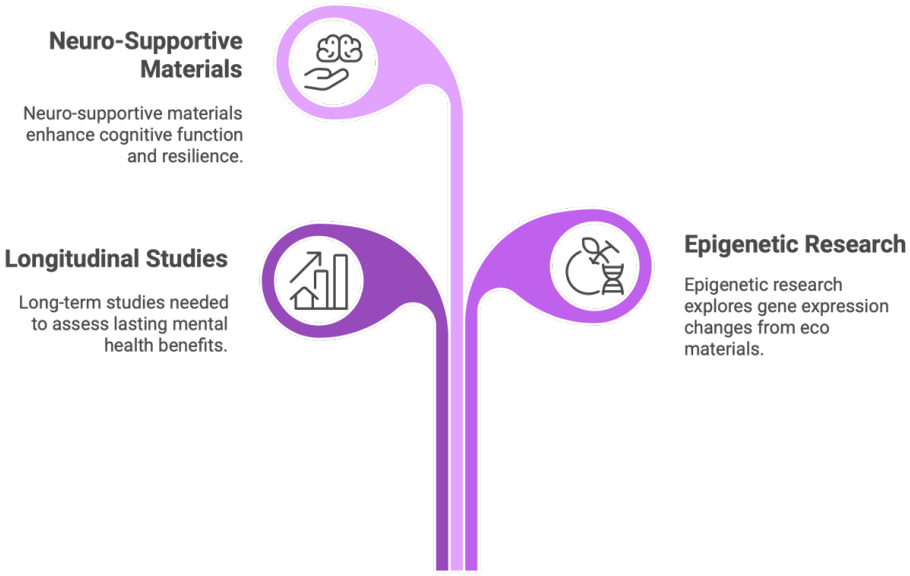

Figure 7. Eco-Materials Show Short-Term Mental Health Benefits; Long-Term Effects Remain Under-Researched. Future Studies, Especially in Neuroarchitecture and Epigenetics, Could Reveal How Natural Materials Influence Gene Expression, Resilience, and Lasting Cognitive and Emotional Well-Being in Everyday Environments.

As our understanding of the brain's response to build environments grows, there is an increasing need for the development of new materials that are not only sustainable but also neuro supportive. While many eco materials are already known to be environmentally friendly, their neurobiological benefits are still being explored [2]. Future innovations could focus on creating materials that are specifically engineered to support cognitive function, emotional health, and psychological resilience [19,47]. For example, smart materials could be developed to actively contribute to brain health by promoting positive sensory experiences or improving indoor air quality [3]. Eco friendly composites that incorporate both natural fibers and advanced neuro supportive properties, such as the release of beneficial natural compounds or the regulation of humidity and air quality, could be utilized in the design of spaces where mental clarity and emotional well-being are critical, such as healthcare facilities, offices, and homes [4]. The creation of such materials would bridge the gap between sustainability and brain health, providing long term solutions for enhancing cognitive and emotional well-being in various built environments [60].

While the field of eco materials in architecture shows tremendous potential for improving mental health, significant research is still required to fully understand their long-term impacts [36]. Longitudinal studies are essential for examining the sustained benefits of eco materials on cognitive function, stress reduction, and emotional resilience [46]. Moreover, exploring the epigenetic effects of environment-based interventions could unlock new insights into how natural spaces and materials influence mental health at a genetic level, offering long term benefits for psychological well-being [7]. Finally, the development of neuro supportive, sustainable materials represents a promising future direction for neuroarchitecture one that will not only promote environmental sustainability but also directly support brain health and emotional stability. By addressing these research gaps, we can create spaces that promote mental wellness while simultaneously contributing to the health of the planet [61].

This study contributes to the evolving field of neuroarchitecture by synthesizing biophilic design principles with emerging insights into brain-environment interactions, thereby laying the groundwork for new hypotheses regarding the neural mechanisms underlying human responses to natural elements. Our findings suggest that specific design strategies may influence cognitive and emotional processes through identifiable neural pathways, offering a more targeted framework for future experimental research. By integrating ecological, psychological, and neurobiological perspectives, this work also proposes a preliminary conceptual model that links environmental features with neu-

ral and behavioral outcomes, advancing neuroarchitecture beyond descriptive accounts toward a more mechanistic understanding. This integrative approach encourages the development of predictive models and interdisciplinary methodologies that can refine design interventions to optimize mental health and well-being.

In addition to the theoretical benefits of eco-materials, practical barriers such as cost and durability present significant challenges to their widespread adoption. Eco-materials often involve higher upfront expenses compared to conventional alternatives, which can limit their accessibility, especially in budget-constrained projects or communities. Furthermore, concerns about the long-term durability and maintenance of some eco-materials may affect their feasibility and overall lifecycle sustainability. Addressing these barriers requires not only advances in material science to improve performance and cost-effectiveness but also policy incentives and market mechanisms that support the integration of eco-materials into mainstream construction and design practices. Future research should also investigate lifecycle analyses and real-world case studies to provide stakeholders with comprehensive data on cost-benefit trade-offs, ensuring that eco-materials can be implemented practically without compromising their environmental and health advantages.

While our findings underscore the promising role of eco-materials in enhancing healing environments, it is important to recognize that these benefits do not occur in isolation. Socioeconomic factors, such as income, education, and access to resources, can significantly influence both the availability of eco-materials and their effectiveness in promoting well-being. For instance, individuals in higher socioeconomic strata may have greater access to thoughtfully designed spaces incorporating eco-materials, alongside other supportive elements, which together contribute to positive health outcomes. Future studies should rigorously control for these confounding variables to disentangle the specific impact of eco-materials from broader environmental and social determinants. Such an approach will provide a more comprehensive and accurate understanding of how eco-materials function within complex healing environments, ensuring that recommendations for their use are grounded in nuanced, evidence-based assessments.

10. Conclusions

In summary, this study highlights the critical role of biophilic design strategies in promoting well-being and environmental sustainability. Moving forward, it is essential to prioritize research that explores the underlying biological mechanisms, particularly through epigenetic studies, to deepen our understanding of how natural environments influence human health at a molecular level. Additionally, longitudinal studies should be emphasized to track long-term effects of biophilic interventions across diverse populations and settings. By focusing on these avenues, future research can not only validate current findings but also inform targeted design practices that maximize health benefits. This strategic approach will advance the field by bridging immediate practical applications with foundational scientific insights.

Author Contributions

Formal analysis, A.S.A. and M.M.R.; investigation, M.M.R.; writing – review & editing, A.S.A. and C.A.P. All authors have read and agreed to the published version of the manuscript.

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On reasonable request, the data sets generated and analyzed during the current study are available if requested from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest.

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