



A Methodological Narrative Review of Neuroscience-Based Laboratory and Simulation Approaches in Neuro-Architecture Research

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ARTICLE INFO

Article type:

Research Article

Article history:

Received 8 January 2026

Received in revised form 27

February 2026

Accepted 10 April 2026

Published Online 22 June

2026

Keywords:

environmental psychology,
architectural and urban
planning research,
laboratory method.

ABSTRACT

Background: In architectural and urban planning research, selecting an appropriate research method is crucial, particularly in studies informed by cognitive sciences and environmental psychology. The choice of method directly influences the accuracy, reliability, and applicability of research findings.

Aims: This article aims to examine the significance of method selection in architectural and urban studies and to provide a framework for applying neuroscience-based approaches in future research.

Methods: This paper presents a methodological narrative review of studies that apply neuroscience-based laboratory and simulation approaches to architectural research. The review covers publications between 2016 and 2024 identified through databases including Scopus, Web of Science, and ScienceDirect, following inclusion criteria focused on peer-reviewed studies employing physiological or neuro-cognitive measurements (EEG, fMRI, eye-tracking, and VR simulations). A total of 59 papers were analyzed through a qualitative synthesis.

Results: The review indicates that laboratory- and simulation-based methods produce more realistic and reliable findings in assessing environmental factors affecting human perception and behavior. Current research demonstrates the growing application of neuroscience approaches in architectural and urban studies.

Conclusion: Selecting appropriate research methods, particularly laboratory- and simulation-based approaches, is essential for producing robust and applicable results in architecture and urban planning research. This study proposes a methodological framework to guide future research in this domain.

Citation: Sadeghi Habibabad, A., Matracchi, P., & Jahanbakhsh Ganjeh, S. (2026). A methodological narrative review of neuroscience-based laboratory and simulation approaches in neuro-architecture research. *Journal of Psychological Science*, 25(160), 1-19. [10.66224/jps.25.160.8](https://doi.org/10.66224/jps.25.160.8)

Journal of Psychological Science, Vol. 25, No. 160, 2026

© The Author(s). DOI: [10.66224/jps.25.160.8](https://doi.org/10.66224/jps.25.160.8)



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Introduction

Current architectural research increasingly requires a scientifically rigorous methodology to understand how humans perceive and behave within built environments. The evolving discipline of neuro-architecture bridges architecture, neuroscience, and environmental psychology by examining the neural correlates of spatial experience. Rather than reiterating the general importance of research design, this study emphasizes the methodological challenge: how can laboratory-based and simulation-based neuroscience tools improve reliability and interpretative depth in architectural studies? This question anchors the paper and directly motivates the need for a methodological narrative review, rather than a purely thematic overview.

Recent findings in neuroscience have the potential to exert a significant influence on building design, leading to the creation of environments that are better aligned with human needs and preferences. Achieving this objective requires more in-depth investigation of the neurophysiological correlates associated with architectural perception, which is highly valuable for understanding how humans interact with built environments and for improving their experiential quality (Vecchiato, 2015). In recent decades, rapid advances in functional brain imaging methods have enabled cognitive neuroscience to address fundamental questions in philosophy and the social sciences. At the same time, innovative perspectives emerging from cognitive science research have had a considerable impact on various disciplines, highlighting the role of cognition and emotion in fields such as architectural planning and design. Since 2003, the Academy of Neuroscience for Architecture has supported the concept of neuro-architecture—an approach that seeks to link neuroscience with the study of human behavioral

responses to built environments (Papale, 2016; Mallgrave, 2010).

Method

A narrative review was chosen to provide an interpretive and flexible synthesis of research methods in neuro architecture. Rather than a systematic meta analysis, the narrative approach enables conceptual mapping and methodological comparison across heterogeneous studies. The justification for this approach lies in the explicit research gap identified during preliminary searches: prior reviews rarely address the integration of neuroscience based laboratory and simulation tools within architectural inquiry. Consequently, this paper focuses on how these techniques operate methodologically and how they contribute to more measurable and reproducible architectural outcomes. The review process involved keyword searches (“neuro architecture,” “EEG,” “VR,” “environmental cognition,” “spatial neuroscience”) in Scopus, Web of Science, and Google Scholar; selected articles were limited to those published between 2016 and 2024 in English peer reviewed journals.

Research Background

A Review of Architectural and Urban Planning Topics Centered on Neuroscience

The study by Şekerci (2024) examines research focused on architecture, interior architecture, and virtual reality within the fields of neuroscience and spatial design. This shift emphasizes the integration of neuroscience to enhance human well-being, reduce stress, and promote biophilic design in environments. This approach indicates that the application of neuroscientific knowledge and virtual reality in spatial design can lead to significant improvements in human life and living environments. Neuro-architecture and neuro-urbanism, by drawing on scientific knowledge related to the brain and nervous

system, investigate the relationship between the brain, body, and environment in order to enrich architecture and urban design. This interdisciplinary approach emphasizes evidence-based design and aims to address individuals' emotional and cognitive needs while improving their everyday experiences. Such an approach not only enhances the quality of daily life but also contributes to the advancement of societal well-being and quality of life by creating spaces and cities that attend to the psychological and mental dimensions of human beings (Charalambous, 2023).

The research by Rad (2023) seeks to comprehensively and analytically examine the intersection between architecture and neuroscience, evaluating the role of this relationship in interior design, urban environments, and buildings. In this context, various techniques related to data measurement in the field of neuro-architecture are classified and analyzed, with emphasis placed on the necessity of a deeper understanding of human experiences within built environments. The importance of employing effective methodological approaches alongside advanced neuroimaging technologies is identified as one of the main focal points of this study. The research argues that aligning architectural and urban designs with psychological conditions and human needs can have positive effects on the quality of everyday life for individuals and communities. Through the use of data-driven scientific approaches, it becomes possible to design living environments with greater precision and adaptability, ultimately leading to enhanced well-being and overall satisfaction.

Neuro-architecture, as an emerging approach at the intersection of neuroscience and architecture, seeks to investigate the deep relationship between spatial design elements and their effects on human perception, emotions, and cognitive processes. This

approach not only highlights the vital role of circadian rhythms and natural environments in improving physical and mental health but also offers valuable strategies for architecture and urban design that can more effectively influence human life. Based on the findings of these studies, designers and architects are able to employ neuroscientific principles and a precise understanding of individuals' psychological, emotional, and physical needs to design spaces that are harmonized with human nature. Such spaces can effectively enhance citizens' quality of life and ultimately play a significant role in improving individual and social health within communities (Kim, 2023).

The study by Ndaguba (2022) provides a comprehensive examination of the relationship between neuroscience and architecture, with particular emphasis on the impact of built environments on residents' emotions, mental health, and physical well-being. In this regard, aspects such as the association between urban living and increased levels of stress and anxiety disorders are highlighted. The study also emphasizes the importance of developing methods and strategies to promote urban health through a neuro-urbanism approach. By addressing these issues, the research contributes to a deeper understanding of the effects of designed environments on the human mind and body and lays the groundwork for improving the quality of cities. Designing spaces that reduce stress and enhance a sense of calm among individuals is one of the key objectives of this field. Through the application of neuro-urbanism, architects and urban planners will be able to significantly enhance citizens' health and well-being. Designing urban environments in a way that not only ensures visual aesthetics but is also psychologically and physically supportive for residents can be considered an effective step toward improving urban quality of life.

The study by Erkan (2024) analyzes and examines the effects of architectural environments ranging from historical structures with distinct cultural identities to modern buildings with innovative approaches on human cognitive and physiological responses. In this context, the importance of adopting integrated neuro-architectural perspectives to redesign built environments in order to enhance emotional well-being and improve users' overall experience is particularly emphasized. The findings indicate that designing environments based on principles derived from neuroscience and human psychology can yield profound and meaningful outcomes in enhancing individuals' mental and physical health. By integrating specialized architectural knowledge with scientific methods in neuroscience, it becomes possible to develop spaces that not only positively influence individuals' mood and emotional state but also play a fundamental role in improving users' quality of life. Accordingly, this multidimensional approach strengthens the human-environment relationship and enables the design of environments that respond to humans' emotional, cognitive, and experiential needs, representing an effective step toward the creation of healthier societies.

Neuro-architecture, as an innovative approach within the field of architecture, examines how the design of built environments can influence human behavior and emotions. This approach places particular emphasis on specific brain regions. In neuro-architecture, elements such as lighting and spatial configuration are highlighted due to their effects on cognitive experiences, spatial navigation, and overall well-being. By utilizing findings from neuroscience, architects and designers are able to create spaces that contribute to improving individuals' quality of life and provide deeper insight into the effects of architectural environments on the human brain and behavior (Abbas, 2024).

Recent studies and research emphasize the significant role that urban environments play in human brain activity and functioning, highlighting the need to develop innovative approaches such as neuro-urbanism to create healthier cities that are better aligned with citizens' psychological and emotional needs (Ancora, 2022). These studies clearly demonstrate that high-quality green spaces and environmental diversity in urban settings can have substantial effects on enhancing individuals' cognitive and emotional well-being. Such spaces not only serve as places for physical and psychological relaxation but also facilitate social interactions, reduce stress, and even strengthen a sense of belonging to the environment. The presence of natural green spaces in cities provides a unique opportunity to escape the pressures of everyday urban life and, by creating moments of tranquility, can significantly enhance the mental and physical health of urban residents.

Neuroscience in architecture and urban planning examines the influence of cognitive functions, empathy, imagination, and emotions on architectural design (Lucchini, 2022). By drawing on neuroimaging findings, this approach offers a deeper understanding of spatial awareness and applies this knowledge to create environments that support human experience and creativity. Within this framework, architects can design spaces that are both cognitively and emotionally beneficial and pleasant for humans by better understanding how the brain functions and interacts with living spaces. This transformative perspective in architecture and urban planning focuses on the inseparable link between the human brain and built environments and can lead to the creation of spaces that exert positive cognitive, emotional, and behavioral effects on individuals, thereby enhancing the quality of their experiences. Moreover, such an approach can play an effective role

in improving the design of cities and urban spaces so that these environments are shaped more intelligently and in accordance with human needs.

In the article by Arbib (2021), three fundamental and significant links between architecture and neuroscience are examined and analyzed: experiential neuroscience, design, and neuromorphic architecture. These three interconnected domains demonstrate how the creative integration of neuroscientific knowledge with architectural principles can lead to a deeper understanding of the multidimensional aspects of perception, human performance, and creativity in architectural design processes. The application of experiential neuroscience in architecture enables architects to design spaces that are not only aesthetically appealing but also provide rich and meaningful experiences for occupants and visitors. Such an approach can play a vital role in creating spaces that are effectively aligned with users' needs and emotions. On the other hand, neuromorphic design offers designers the opportunity to draw inspiration from patterns, complex structures, and principles found in nature and to integrate them with innovation in the design process. This method not only contributes to the creation of functional and beautiful spaces but also establishes a bridge between science, art, and nature, ultimately enriching architectural works.

Research Literature

Environment, Space, and Mind

Spatial design has increasingly moved toward an approach focused on creating environments that not only meet users' functional needs but also take into account their emotions and experiences (Mahdi Nejad et al., 2019; Sadeghi habibabad et al., 2021). This approach has led to the creation of spaces with multisensory characteristics (Zomorshidi & Sadeghi, habibabad., 2018). With advances in information

technology and the emergence of embedded digital media within environments, the nature of users' interactions with spaces has expanded, adding new dimensions to user experience (Shaer, 2010; Essa, 2000; Cho, 2017). Attention to users' emotions and experiences in spatial design has become increasingly important; however, there remains a need for research methods and approaches to move toward cognitive sciences in order to measure emotions within architectural spaces. In the field of architecture, understanding and awareness of the complexities associated with cognitive and emotional processes that play a role in humans' daily experiences of spaces and designed environments have expanded significantly. Valuable achievements and notable collaborations have emerged between these two scientific domains, contributing to the enrichment of knowledge in both architecture and cognitive sciences (Eberhard, 2009; Robinson, 2015).

Neuro-Architecture

Neuro-architecture, as a multidimensional approach arising from the integration of neuroscience, psychology, and architecture, focuses on examining the effects of spatial design on human emotions, physical and mental health, and behavioral patterns. More specifically, this scientific field investigates brain responses to architectural elements such as spatial texture, lighting quality, and the influence of colors. From this perspective, the goal is not only to understand the relationships between these factors and human responses, but also to improve individuals' quality of life in architectural and urban environments through the application of informed design methods. This innovative approach helps architects create spaces that are not merely functional, but also capable of fostering positive emotions, enhancing psychological well-being, and transforming the human environment into a more calming and pleasant setting (Elborgy, 2023).

Neuro-architecture represents a contemporary approach to the design of built environments that, by drawing on principles of neuroscience, seeks to enhance user experience and the overall quality of these spaces (Assem, 2023). This method can be particularly emphasized in the design of healthcare and therapeutic facilities, aiming to exert a positive influence on individuals' psychological states, perception, and sense of satisfaction through the intentional use of design elements. Ultimately, the primary objective of this approach is to improve users' mental health and accelerate their recovery processes. By utilizing findings from neuroscience, architects are able to design spaces that more effectively address individuals' cognitive, emotional, and physical needs. For example, the use of lighting that creates a balance between functionality and tranquility, the application of colors that evoke a sense of calm, the design of spaces with stronger naturalistic qualities and interaction with natural elements, as well as consideration of the specific psychological and physical needs of different individuals, are among the key measures in this field. Such spaces can both enhance the quality of human experience and promote public health.

More broadly, integrating neuroscientific principles into the architectural design process can lead to the creation of environments that not only possess visual appeal and functional efficiency but also exert a profound influence on mental health and overall public well-being. This innovative approach provides architects with a unique opportunity to design spaces that are not only aesthetically pleasing but also intelligent and aligned with human needs. In this way, neuro-architecture, in addition to developing effective and user-centered environments, plays an efficient role in improving individuals' quality of life. Attention to external aspects and sensory-motor responses has been examined as key elements of

human interaction with the environment. In this context, the importance of neural dynamics has been highlighted, as they represent an effective tool for understanding sensory and motor changes in response to environmental features. This perspective emphasizes the role of the brain's active predictions and their influence on sensory information processing. Studies indicate that the interaction between sensation and action constitutes a fundamental cycle for understanding human behavior and its susceptibility to environmental influences. These discussions can pave the way for advances in neuroscience and architecture and lead to the design of environments that have a direct impact on human behavior and quality of life (Djebbara, 2022).

Approaches and Strategies in Cognitive Science Research and Built Environments

Indoor lighting environments play a key role in enhancing comfort levels and energy efficiency in building spaces from multiple perspectives. Light, as a fundamental element in delivering visual information, exerts profound effects on the physical and psychological health of individuals present in an environment. Improper design and use of indoor lighting can lead to undesirable consequences such as eye fatigue, reduced concentration and visual accuracy, and an increased likelihood of errors in daily activities. On the other hand, EEG technology, as one of the most advanced scientific tools, with its non-invasive nature and high temporal resolution in recording brain activity, provides significant opportunities for researchers. This technology can serve as an effective instrument for examining the effects of various lighting conditions on aspects such as individuals' cognitive performance, their level of comfort within the environment, and overall productivity. Accordingly, integrating the achievements of modern technology with indoor lighting design can offer innovative solutions for

improving the quality of living environments (Zhang et al., 2024).

In the study by Mostafavi et al. (2023), the results indicate that classification accuracy for predicting emotional responses was reported at 74%, while accuracy for predicting preferred lighting behaviors reached 79%. These findings demonstrate the considerable potential of using EEG data to predict emotional reactions and lighting-related choices within environments. Analysis of such data can not only provide deeper insight into the relationship between brain activity and human behavior but also contribute to the development of novel methods for examining mind–environment interactions. Moreover, these results emphasize that the proper use of advanced tools can help identify and predict complex human responses with greater precision (ibid).

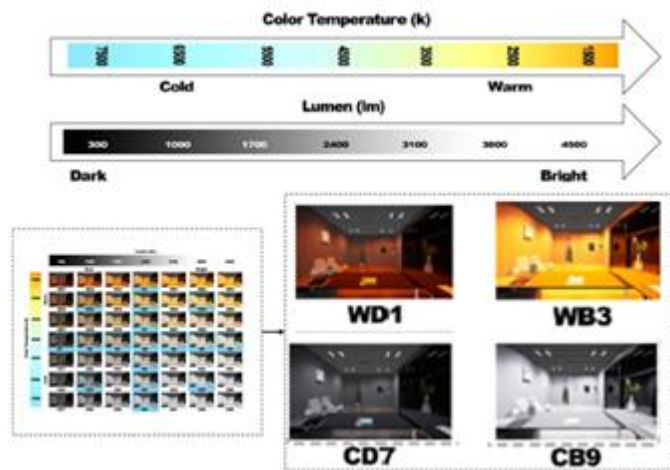


Figure 1. Experimental conditions and the spectrum of light and various colors used to conduct the EEG-based experiment. Source: (Mostafavi et al., 2023).

The aim of the study by Li and Du (2024) is to examine the potential capacity of nature and roof gardens as restorative elements in high-rise buildings. This research seeks to contribute to improving the quality of urban and architectural spaces by identifying the effects of such gardens on individuals’ physiological and psychological restoration. Among

the key research questions is the investigation of significant differences among various types of sky gardens and the evaluation of their effects on restorative indicators. In the methodology section, different types of sky gardens were identified and classified using five indicators across three functional dimensions, including plaza–park, rest–stay, and movement–passage. Following this classification, representative samples from each category were selected for more detailed experimental analysis. The data collection process involved the participation of 36 volunteers, each of whom was examined across 12 different visual scenarios. Throughout this process, the data encompassed both physiological responses and individuals’ subjective and psychological evaluations. To measure physiological responses, advanced tools such as skin conductance response (SCR), heart rate variability (HRV), electroencephalography (EEG) for analyzing electrical brain activity, and eye-tracking were employed. These precise methods provided comprehensive information regarding how gardens influence participants’ physical and psychological restorative indicators. The results of this study not only clarify the role of gardens in improving users’ health but also help to define the position of these elements in the design of architectural and urban environments (ibid).

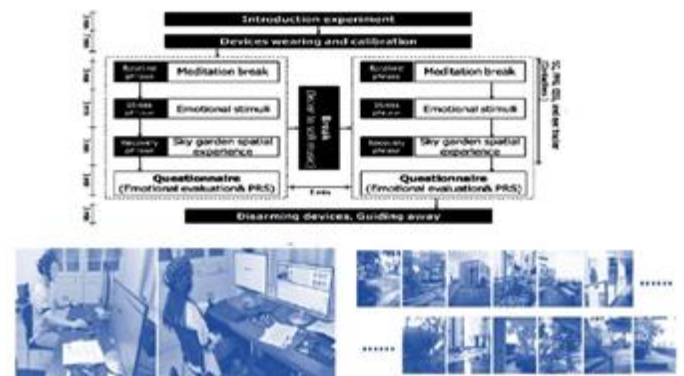


Figure 2. Experimental procedures and assessment of the effects of nature and gardens in high-rise buildings using SCR, HRV, and EEG methods. Source: (Li & Du, 2024).

In the field of future-oriented research related to neuroscience and architecture, the application of advanced research methods can open new pathways for developing and enhancing our understanding of the complex dynamics of the brain in interaction with the environment. One notable advancement in this area is the use of Mobile Brain/Body Imaging (MoBI) techniques, which allow for the recording of brain activity under real-world conditions and while in motion (Djebbara et al., 2022). This method not only facilitates the observation of brain changes in response to environmental stimuli but also provides a deeper understanding of the precise links between specific environmental features and sensorimotor responses. Given the importance of this topic, there is a pressing need for broader research in this domain to achieve a more profound understanding of how physical environments affect the brain and human behavior. Urban and natural space design must be carried out with greater precision, so that it not only positively influences human behavior but also enhances individuals' quality of life. The findings from such research can pave the way for creating environments that maintain health standards while

providing motivating and effective spaces for daily living. These advancements can not only contribute to improving mental and physical health but also facilitate the construction of higher-quality and more livable cities and regions (ibid).

The study by Jung et al. (2023) emphasizes the critical role of biophilic design in improving various aspects of human health, particularly in therapeutic environments such as hospitals, using EEG methods. The results of this research can assist architects and designers in applying biophilic design principles to create projects that are not only aesthetically outstanding but also positively impact users' mental health. Furthermore, the effective use of multimodal technologies, such as EEG devices for recording brain activity or virtual reality simulations, offers a unique opportunity to gain a more precise understanding of the relationships between designed environments and human mental health. These technologies can guide designers in selecting innovative and optimal strategies for biophilic space design, significantly enhancing the creation of environments with substantial psychological value (ibid).

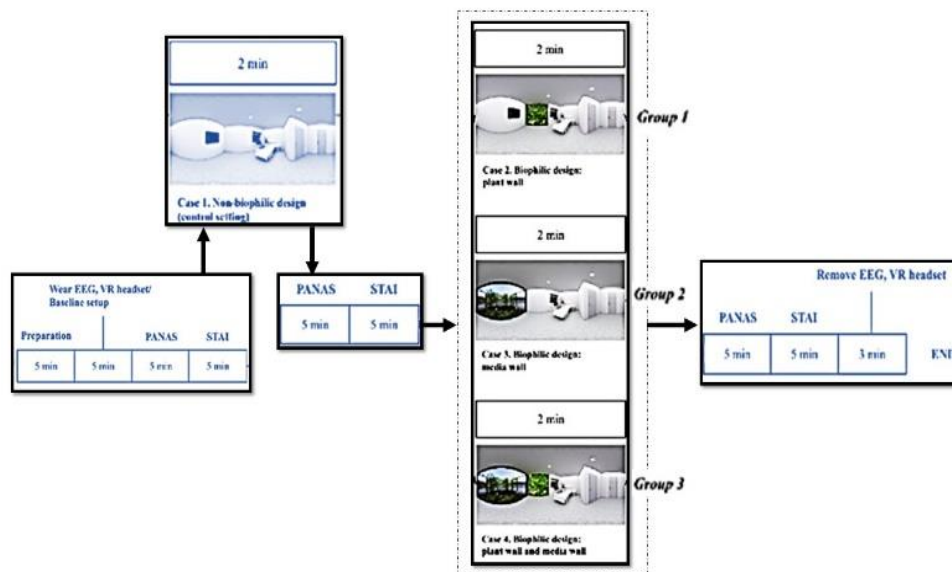


Figure3. Experimental procedure and assessment of users' mental responses to nature and hospital architecture using EEG. Source: (Jung et al., 2023).

In the study by Zhang et al. (2025), exposure to traffic noise is identified as a major public health concern. This issue is significant due to its association with cardiovascular diseases, effects on the central and autonomic nervous systems, and negative impacts on individuals' mood. The article also examines the adverse consequences of such noise using the Profile of Mood States (POMS), electrocardiography (ECG), and electroencephalography (EEG). The research aims to investigate the effects of varying traffic noise levels on psychological and physiological responses and to evaluate the relationship between these two types of responses. In this study, 38 architecture students with an average age of 22.08 years and normal hearing were selected to participate in the experiments. The auditory stimuli included traffic noise at five intensity levels (40, 45, 50, 55, and 60 decibels) and a control group with no sound. The results indicate that traffic noise significantly increased negative emotions among the participants (ibid).

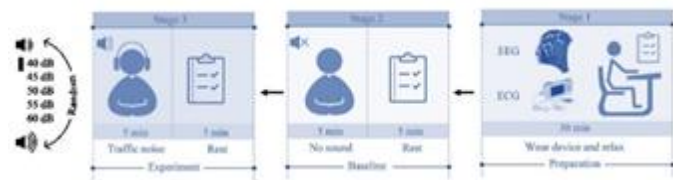


Figure 4. Research procedure and assessment of the effects of urban traffic noise using EEG. Source: (Zhang et al., 2025).

Emotion plays a critical role in shaping human mental experience, and architecture has a significant impact on individuals' emotions, perception, preferences, behavior, and brain responses. The study by Khaleghimoghaddam et al. (2022) examined the relationship between brain regions associated with emotion and emotional-behavioral experiences in different physical environments. Functional magnetic resonance imaging (fMRI) was employed to measure brain activity and analyze patterns related to environmental experience and emotions elicited by

architectural spaces. Neuroscientific findings indicated significant differences between the ratings of pleasant and unpleasant locations. Pleasant places, compared to unpleasant ones, were able to activate brain regions and areas associated with emotions more strongly. Additionally, it was found that the amygdala, a key brain structure, is linked to negative emotions evoked in unpleasant environments. Furthermore, increased blood flow in specific brain regions was observed during environmental experiences, correlating with both positive and negative emotional changes. In this study, 250 architecture students evaluated 60 images of different environments. Among them, 32 right-handed participants (19 males and 13 females) participated in the brain imaging procedure. For the fMRI experiment, 30 images (15 pleasant and 15 unpleasant) were selected. The study employed a block design paradigm for the fMRI testing (ibid).



Figure 5. Images of pleasant and unpleasant locations used in the fMRI experiment. Source: (Khaleghimoghaddam et al., 2022).

The study by Payedar-Ardakani (2024) investigates the effects of different daylight illumination levels on architectural experiences in a virtual office environment, employing a combination of subjective assessments and electroencephalography (EEG) data. The primary aim of the study is to gain a deeper understanding of how lighting influences emotional and neurophysiological responses. In this research, participants were exposed to nine different lighting levels, ranging from 66 to 1500 lux. Subjective

evaluations were collected through questionnaires, while EEG data were used to record and analyze neural and physiological changes (ibid).

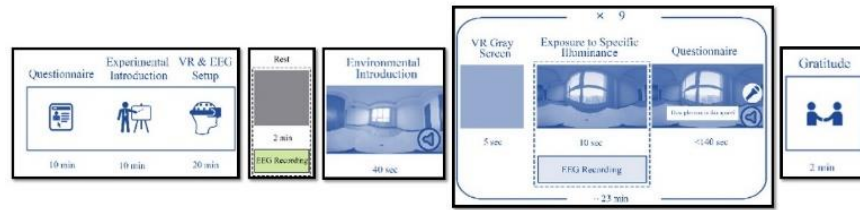


Figure6. Experimental procedure for assessing lighting quality in office environments. Source: (Payedar-Ardakani et al., 2024).

The study by Wang et al. (2022) examines “intermediate” spaces to optimize their design in elderly care facility architecture. In most senior centers in China, interior public spaces typically follow repetitive spatial patterns, which reduces overall spatial functionality and limits the ability to meet the diverse needs of users. This study proposes an innovative approach to optimizing the design of architectural spaces for the elderly. To this end, subjective assessment data (STAI) and physiological data, including HRV and EEG, were collected from 40 participants while they observed videos, and the architectural spaces under study were subsequently improved based on these findings (ibid).

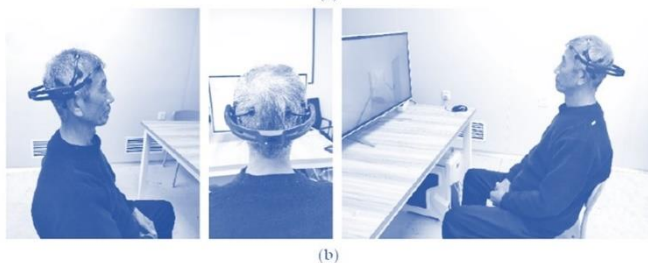
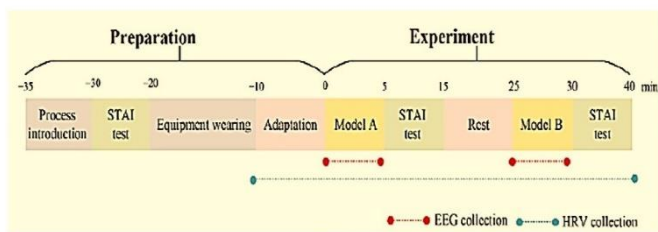


Figure7. Experimental procedures and conditions for examining intermediate spaces in elderly care facility architecture using STAI, HRV, and EEG methods. Source: (Wang et al., 2022).

In the study by Kim et al. (2024), an innovative technique was introduced that enables designers to develop low-energy buildings from the early stages of design while focusing on occupants’ needs. This method simultaneously examines individuals’ physiological responses and the building’s energy performance. Using variables such as aspect ratio, ceiling height, and window-to-wall ratio, 30 design options were created for a single-occupancy room in a healthcare facility. These designs were presented to 33 participants through virtual reality simulations to allow experiential evaluation. EEG data were collected and, combined with energy analysis, a design option was selected that positively influenced physiological responses while maintaining low energy consumption. The findings of this study indicate that integrating human physiological components with architectural principles can represent a significant step forward in enhancing building design (ibid).

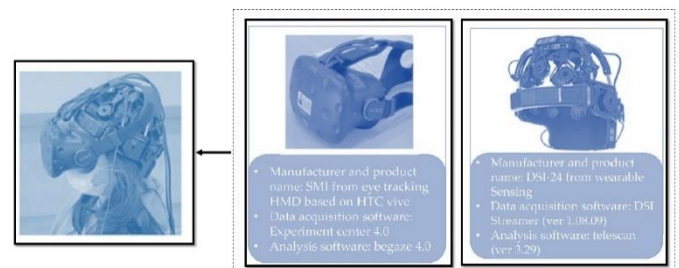


Figure8. Experimental tools using VR and EEG methods. Source: (Kim et al., 2024).

The study by Zhang et al. (2024) demonstrates that exposure to natural environments promotes relaxation, reduces stress, and enhances cognitive abilities. Consequently, the use of natural views in educational settings has gained popularity. This research examined the effects of natural views from university classroom windows on students' physiological, emotional, and attentional responses. Thirty undergraduate students (mean age 21 years)

observed natural scenery and classroom window architecture for three minutes, during which their physiological (EEG) and psychological responses were assessed. The results indicated that natural views stimulated brain activity, increased feelings of relaxation and focus, and improved learning efficiency. These findings highlight the importance of designing classrooms with access to natural views (ibid).

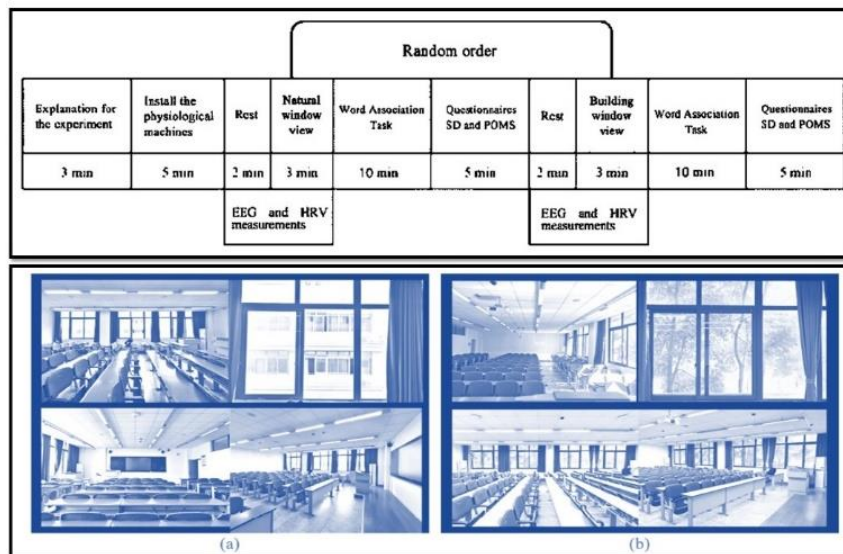


Figure9. Experimental procedure for assessing the impact of nature in educational environments using EEG. Source: (Zhang et al., 2024).

The study by Zhao et al. (2023) explores the integration of human physiological data and deep learning technology within virtual reality visualization for architectural design. The primary aim of this research is to achieve a deeper understanding of human interaction with virtual architectural environments, ultimately enhancing design decision-making and human-centered

architectural processes. The results indicate a significant relationship between users' experience of the environment and their brain activity. Findings suggest that integrating EEG technology with deep learning can serve as a complementary tool to improve human perception in expansive virtual reality architectural environments (ibid).

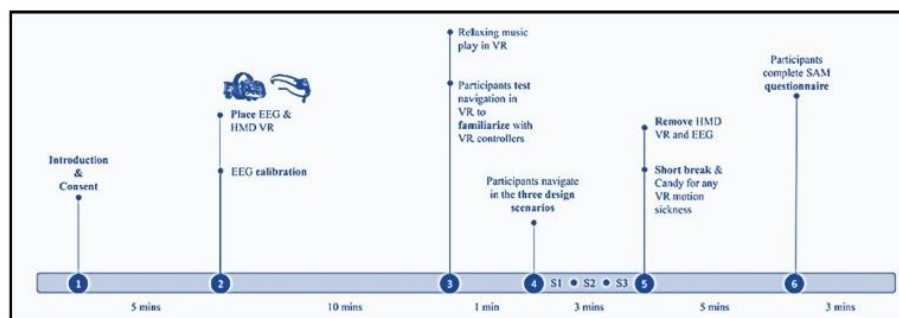


Figure10. Experimental procedure for examining human interaction with architectural environments using EEG. Source: (Zhao et al., 2023).

In neuroarchitecture, neuroscientific tools are employed to better understand the impact of architectural design on human cognition and experience. The shape of the built environment plays a significant role in architectural design. The study by Banaei et al. (2017) examined the relationship between interior shapes, emotional states, and individuals' brain activity. The results indicated that curved geometries have a significant effect on activity in the anterior cingulate cortex (ACC). This research utilized mobile EEG and VR in architectural contexts, enabling the investigation of dynamic brain responses during active experiences of architectural environments (ibid).

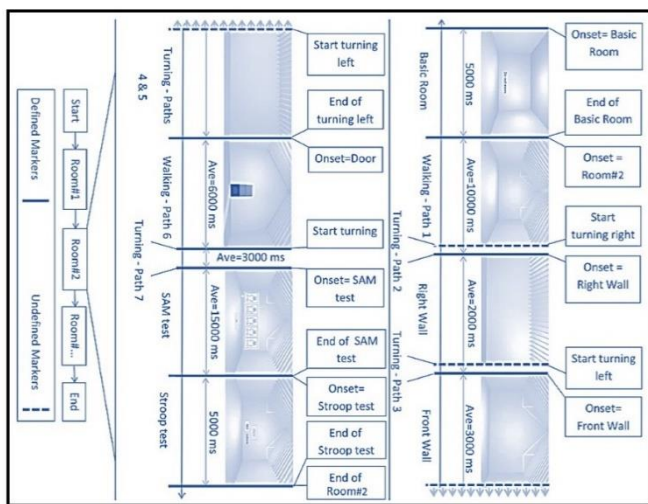


Figure 11. Experimental procedure for examining the effects of form in architecture using EEG. Source: (Banaei et al., 2017).

The study by Li et al. (2022) examined the effects of restorative virtual environments on creativity using VR technology and EEG. Seventy-two students participated in this research, and the findings provide evidence of the positive impact of VR on creativity while contributing to the understanding of interactions between the environment and individuals (ibid).

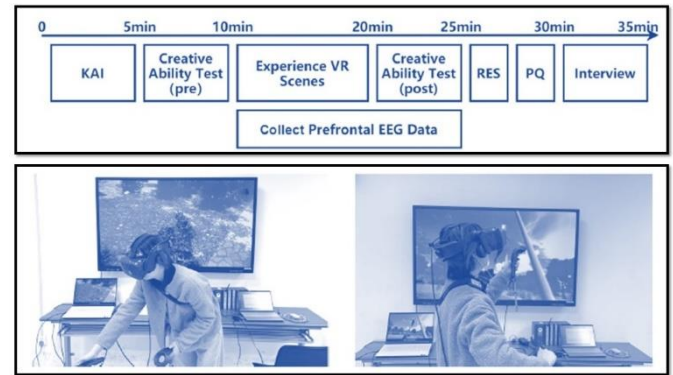


Figure 12. Experimental procedure for assessing the impact of virtual environments on student creativity using VR and EEG. Source: (Li et al., 2022).

Environmental psychologists have confirmed that interaction with natural environments has more positive psychological effects on emotions, cognition, and attention compared to urban settings. With increasing urbanization, understanding the impact of different urban environments on human psychological experience becomes crucial. The study by Mavros et al. (2022) investigated the effects of physical (indoor or outdoor) and social environments on young adults while walking, using EEG. The results indicated that green spaces were more relaxing and positive, reducing attentional demands. Additionally, the findings revealed a complex interaction between active movement, social characteristics of environments, and emotional responses (ibid).

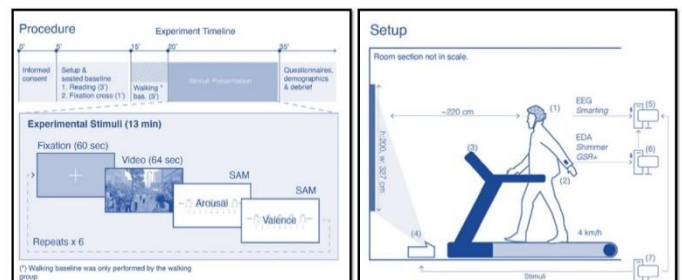


Figure 13. Experimental procedure for examining the psychological effects of urban environments and green spaces using EEG. Source: (Mavros et al., 2022).

The study by Zhang et al. (2024) investigated the effects of physical characteristics of classrooms on university students' physical and mental well-being, as well as their learning performance, using virtual reality technology and EEG. The research indicates that classroom size and ceiling height play a significant role in enhancing learning performance and provides recommendations for the optimal design of classrooms (ibid).

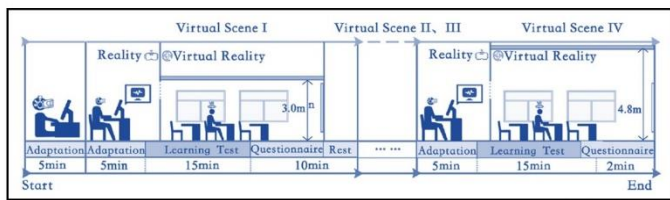


Figure 14. Experimental procedure for examining the effects of classroom physical characteristics on students' physical and mental health using virtual reality and EEG. Source: (Mavros et al., 2022).

Comparative and Trend-Based Synthesis of Neuroscience-Informed Architectural Studies

Across the reviewed literature, a clear methodological and conceptual evolution can be identified beyond the sequential presentation of individual studies. When the studies are examined comparatively within thematic clusters, several shared patterns, divergences, and emerging trends become evident.

First, studies focusing on neural activation and affective responses to architectural elements (e.g., lighting conditions, spatial geometry, and materiality) consistently demonstrate that objective neurophysiological measures such as EEG and fMRI reveal responses that are not fully captured by self-reported evaluations. While earlier studies primarily relied on questionnaires to assess comfort or preference, more recent research shows a systematic shift toward brain-based indicators (e.g., alpha and beta wave modulation, activation of the anterior cingulate cortex), enabling a more precise differentiation between conscious appraisal and subconscious emotional processing of space.

Second, within the cluster of studies addressing environmental stressors and restorative design (e.g., noise exposure, biophilic elements, and natural light), a convergent trend emerges across different measurement techniques. Despite methodological differences, these studies collectively indicate that natural and restorative architectural features are associated with reduced physiological stress markers, such as decreased skin conductance response and increased heart rate variability. This convergence suggests a growing consensus in the field that certain spatial qualities produce measurable and replicable neurophysiological benefits, strengthening the validity of neuroscience-based design principles.

Third, a comparative analysis of studies employing simulation-based and immersive technologies, particularly Virtual Reality (VR), reveals a notable methodological advancement. Earlier laboratory studies often suffered from ecological validity limitations due to static or simplified stimuli. In contrast, recent VR-based experiments enable dynamic, multisensory, and controllable environments while maintaining experimental rigor. When VR is combined with EEG or eye-tracking, the studies demonstrate enhanced predictive capacity regarding users' real-world spatial behavior and cognitive performance. This trend reflects a shift from post-occupancy evaluation toward pre-design evidence generation, positioning simulation as a strategic tool in early architectural decision-making. Finally, across all clusters, a critical gap becomes apparent: although neuroscientific tools are increasingly adopted, their theoretical integration with architectural and environmental psychology frameworks remains uneven. Many studies prioritize technological sophistication over conceptual alignment, resulting in fragmented interpretations of neural data. This observation highlights an emerging need for integrative methodological frameworks that

explicitly connect neurophysiological indicators to architectural theory, spatial cognition, and design intent. Overall, the comparative synthesis of these studies indicates a transition in neuro-architecture research from exploratory, tool-driven experimentation toward methodologically structured, theory-informed, and application-oriented approaches. This trend underscores the importance of combining laboratory precision, immersive simulation, and conceptual coherence to advance neuroscience-based architectural research beyond isolated case studies.

Results

All results discussed here are drawn from secondary analysis of prior research. The findings are not empirical data collected by the authors but synthesized methodological patterns across the reviewed studies. The summary tables and thematic structuring therefore represent interpretive outcomes of the narrative synthesis.

The findings from this narrative review indicate that over the past two decades, the “neuro-architecture”

approach has gradually established itself as an emerging paradigm in architectural and urban studies. Analysis of the selected studies shows a shift in research focus from purely qualitative descriptions and subjective user impressions toward the utilization of objective, laboratory-based, and physiological data grounded in neuroscience. This paradigmatic shift directly responds to the limitations of traditional methods in assessing spatial experience, perception, emotion, and human behavior in built environments.

Prevalence of Laboratory Approaches and Neuroscientific Tools

The review of articles reveals that tools such as EEG, fMRI, HRV, SCR, and eye-tracking have been used as primary methods for measuring human responses to architectural spaces. These tools allow simultaneous recording of cognitive, emotional, and physiological reactions, enhancing the accuracy and reliability of research findings. Unlike self-reported questionnaire methods, neuroscientific data are extracted at a subconscious level, providing a more authentic representation of spatial experience.

Table1. Comparison of Neuroscientific Tools Used in Architectural and Urban Studies

Neuroscientific Tool	Data Type	Application in Architecture	Key Advantage
EEG	Brain activity	Light, form, space, nature, sound	High temporal resolution, non-invasive
fMRI	Brain blood flow	Emotional experience of space	High spatial resolution
HRV	Heart rate	Stress, relaxation	Measures physiological arousal
SCR	Skin conductance	Emotion and arousal	Sensitive to emotional changes
Eye Tracking	Eye movements	Focus, visual attention	Analysis of perceptual behavior

Note. This comparison demonstrates relative usage trends among neuroscientific tools in architectural and urban studies. EEG appears most prevalent due to its flexibility in both controlled and naturalistic settings, whereas fMRI, despite precision, is limited in spatial research feasibility.

Table 1 shows that EEG is the most widely used tool in neuro-architecture studies due to its applicability in both simulated and real environments. In contrast, fMRI, despite its high spatial accuracy, is less frequently used in architectural research due to practical limitations. These findings indicate researchers’ preference for methods that balance

scientific precision with feasibility in architectural contexts.

Role of Architectural Elements in Neural and Psychological Responses

Findings from the review indicate that architectural elements such as light, nature, form, spatial scale, sound, and color have a direct and significant impact on users’ brain activity and psychological states.

Specifically, spaces with natural light, green views, and biophilic design were associated with increased

alpha waves and reduced stress indicators, reflecting higher relaxation and concentration levels.

Table2. Associations Between Architectural Components and Users' Neural Responses

Architectural Component	Dominant Neural Response	Related Psychological Outcome
Natural light	Increased alpha waves	Relaxation and focus
Nature and green space	Decreased HRV and SCR	Lower physiological stress
Curvilinear forms	ACC activation	Positive spatial perception
Traffic noise	Increased beta waves	Heightened tension and negative affect
High ceilings	Enhanced attention-related activity	Improved cognitive performance

Note. Relationships reported here indicate observed correlations, not direct causation. Neural and emotional responses tend to vary with spatial features such as light, form, and natural elements.

This table demonstrates a meaningful relationship between physical characteristics of spaces and human neural responses. The findings confirm that conscious design of architectural elements can directly influence mental health, spatial experience, and even cognitive performance. Such evidence underscores the importance of neuroscience-informed design in creating environments that support well-being and optimal human experience.

Role of Virtual Reality and Simulation in Neuro-Architecture

A key finding from this review is the increasing use of Virtual Reality (VR) in conjunction with neurophysiological tools. The integration of VR and EEG enables testing of design scenarios in the early stages, reducing costs and execution errors. This approach has found extensive application in the design of therapeutic, educational, and urban spaces.

Table3. Methodological Approaches Employed in Neuro Architecture Research

Research Approach	Approximate Validity Level	Typical Application
Questionnaire-based	Medium	Subjective evaluation
Laboratory experiments	High	Measurement of physiological responses
VR simulation	High	Behavioral prediction
Combined (EEG + VR)	Very high	Evidence-based design during early stages

Note. Multi-modal approaches integrating physiological and immersive data provide the most comprehensive basis for understanding the human–environment relationship.

The findings indicate that combined methods achieve the highest scientific validity. Simultaneous use of physiological data and simulated experience allows for a more precise analysis of the human–space relationship and guides future architectural research toward interdisciplinary approaches.

Overall, this narrative review demonstrates that neuro-architecture is evolving from a nascent theoretical approach into a practical and methodical framework. Leveraging cognitive neuroscience allows a shift from intuitive design to evidence-based design, offering a decisive role in enhancing the

quality of built environments, user mental health, and social sustainability.

Conclusion

This methodological narrative review demonstrates that the emerging field of neuro-architecture draws its scientific strength from the systematic incorporation of neuroscience-based laboratory and simulation methods into architectural research. By synthesizing diverse studies across EEG, fMRI, eye-tracking, and VR frameworks, the paper reveals how the measurement of neural and physiological responses can deepen the understanding of spatial cognition,

emotional appraisal, and behavioral interaction within built environments.

The review confirms that laboratory and simulation protocols offer controlled and physiologically grounded perspectives on the human–environment relationship. These approaches complement—but do not replace—interpretive and phenomenological paradigms in architectural psychology. The integration of both bodies of knowledge enables researchers to simultaneously capture the empirical and experiential dimensions of design.

A critical insight arising from this synthesis is that methodological coherence remains underdeveloped in the current literature. Many studies adopt advanced technologies without fully articulating how these methods connect to architectural theory or psychological constructs. Therefore, neuro-architecture should evolve toward an interdisciplinary framework where neuroscientific data are theoretically anchored in environmental cognition models and design intention.

Overall, this review advocates a balanced, evidence-based research culture in which architecture becomes not only an artistic and cultural expression but also a measurable domain of human experience. Strengthening methodological rigor through combined laboratory, simulation, and interpretive analyses will empower future architects and researchers to design environments that are scientifically informed, emotionally attuned, and cognitively responsive to human needs.

Recommendations

Future investigations should directly address the methodological gap identified in this review by:

(1) employing combined EEG-VR laboratory setups to examine neural responses to spatial stimuli under controlled conditions;

(2) developing simulation-based protocols for testing emotional and cognitive reactions to architectural forms; and

(3) integrating physiological data with self-report measures to bridge laboratory precision and lived experience.

These directions explicitly align with the identified limitations of previous reviews and aim to consolidate neuro-architecture as a reproducible and evidence-driven research domain.

Ethical Considerations

Compliance with ethical guidelines: Not applicable.

Funding: no funding-not applicable.

Authors' contribution: A.SH: (Writing, original draft, Visualization, Validation, Supervision, Methodology.), P. M & S.JG: (Writing – review & editing, Investigation, Formal analysis)

Conflict of interest: the authors declare no conflict of interest for this study.

Acknowledgments: Not applicable.

AI disclosure: During the preparation of this work the authors used Chat GPT-40 in order to improve readability and language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article

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