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Neuroarchitecture: A Guiding Principle for Sustainable and Inclusive Projects

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Abstract: The COVID-19 pandemic in 2020 sparked a new awareness of fundamental human needs, bringing mental health to the forefront as a global priority. Social isolation and the abrupt shift in daily routines revealed how environments directly impact physical and emotional well-being. In this context, Neuroarchitecture emerged as an innovative solution, applying neuroscience principles to spatial design in order to enhance quality of life. This field studies how elements such as color, lighting, acoustics, layout, and natural features affect the brain and emotions. These parameters guide the creation of spaces that reduce stress, increase productivity, and foster a sense of comfort. Within the scope of biophilic design, strategies such as the use of natural light and the arrangement of areas that encourage social interaction have proven effective. With the rise of remote work and the growing value placed on functional homes, Neuroarchitecture has gained significance, demonstrating that well-designed environments can improve mental health. Businesses, schools, and hospitals have also begun adopting these concepts, creating more welcoming and efficient spaces. Therefore, the pandemic accelerated a transformation in how spaces are inhabited and designed, underscoring that architecture and psychology must go hand in hand. Neuroarchitecture is not just a trend, but a necessity in a world seeking balance between functionality and well-being.

Key words: Neuroarchitecture, urban well-being, cognitive environment, biophilic design and sustainable urban planning.

1. Introduction

The COVID-19 pandemic, declared by the WHO (World Health Organization) in March 2020 [1], marked a turning point in the understanding of fundamental human needs. Longitudinal studies showed that rates of anxiety and depression increased by approximately 25% to 30% globally during this period [2], prompting the WHO to warn of a “second pandemic”—a global mental health crisis resulting from social isolation and economic instability [1].

In this context, research in the field of Environmental Psychology has revealed the influence of built environment quality as a key determinant of psychological well-being [3]. Forced confinement transformed homes into multifunctional spaces—simultaneously serving as offices, schools, and social centers—exposing the limitations of conventional architectural design [4]. This collective experience underscored the urgent need to rethink architectural design based on scientific evidence of its impact on mental health.

Neuroarchitecture, an interdisciplinary field integrating neuroscience, environmental psychology, and architecture [5], offers solutions grounded in empirical research. Studies supported by fMRI (functional magnetic resonance imaging) have demonstrated that environments with adequate natural lighting activate the medial prefrontal cortex—an area associated with emotional well-being—while poorly lit spaces stimulate the amygdala, the brain region linked to stress [6]. Furthermore, research on biophilic design has shown that the presence of natural elements in built

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environments reduces cortisol levels by 15% and improves cognitive function by 8%-10% [7].

In clinical practice, the application of these principles yields measurable results. The incorporation of therapeutic gardens in hospitals, as shown in studies by Ulrich et al. [8], reduced postoperative recovery times by 22%. In corporate settings, offices that implemented neuroarchitectural principles reported a 20% increase in productivity and a 15% rise in job satisfaction [9]. In residential contexts, research indicates that functionally zoned layouts based on cognitive flow can reduce family conflicts during remote work by 30% [4].

Nonetheless, challenges remain in large-scale implementation. A study by Augustin [10] found that only 28% of architects are trained in neuroscience-based design principles. Moreover, economic analyses show that although the initial cost is 10%-15% higher, the return on investment in neuroarchitectural projects is realized within 3-5 years through reduced healthcare expenses and increased productivity [3].

As society progresses into the post-pandemic era, Neuroarchitecture is becoming an essential paradigm. A recent meta-analysis by Sussman and Hollander [11], encompassing 127 studies, confirmed that environments designed based on neuroscientific evidence reduce anxiety symptoms by 40% and improve quality-of-life indicators by 35%. These findings support the transformation of the built environment into an active tool for promoting collective mental health—a lasting legacy born out of the health crisis.

Therefore, Neuroarchitecture represents one of the most promising frontiers of contemporary knowledge, bridging neuroscience, environmental psychology, and architectural practice. Its foundational milestone was the establishment of the ANFA (Academy of Neuroscience for Architecture) in California in 2003. However, it was only in the past decade—and particularly in the post-pandemic period—that this discipline gained scientific and practical relevance [12].

Advancements in functional neuroimaging techniques have unveiled how the brain reacts to and processes constructed spaces. Studies using fMRI have shown that environments with organic forms and natural textures activate the brain's default mode network—associated with relaxation and creativity—whereas spaces with sharp angles and chaotic patterns overstimulate the amygdala, triggering stress responses [13]. These groundbreaking discoveries are radically reshaping architectural design paradigms.

In practical terms, the application of Neuroarchitecture principles has yielded measurable outcomes across various contexts. In healthcare facilities, as demonstrated by Ulrich et al. [8], incorporating natural elements and circadian lighting reduced analgesic use by 23% and accelerated patient recovery by 18%. In education, studies by Heschong [14] revealed that schools designed with these principles experienced 15%-20% improvements in academic performance and a 30% reduction in student conflict.

Biophilic design—a core pillar of Neuroarchitecture—has proven especially effective. A recent meta-analysis by Browning and Ryan [15] confirmed that integrating vegetation, water features, and natural materials into built spaces enhances cognitive function by 12% and significantly reduces cortisol levels. These effects are particularly relevant in today's urban context, where people spend approximately 90% of their time indoors [9].

However, as Coburn et al. [16] point out, the full implementation of this approach still faces major hurdles. Only 12% of architecture schools worldwide systematically incorporate neuroscience principles into their curricula [17].

In this context, the present study was developed with the objective of conducting a systematic and critical literature review that integrates cognitive neuroscience principles into the architectural design process. Adopting an interdisciplinary approach, the research aimed to map the theoretical and practical interfaces among these fields, systematizing scientific evidence that demonstrates how neurophysiological mechanisms (sensory processing and spatial attention), psychobehavioral factors (well-being and environmental cognition), and socio-perceptual elements (human-built environment interaction) can redefine user-centered architectural spaces.

2. Methodology

This study was developed using a mixed-methods approach, combining qualitative and quantitative techniques in two complementary phases:

(1) Systematic bibliographic mapping (2019-2024): A structured search was conducted in the Scopus, Web of Science, and SciELO databases to identify relevant scientific publications. The keywords used included "neuroarchitecture", "biophilic design", and "neuroscience for architecture", among other related terms. Inclusion criteria were based on thematic relevance, methodological rigor, and the impact of the journals.

(2) Critical synthesis of empirical evidence: In the second phase, a critical analysis of empirical studies examining the relationship between architectural elements and mental health and well-being indicators was conducted. Priority was given to the works of prominent authors such as Ulrich, Browning, and Sussman, whose research employs neuroimaging techniques, biomarkers, and behavioral metrics. Data triangulation allowed for the identification of consistent patterns in the neuropsychological impacts of built environments.

3. Results and Discussion

3.1 Strategies for Architectural Projects

Contemporary architecture transcends aesthetics and functionality, establishing itself as a discipline attuned to the emotional and cognitive aspects of its users. Within this context emerges Neuroarchitecture, an interdisciplinary approach that integrates principles from neuroscience, cognitive psychology, and architecture, with the aim of designing environments that take into account human neurological responses to the built space [18].

Architects who incorporate the principles of Neuroarchitecture seek, in a conscious and evidence-based manner, to influence human behavior—even at the unconscious levels of perception (Fig. 1). The brain continuously interprets spatial stimuli, triggering sensations and emotions that affect an individual's emotional state, behavioral patterns, and mental health [19]. Spatial perception is deeply intertwined with personal memories and experiences, with environments capable of evoking emotional responses through the activation of specific neural circuits [20].

Multisensory perception in architecture primarily involves the integration of visual, auditory, tactile, olfactory, and emotional stimuli. The simultaneous stimulation of multiple senses enhances spatial perception and amplifies the cognitive and affective impact of the environment on users [21].

Designing environments that foster productivity, well-being, and holistic health should be a core directive for architects, urban planners, and designers. Natural elements, such as green areas within urban settings, have demonstrated significant benefits, including stress reduction, improved air quality, noise pollution mitigation, encouragement of physical activity, and facilitation of social interaction [22, 23]. Additionally, the presence of vegetation and other natural elements in urban environments contributes to the reduction of chronic diseases and the enhancement of cognitive functions [24].

Biophilia, a central concept in Neuroarchitecture, promotes the reconnection between humans and nature through the integration of elements such as wood, natural stones, plants, and water within built environments. These elements have been shown to reduce stress, improve mood, boost productivity, and increase user satisfaction [20, 25].

Natural lighting also plays a crucial role in mental and physiological health. Exposure to sunlight regulates circadian rhythms, improves sleep quality, reduces the risk of depression, and supports hormonal and metabolic balance [26].

Additionally, aspects such as the choice of colors, shapes, and the arrangement of furniture and objects must be carefully considered. The use of nature-inspired colors can induce states of relaxation and comfort, positively influencing the sensory perception of space [27]. Conversely, spatial organization and the placement of objects can encourage movement flow and facilitate social interaction, fostering a more coherent and fluid spatial experience [28].

Therefore, the creation of healthy and responsive environments requires a deep understanding of the impacts that physical space exerts on the human brain. Neuroarchitecture provides a scientific foundation for designing environments that not only meet the users' functional needs but also support their psychological and physiological well-being. Professionals involved in the design of built environments must be aware of the potential positive and negative effects of each design decision, consistently prioritizing the creation of spaces that respond to the real needs and objectives of their users.

3.2 A Neuroarchitecture and the Development of Cities

Interdisciplinary studies involving neuroscience, cognitive psychology, and urban planning have demonstrated that the shape of buildings and the design of cities exert a significant influence on individuals' behavior, well-being, and mental health. Specialized cells located in the human hippocampus, known as place cells and grid cells, are activated in response to the geometry, layout, and orientation of spaces, establishing a direct relationship between the built environment and the neurological systems of navigation and spatial memory [29, 30].

Despite this scientific evidence, many urban projects still neglect the neurological effects of architecture on users. Studies indicate that architectural façades with visual complexity and rich detail evoke positive emotional responses, whereas monotonous or overly simplified façades are associated with sensations of discomfort or apathy [19, 31].

In addition to urban geometry (Fig. 2), access to green areas is a crucial factor in mitigating urban stress. The presence of vegetation, parks, and natural elements contributes to lower cortisol levels, improved air quality, temperature regulation, and the promotion of healthy social interactions [23, 32]. The absence of these elements, on the other hand, has been correlated with an increased prevalence of mental health disorders in densely populated urban centers, including generalized anxiety, depression, and mood disorders [33].

In light of this evidence, it is clear that urban planning cannot be limited to aesthetics or technical functionality. The COVID-19 pandemic, by exposing the vulnerabilities of contemporary urban lifestyles, reinforced the urgency of integrating mental health considerations into urban design. Neuroarchitecture emerges in this context as an innovative and necessary approach. This field proposes the development of spaces that respond to users' sensory, cognitive, and emotional needs, prioritizing stress reduction, enhanced productivity, and the promotion of well-being [34].

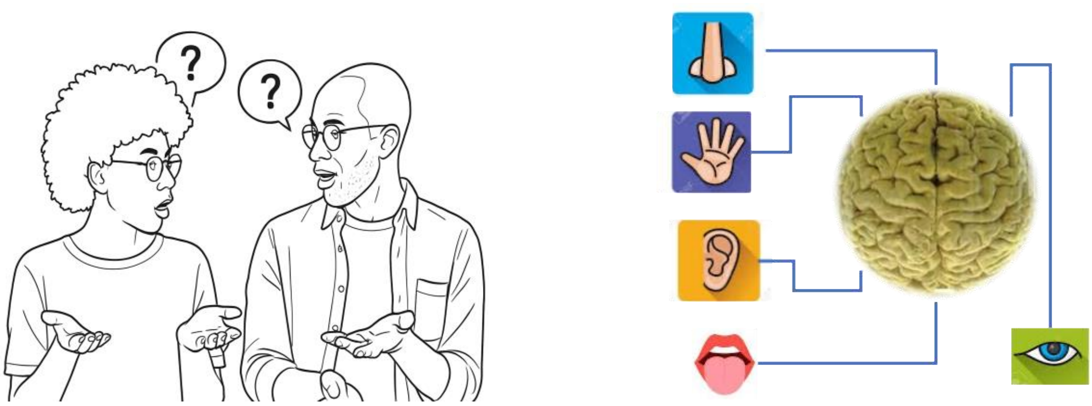

Fig. 1 Neuroarchitecture as a conscious way to influence human behavior (by the authors).

Fig. 2 Relationship between urban geometry and human consciousness (by the authors).

Therefore, with increasing urban density and a shortage of green spaces, applying the principles of neuroarchitecture becomes imperative to transform the urban environment into a more balanced and human-centered system. This transformation can be achieved through solutions such as smart neighborhoods, which, in addition to integrating technology for efficient resource management, emphasize social cohesion, sustainability, and connection to the natural environment. These neighborhoods can function as catalysts for urban innovation, fostering quality of life, safety, a sense of belonging, and collective identity [28, 35].

Finally, neuroarchitecture provides tools to create cities centered on human needs, where urban planning and management are aligned with the scientific principles that govern brain function. Thus, more than a trend, this science constitutes an essential guideline for the development of inclusive, resilient, and emotionally sustainable urban spaces.

3.3 Neuroarchitecture and Sustainability

The convergence between the principles of neuroarchitecture and the practices of sustainable architecture, especially bioclimatic architecture, points to a new paradigm in urban and housing planning. Bioclimatic buildings, which make use of local materials, natural ventilation, and renewable energy sources, go beyond reducing the ecological footprint: they create environments that favor the physical, emotional, and mental well-being of their occupants.

According to the World Health Organization [1], the presence of accessible green spaces in urban areas is directly associated with a reduction in mental health disorders, particularly depression and anxiety, and contributes to the prevention of cardiovascular diseases. The data reinforce the premise of neuroarchitecture that built environments profoundly influence the human nervous system, with the ability to either activate or reduce responses to stress, anxiety, and other neurological disorders [36].

In the context of bioclimatic architecture, environmental benefits are coupled with positive social impacts. The use of passive climate control strategies, such as solar orientation, shading, cross ventilation, and the use of vegetation, provides thermal comfort without relying on mechanical systems, thereby reducing both energy consumption and operational costs of buildings. According to Guedes [37], in tropical countries such as Angola, the inadequacy of ventilation systems and poor thermal quality in low-income housing have been linked to high rates of respiratory diseases and frequent episodes of thermal stress, especially in vulnerable populations.

In the context of housing development with a housing deficit, alongside the coexistence of sanitary and climatic challenges, the integrated application of neuroarchitecture and sustainability principles in social housing can be transformative. The construction of homes using local materials with low environmental impact, and construction techniques adapted to the climate, can not only reduce greenhouse gas emissions but also significantly improve public health, by mitigating the effects of heat islands, promoting thermal comfort, and reducing exposure to indoor pollutants.

Moreover, initiatives incorporating biophilic design—that is, the use of natural elements such as light, vegetation, water, and textures—have shown a direct impact on the improvement of cognitive function, productivity levels, and sleep quality, aspects that are particularly relevant in densely populated housing [20].

Therefore, the construction of more humanized, green, and energy-efficient urban and residential spaces requires a transdisciplinary approach, where the science of mind and behavior converges with engineering, architecture, and sustainable urbanism. In Angola, this approach can represent a strategic leverage for public housing policies that prioritize not only the quantity but also the quality of life for the growing urban populations.

4. Conclusions

Based on the descriptions presented, it can be concluded that:

(1) The design of spaces profoundly impacts the neurological and behavioral processes of individuals. Elements such as structure, shapes, colors, lighting, and the arrangement of objects directly influence mood, emotional state, productivity, and mental health of users. Neuroarchitecture emphasizes the importance of designing environments based on the understanding of brain functions to enhance quality of life.

(2) Research shows that the brain responds positively to varied and harmonious visual stimuli, while repetitive, simple facades devoid of interesting elements can trigger negative emotional responses such as boredom, anxiety, and disorientation. Therefore, urban design should prioritize aesthetic diversity as a tool for cognitive and emotional stimulation.

(3) The presence of natural environments, such as tree-lined squares and parks within urban spaces, plays a crucial role in reducing blood pressure, improving cognitive function, and strengthening mental health. Additionally, these spaces encourage physical activity, foster social interactions, and create pleasant and restorative environments for the community.

(4) Life in large urban centers, particularly when marked by social isolation, lack of natural spaces, and urban planning that does not prioritize human needs, is directly associated with the increase in diseases such as depression, anxiety, and schizophrenia. The absence of community ties and social support exacerbates this scenario.

(5) By considering the environmental and sensory impacts of spaces on the human brain, neuroarchitecture offers an approach that enables the creation of environments that promote calm, reduce stress, stimulate creativity, and enhance cognitive performance. This approach is based on scientific evidence and aims to transform urban and architectural design into an effective tool for human well-being.

(6) The integration of architecture, urbanism, technology, and social management enables the transformation of neighborhoods into living, resilient, and adaptable spaces that meet the needs of their inhabitants. These neighborhoods foster sustainability, social inclusion, rational resource use, and collective well-being.

(7) Urban development should be guided by scientific evidence that considers the physical, emotional, and cognitive needs of individuals. Cities that apply the principles of neuroarchitecture tend to be more humane, balanced, and welcoming, with the ability to promote quality of life and social cohesion.

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