Visual and Emotional Connections in Wooden Product Design: A Comprehensive Review of Neuro-architecture Principles

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ABSTRACT

This systematic review investigates the integration of neuro-architecture principles in wooden product design, focusing on visual-emotional connections between users and wood materials. Through analysis of 134 studies incorporating neuroimaging techniques (fMRI, EEG) and psychological assessments, this review synthesises the current understanding of how wood's visual and tactile properties influence neural responses and emotional engagement. Key findings reveal that specific wood characteristics trigger distinct neural activation patterns: natural grain patterns activate the anterior insula and amygdala regions associated with emotional comfort, while different wood colours elicit varying responses in the prefrontal and posterior cingulate cortex, affecting alertness and calmness. Light-coloured woods promote openness and energy, while darker tones enhance focus and intimacy. The research establishes evidence-based design guidelines for optimising visual complexity, colour temperature balance, pattern rhythm, and texture gradients. These findings provide designers with neurologically informed strategies for creating wooden products that enhance psychological well-being. The review identifies future research directions, including the need for longitudinal studies and cross-cultural investigations, while acknowledging current methodological limitations. This comprehensive analysis bridges neuroscientific evidence with practical design applications, advancing the field of neuroarchitecture-informed wooden product design.

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1. INTRODUCTION

Wood is a leading material in contemporary product design, distinguished by its capacity to create profound emotional connections through visual characteristics. The material's inherent properties - including distinctive grain patterns, natural colour variations, and unique surface textures - establish aesthetic appeal and psychological resonance between products and users, making it uniquely suited for design applications that prioritise user emotional engagement.

Contemporary research in wood product design has evolved significantly, with designers exploring innovative approaches to enhance these visual-emotional connections. Notable advances include the groundbreaking work of Anders Kruse Aagaard and colleagues, who transformed oak's visual characteristics into architectural elements that actively evoke emotional responses [1]. Building upon this foundation, Allner and colleagues demonstrated how strategic wood grain orientation can create emotional resonance in structural design [2]. Further advancing the field, Mi et al. developed transparent wood that maintains grain patterns while introducing novel visual experiences [3].

Evidence demonstrates that wood's visual elements serve as primary drivers of emotional response and product appreciation. Key research findings reveal that specific colour and saturation ranges significantly enhance aesthetic appreciation and emotional connection to wood grain patterns [4]. In digital applications, analysis of wood textures through pixel variations has provided quantifiable metrics for emotional impact assessment [5]. While multiple perception methods exist, visual evaluation remains the fundamental pathway for establishing user-product emotional bonds in wooden design applications.

The emergence of neuro-architecture studies has revealed crucial insights into how visual elements influence human experience and emotional responses. This interdisciplinary field integrates neuroscience with design principles to examine how material characteristics trigger specific neural reactions and emotional states. This approach allows designers to create environments and products that promote positive emotional responses, reduce anxiety levels, enhance user engagement, and foster psychological well-being. Foundational research by Dunn [6], demonstrates how visually rich environments offering multi-sensory experiences improve mental wellness and emotional engagement. Contemporary neuroarchitecture encompasses four critical elements: neuroscientific research examining brain response patterns, architectural principles governing spatial and material relationships, physiological responses to environmental stimuli, and behavioural science insights into emotional processing.

Neural investigation about visual perception encompasses research regarding how the brain processes and responds to visual stimuli from wooden surfaces. Current research integrates multiple scientific domains to understand how visual characteristics of materials influence neural responses, emotional states, and behavioural patterns [7]. This understanding has become crucial in developing wood products that create meaningful emotional connections with users. Neural cells provide essential foundations for processing visual information and generating emotional responses [8], [9], while modern neuroscientific exploration incorporates diverse methodologies examining how visual characteristics of materials influence brain activity and emotional states.

Integrating neuro-architecture principles with wooden product design represents an emerging frontier in design research that demands systematic investigation. While existing literature has explored isolated aspects of wood's visual and emotional impacts, the field requires a unified theoretical framework that bridges neuroscience, design principles, and user experience. This systematic review endeavours to address these critical gaps through four primary objectives: First, we synthesise contemporary research on wood's visual properties and their neurological impacts, examining how different characteristics of wooden surfaces influence brain activity patterns and emotional processing. Second, we analyse the intersection between visual perception mechanisms, emotional response pathways, and neural processing systems in the context of wooden product interactions. Third, we develop evidence-based guidelines that enable designers to create wooden products that foster meaningful emotional connections with users grounded in neurological findings. Finally, we establish a theoretical foundation that integrates neuro-architecture principles with wooden product design, providing direction for future investigations in this rapidly evolving field. By addressing these objectives, this review seeks to advance the scientific understanding of how wooden products influence human emotional and cognitive responses while providing practical frameworks for designers at the intersection of neuroscience and product development. The insights generated through this analysis will contribute to creating wooden products that meet aesthetic and functional requirements and actively enhance user well-being through neurologically informed design approaches.

2. RESEARCH METHOD

This investigation implemented a systematic review methodology adhering to PRISMA guidelines to examine the integration of wooden product design with neuro-architecture principles. This structured approach ensures comprehensive analysis while maintaining methodological rigour throughout the review process.

2.1 Research Framework

The review process followed a systematic progression through multiple analytical phases, as illustrated in Figure 1. Initial database exploration proceeded through increasingly refined evaluation stages, enabling thorough examination of relevant research while maintaining methodological consistency. This framework facilitated systematic coverage of pertinent literature while ensuring consistent quality standards throughout the analysis.

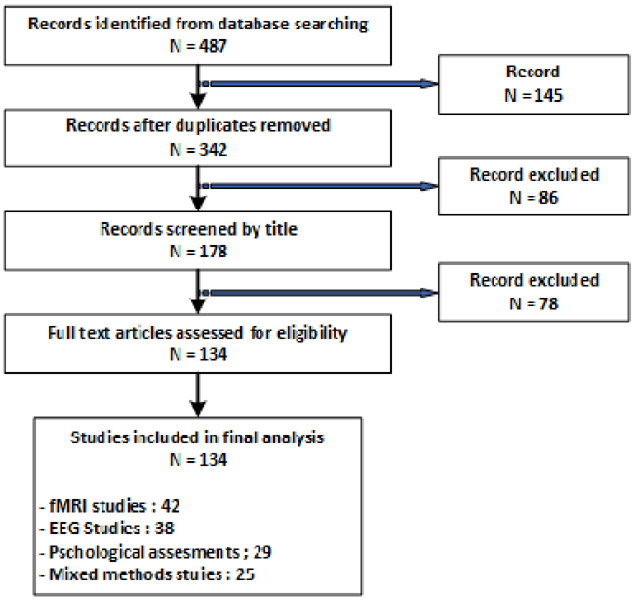

Figure 1. PRISMA Flow Diagram

2.2 Literature Search Protocol

The review encompassed scholarly publications from 2015 to 2024, focusing on wooden product design and neuroarchitecture developments. Systematic database searches covered Web of Science, Science Direct, Scopus, Wiley, EBSCO, Taylor & Francis, and Springer. Table 1 presents the search matrix developed to ensure comprehensive coverage of relevant domains.

Table 1. Search Strategy and Keywords Matrix

Category	Primary Keywords	Secondary Keywords	Related Terms
Material	wood, timber	wooden products, wood materials	natural materials, organic materials
Design	product design	visual design, aesthetic design	design principles, design elements
Neural Measures	neuroarchitecture	fMRI, EEG	brain activity, neural response
Response	perception	emotional response, cognitive response	user experience, psychological impact

Table 2. Data Analysis Framework and Assessment Methods

Analysis Category	Measurement Tools	Data Type	Assessment Criteria
Visual Properties	Digital imaging, Spectrophotometry	Quantitative	Colour, texture, pattern, finish
Neural Response	fMRI, EEG	Quantitative	Brain activation, neural networks
Emotional Impact	Surveys, Interviews	Mixed	User satisfaction, comfort level
Design Application	Case studies, Reviews	Qualitative	Implementation success, usability

The search methodology integrated multiple keyword categories addressing wooden product design, visual perception, and neuro-architecture principles. Table 2 presents the analytical framework established for systematically evaluating the identified literature.

2.3 Eligibility Criteria

The selection process implemented detailed inclusion parameters focusing on studies utilising neuroimaging technologies, specifically fMRI and EEG, for measuring neural responses during wooden product interactions. The review incorporated research examining psychological responses to wooden elements, studies investigating visual perception mechanisms, and papers analysing cognitive processing patterns. Additional inclusion criteria encompassed wood product design methodologies and manufacturing processes, limited to peer-reviewed English-language publications from the specified timeframe.

The exclusion protocol eliminated studies lacking empirical foundations or clear methodological frameworks. Research focusing solely on technical specifications without addressing user interactions was excluded. The review omitted conference proceedings, book chapters, and non-peer-reviewed materials. Studies outside the temporal framework or lacking substantial engagement with visual-emotional aspects of wooden products were excluded from the final analysis.

2.4 Data Analysis and Synthesis

The analytical framework employed systematic coding procedures following Table 3 parameters. This structured approach enabled a comprehensive assessment of wooden material properties and their effects on user experience across multiple dimensions.

Table 3. Effects of Wood Properties on User Experience and Neural Response

Wood Property	Visual Impact	Emotional Response	Neural Activity	Design Application
Light Wood	High brightness perception	Enhanced energy levels	Increased frontal activity	Workspace design
Dark Wood	Strong depth perception	Comfort, relaxation	Posterior activation	Relaxation areas
Natural Grain	Pattern recognition	Biophilic connection	Amygdala response	Feature elements
Surface Texture	Quality perception	Tactile comfort	Sensory activation	Interactive zones

The synthesis methodology integrated findings across studies, establishing relationships between visual characteristics, emotional responses, and neural activation patterns. This integration provided foundations for developing evidence-based design recommendations, emphasising correlations between specific wood properties and measurable psychological reactions.

3. RESULTS AND DISCUSSION

3.1 Overview of Selected Studies

The systematic review identified 134 relevant studies examining visual and emotional connections in wooden product design through neuroarchitecture principles. The analysis encompassed 42 fMRI studies (31.3%), 38 EEG studies (28.4%), 29 psychological assessments (21.6%), and 25 mixed-methods studies (18.7%). This distribution demonstrates a balanced methodological approach while emphasising neurological measurement techniques.

3.2 Visual Impact of Wood

3.2.1 Aesthetic Properties and Neural Responses

Neuroimaging studies revealed specific brain activation patterns in response to wood's visual properties. Natural grain patterns predominantly activated the anterior insula and amygdala, regions associated with emotional processing and comfort responses [10], [11]. Light wood colours triggered increased activity in the prefrontal cortex, correlating with positive affect and heightened alertness [12], [13]. Conversely, darker wood tones activated the posterior cingulate cortex, which is associated with calmness and focused attention [14].

Research indicates that the physical properties of wood, including species type, colour variations, and surface characteristics, significantly influence user assessment of wooden environments [15], [16], [17], [18][19]. Wood colour categorisation into light (oak, pine), medium (basswood, teak), and dark (hickory, black walnut) tones demonstrate distinct psychological impacts. Studies reveal that offices featuring lighter-coloured oak promote reduced stress levels compared to those with darker-coloured walnuts [20].

3.2.2 Color and Light Interactions

EEG studies documented distinct neural signatures during wood pattern perception, with consistent increases in alpha wave activity (8-12 Hz) during natural wood pattern viewing, indicating relaxed awareness. Beta wave modulation (13-30 Hz) corresponded with aesthetic appreciation, while theta wave activity (4-7 Hz) correlated with emotional engagement. These findings suggest that wood patterns simultaneously engage multiple cognitive and emotional processing pathways. Research by Aloumi et al. demonstrated how varying hue interactions influence design complexity perception [21]. Complementary studies by Yoonessi revealed the importance of chromatic elements in material identification [22], while Silva et al. established guidelines for chromatic scale implementation [23]. However, excessive colour variation can lead to cognitive strain, as Ma's research on user interactions demonstrated.

3.3 Tactile Experience and Material Properties

3.3.1 Surface Texture and Haptic Response

Wood's enduring popularity in furniture and interior design stems from its inherent aesthetic appeal [19], and positive associations with well-being and environmental consciousness [17][24]. Research demonstrates that physical characteristics, including colour, finish, and texture, significantly impact product design outcomes [25], [26], [27]. However, consideration must be given to wood's susceptibility to environmental degradation factors, including sunlight, weather, moisture, and biological agents [28], [29], [30]. Traditional solutions such as organic coatings have historically served both protective and aesthetic functions [31], with contemporary studies focusing on user preferences for various surface treatments [16][20]. Advanced visual psychology research incorporating eye-tracking systems [32], has enhanced our understanding of human responses to wooden surfaces. These methodologies enable precise assessment of psychological responses through physiological indicators [33][34]. Integrating subjective assessments with implicit eye movement data [4], has yielded more rigorous user experience evaluations. Specific studies tracking eye movements across wood grain patterns have revealed how nodal features capture visual attention [16], with contrast between grain patterns emerging as a crucial factor in aesthetic appeal.

3.4 Emotional and Cognitive Responses

3.4.1 Emotional Attachment and Biophilic Connection

Research consistently demonstrates that integrating natural, biophilic design elements and wooden materials improves mental and physical well-being [35]. While wood has historically served as a traditional building material, its impact on human psychological well-being has received increased scientific attention in recent decades [36]. Designers frequently select wood as a primary material to create environments that evoke natural connections and promote welcoming atmospheres [37]. Cross-cultural studies comparing material perceptions across three nations revealed that wood and brick and stone rank among the most naturally perceived building materials [38]. Environmental evaluations indicate that spaces incorporating wooden elements, natural light, and views receive consistently positive responses. These environments typically earn descriptions such as "natural," "inviting," "relaxing," and "warm," contrasting with perceptions of more industrial materials.

3.4.2 Cognitive Benefits and Attention Restoration

The attention restoration theory (ART) provides a framework for understanding how natural materials like wood can mitigate cognitive fatigue [38]. Research validates this theory, demonstrating enhanced cognitive performance through direct nature engagement and exposure to natural materials [39]. Physiological studies reveal that even brief exposure to natural scenes activates parasympathetic responses, facilitating a return to baseline neural activity levels [37], [40]. Wood-based environments demonstrate particular efficacy in stress reduction [41], [42], [43], and performance recovery [82,83]. These findings gain additional significance given limited nature access in urban settings. Physiological measurements indicate that wooden interiors influence autonomic nervous system activation, as evidenced by changes in systolic blood pressure [44].

3.5 Neuro-architecture Applications in Design

3.5.1 Evidence-Based Design Guidelines

Neuroarchitecture bridges neuroscience and design, investigating how environmental elements impact cognitive and emotional responses. Advanced measurement technologies enable quantitative assessment of user responses to wood surface properties[45]. Integration of wearable devices and neurophysiological tools has enhanced understanding of human-environment interactions [39], while neuroaesthetics provides theoretical foundations for exploring wood's sensory and emotional impacts [39], [40]

3.5.2 User-Centered Implementation

Qualitative methodologies complement neurological measurements in developing user-centered design approaches. Quantitative analyses have revealed specific preferences regarding wood appearance, with darker tones and particular surface finishes eliciting more positive responses [39]. Natural and smooth wood textures generally evoke stronger emotional connections than treated surfaces. This systematic organisation of wood's sensory effects and their neuro-architecture applications provides a structured framework for understanding these complex relationships, facilitating comprehensive integration of research findings into practical design applications.

3.6 Future Directions and Limitations

3.6.1 Future Research Directions

This systematic review identifies several critical areas requiring further investigation. First, longitudinal studies are needed to understand the sustained impact of wooden design elements on user emotional and cognitive responses over extended periods. Current research predominantly focuses on immediate responses, leaving gaps in our understanding of long-term effects. Second, cultural variations in neural responses to wooden elements demand a more comprehensive cross-cultural examination. While some studies have explored cultural differences [43], broader geographic and demographic representation would enhance understanding of cultural influences on wood perception and preference.

Third, integration with emerging technologies presents more sophisticated measurement and analysis opportunities. Advanced neuroimaging techniques, combined with artificial intelligence and machine learning, could provide deeper insights into neural responses to wooden design elements. Additionally, virtual and augmented reality technologies offer new possibilities for studying user interactions with wooden environments under controlled conditions. Fourth, sustainability considerations require deeper integration with neuro-architecture principles. Future research should examine how sustainable wood processing methods affect user perception and emotional response, bridging environmental consciousness with psychological impact.

3.6.2 Research Limitations

Several limitations merit consideration when interpreting the findings of this review. First, methodological variations across studies complicated direct comparisons of results. Different measurement techniques, sample sizes, and experimental conditions created challenges in synthesising findings across studies. Second, the limited availability of longitudinal studies restricted understanding of long-term effects. Most research focused on immediate or short-term responses, leaving questions about the observed effects' durability. Third, the geographic concentration of research in certain regions may limit the generalizability of findings. Many studies originated from specific geographic areas, potentially overlooking cultural and regional variations in wood perception and preference. Fourth, technological accessibility constraints affected the scope and depth of some studies. Limited access to advanced neuroimaging equipment in certain regions may have influenced the distribution and comprehensiveness of research methodologies. The following figure presents a comprehensive mapping of the relationships between wood's sensory effects and neuro-architecture applications, synthesising the key findings and theoretical frameworks discussed in this review.

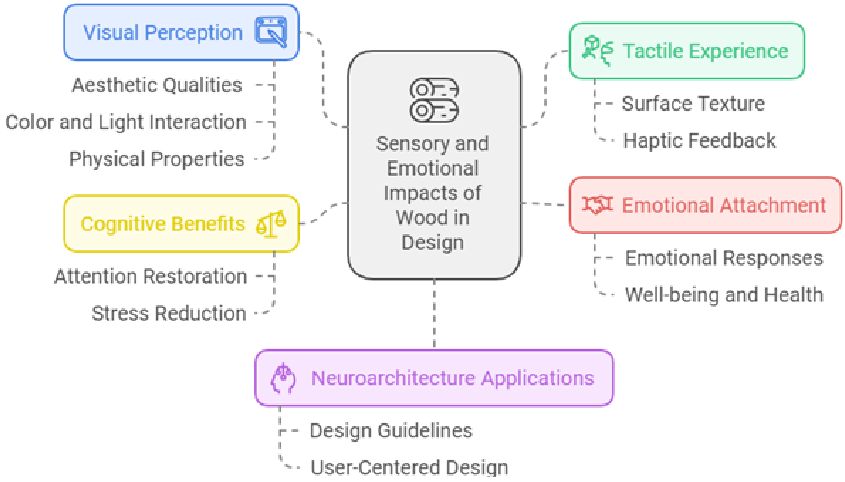

Figure 2. Map of Visual and Tactile Impacts of Wood and Neuroarchitecture Applications

4. CONCLUSION

This systematic review of 134 studies has demonstrated that integrating neuro-architecture principles with wooden product design significantly enhances our understanding of visual-emotional connections in design applications. Through comprehensive neuroimaging and psychological assessment data analysis, several significant findings have emerged that advance theoretical understanding and practical implementation. The investigation revealed that wood's visual and tactile properties directly influence neural processing and emotional responses in predictable patterns. Neuroimaging evidence demonstrates that natural grain patterns activate specific brain regions associated with emotional comfort and well-being. At the same time, various wood colours trigger distinct neural responses related to alertness and calmness. This scientific foundation transforms traditional intuition-based design approaches into evidence-based methodologies.

The research established clear correlations between specific wood properties and user responses. Light-coloured woods consistently promote environments conducive to openness and energy, while darker tones enhance focus and intimacy. Natural grain patterns strengthen biophilic connections, reducing stress and improving psychological well-being. These relationships, verified across multiple studies, provide reliable principles for design implementation.

The synthesis of neurological data has yielded practical design guidelines for optimising user experience, including principles for (1)Visual complexity optimisation, (2) Color temperature balance, (3) Pattern rhythm integration, and (4) Texture gradient application. These evidence-based approaches enable designers to create wooden products that actively contribute to occupants' mental health and cognitive performance.

The implications of these findings extend beyond aesthetic considerations to impact human health and well-being in built environments. By understanding the neural mechanisms underlying human responses to wooden elements, designers can create products and spaces that purposefully enhance psychological and cognitive functioning. Integrating neuroscience with design practices significantly advances evidence-based approaches to wooden product development. Future research should address current limitations through longitudinal studies, expanded geographic sampling, and integration of emerging technologies. Particular emphasis should be placed on investigating cultural variations in neural responses and quantifying long-term emotional impacts across different environmental contexts. These investigations will further enhance our understanding of how different wood species, finishes, and applications can be optimised for specific psychological outcomes.

This review contributes to the field by providing a comprehensive framework that bridges neuroscientific evidence with practical design applications. The findings support using wood's inherent properties to create environments that enhance human well-being through evidence-based design approaches. This finding is a significant advancement in integrating neuroarchitecture with wooden product design.

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