# neuroarchitecture

## roots, ambitions, future

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The aesthetic qualities of a building have an impact on human experience. It is an obvious point; a truth answering a question that has never needed to be asked. For this reason, Roman architect and civil engineer Vitruvius argued two millennia ago that his predecessor, Pytheos, "made a mistake" by not considering "that art is made of two things: the actual work and the theory of it." Architectural form must be of "considerable importance not only to builders, but also to all." He declares the most essential component of an architect's training to be a "broad education" so that he leaves "a more lasting remembrance in his treatises", going as far as to implore practitioners to "also have a knowledge of the study of medicine"[1]. The sense that architectural aesthetics are of import to the human experience has certainly not died down, nor is it isolated to a single tradition, finding extensive attention in practices and writings as temporally and geographically diverse as the Chinese fengshui, the Indian Vaastu shastra, and 19th century German philosopher Herbart[2].

As academic considerations of the relationship between the human mind and aesthetics have evolved from pure philosophy to a more rigorous scrutiny, a small pocket of the scientific community has begun to openly pursue the mechanism of architectural appreciation. Discourse in the nascent field of neuroarchitecture has thus far provided a basic theoretical and analytical framework for studying the subjective experience of architecture with neuroscientific tools. However, no attempt has been made to integrate experimental science into the architectural design process, or to make architectural design itself an experimental science. In this paper, I review the historical underpinnings that preceded the emergence of neuroarchitecture and explore the current extent and limitations of the field. I then draw upon lessons and techniques from the field of computational machine learning to briefly describe a computationally-augmented architectural development framework that identifies visual and material choices that maximize certain subjective experiences while working within the constraints of the field's limitations.

The foundation of neuroarchitecture is primarily informed by the parallel functionalization and medicalization of architecture over the past century-and-a-half. The opening decades of the 20th century saw a gradual de-emphasis of architecture's aesthetic dimension as such tragedies as the Triangle Shirtwaist Factory fire thrust a newly urbanized public's attention onto the miserable safety and health conditions in contemporary structures. The era's building science focused on the efficient construction of an environment that was safer, taller, and supremely functional[3]. This indicates an extension of architecture's ambitions from fulfilling the Vitruvian goal of venustatis (beauty) to the more holistic qualities of firmitatis and utilitatis (stability and utility)[4].

Functionally targeted architecture grew in stature as the 20th century continued. Alvar Aalto decisively broke from the preeminent International Style in his 1940 essay "The Humanizing of Architecture", wherein which he called for architecture that provided "for the human being the most harmonious life". To achieve this, Aalto argued for the expansion of design practices to develop architecture that accounted for the totality of human experience, including both physiological and psychological phenomena. To his eye, the immoderate adoption of Modernist architecture across the globe betrayed the more sensitive principles of architecture, reflecting a global taste overly concerned with specious exterior form[5]. This holistic ideology is embodied throughout his work, even those from his earlier Modernist period. His Paimio Tuberculosis Sanatorium's "main purpose" was explicitly coded as being "to function as a medical instrument." The most subtle material and formal choices of the building were so chosen to complement its humanist

*Figure 1. Lighting element suspended from gently-colored ceiling in Aalto's Paimio Tuberculosis Sanitorium. Image from FINNISH DESIGN STUDIO.*

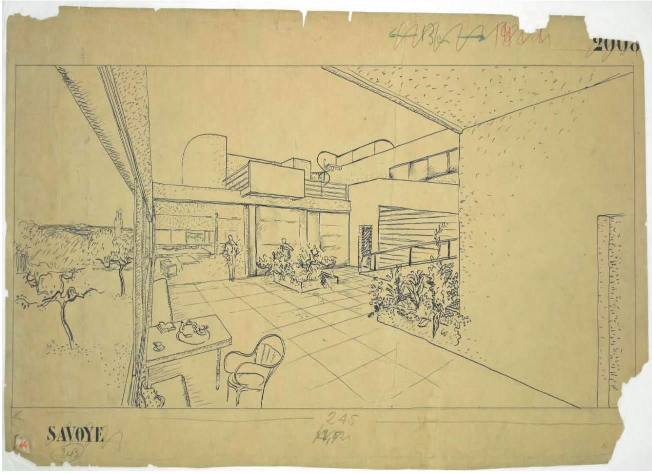

Figure 2. Le Corbusier's original sketches of his 1928 Villa Savoye. Image from Phaidon.

program. The "soundless water", hidden light sources, and quietly atmospheric tone of each room's ceilings all support the healing process by fostering "complete peace" in patients[6].

Aalto's contemporary, Le Corbusier, shared a strong interest in the use of design to further the biological condition of the public. During a 1909 trip to Athens, Le Corbusier famously studied the Parthenon and its ideal proportions, which would prove to be foundation for his Vers une architecture. His journey's other peculiar fascination would not be revealed until the posthumous publication of his diary, Le Voyage d'Orient, in 1966. The flat room of the traditional Greek home was the conceptual foundation for his characteristic rooftop garden terraces (Figure 2), employed to give occupants a place "to run in the fresh air" in the pursuit of "bodily health" and "the harmonious functioning of bodily organs"[7] (Figure 3). The use of the word harmonious is key. Despite the medical locution, his design has no specific biological goal. Rather, it identifies a key sensation-- wellness-- and works to support that.

Formal beauty has increasingly emerged from complete fulfillment of architectural function (mirroring the popular paradigm form follows function). However, remarkably little literature has attempted to analyze the degree to which functionalist architecture has been able to support its own goals. Neuroarchitecture promises to address this oversight—to audit the success of forms that primarily draw merit from their functionalism. The field is extremely small and limited in scope; its work largely an extension of existing research in neuroaesthetics (which attempts to frame aesthetic appreciation in neural terms). Despite these limitations, the discipline has thus far succeeded in bolstering the academy's understanding of the myriad ways that the built environment influences the human psyche[8]. The current zeitgeist uses an "aesthetic triad" model (again, borrowed from neuroaesthetics) to organize the brain's responses to architectural experience. According to this framework, architectural experiences arise from the brain's sensory-motor, emotional-valuation, and knowledge-meaning reactions.

Sensory networks, usefully conceptualized as the "gatekeepers of architectural experience", are deeply tied to downstream reactions of approach/avoidance instinct and navigation[9]. Research, dominated by studies of vision, suggests that humans experience attraction to patterns and forms with fluency, defined as "configurations with some degree of complexity that are… processed easily or fluently"[10]. The visual system is also sensitive to such features as contrast, grouping, and symmetry. Regions of high contrast consistently stimulate the retinal cells and neurons of the occipital cortex moreso than regions of low contrast because they contain a comparatively great amount of high-density visual information for object identification. Grouped features of both form and color trigger synchronized action potential gradients in the neural regions responsible for their processing[11]. Symmetry (and, more broadly, visual balance) seem to enable more efficient visual recognition. In classic neuroaesthetic experimentation, patterns with more local symmetries were able to be remembered and recreated more accurately and more quickly than patterns with fewer such symmetries[12]. Let the reader know that another subgenre of evolutionary neuroaesthetics, concerned with the biologically historic origins of present-day human aesthetic preferences also exists, but is less relevant to the scope of this article. Additionally, some research has claimed that humans express a preference for geometries with certain fractal dimensions (a statistical index for visual complexity), but this has been met with equal resistance[13]. Critics of the paper (which claimed to reliably identify the provenance of Pollock paintings with algorithmic techniques) note that the analytical techniques used were essentially arbitrary, and that random scribbles also fulfill the requirements for a genuine Pollock[14]. These sorts of inconsistencies are not altogether for-

Figure 3. Illustrated sunbathers atop Le Corbusier's Unité d'habitation. Image from BIGMAT INTERNATIONAL ARCHITECTURAL AGENDA.

*Figure 4. Typical open office; this one in Brooklyn. Image from Fortune.*

eign to the discipline.

Research that could be classified as dealing with the knowledge-meaning and emotion-valuation systems of the brain and their responses to formal design have received little attention, even by the modest standards of the field. Most relevant research confirms or provides a vague mechanism for what would likely be deemed obvious by even the non-scientific reader. Repeated visits to a space result in increasingly efficient navigation through that space because a cognitive map is formed in the hippocampus' place and grid cells[15]. Because ease of navigation and familiarity influence an individual's liking of a space, it is thought that familiarity influences architectural appreciation[16]. Further, there is clear evidence that the qualities of a space influence a person's emotional reactivity. Study participants that were subjected to an emotional stress test in a simulated virtual room without windows exhibited heightened reactivity compared to those that were given the test in a comparable virtual room with windows. Subjects from the windowless simulated room experienced prolonged spikes in stress hormone (including cortisol) levels[17]. Because high levels of stress hormones have been demonstrated to be detrimental to long-term physical health, it is theorized that there may be a relationship between prolonged exposure to closed spaces and long-term health[18]. There is clearly robust experimental support throughout the relevant scientific literature for the idea that architectural and aesthetic experience impacts the physical and mental state of people. However, the question of whether this research qualifies as or sufficiently supports a novel concept of neuroarchitecture remains.

Scientific progress in analyzing the neural aspects of aesthetic appreciation is valuable and appreciated, if at least for its worth in advancing to the ultimate goal of a comprehensively understood human mind. However, it has done much more for the world of neuroscience and psychology than it has for the world of design. How, exactly, can any of the above findings be reconciled with architectural practice? If they can be, have these new theories been successfully and responsibly implemented? Architects were unlikely to design rooms without windows before Fich's research—they are not now doubly so. One could most closely point to the realm of workplace and office design as a field whose practices have been heavily driven by psychoanalytic, if not neurological, research. But I would not point to this as a success story.

Traditional logic (supported by empirical research) suggested that geographic disparity and organizational boundaries drove interpersonal interactions to be unnecessarily homophilous (signifying a tendency for individuals to seek out those most like themselves), decreasing the potential for organization intelligence and collaboration[19, 20]. So, open offices have proliferated throughout the American workplace, their advent brought about by designers (and executives) eager to capitalize on increased workforce productivity. They have erased walls and brought employees physically closer (Figure 4). But have they brought about the changes they so optimistically promised? Recent, more comprehensive research suggests not. As it turns out, the so-called "war on walls" appeared to "trigger a natural human response to socially withdraw from officemates and instead communicate over email and IM". What's the difference between

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this study and past analyses? This was the first to empirically measure “both face-to-face and electronic interaction before and after the adoption of open office architecture”[21]. Previous studies have relied on self-reporting surveys and have carelessly generalized findings from a single company to craft grand theories of workplace interactions. Those responsible for designing office spaces used those findings to support preexisting assumptions about interaction, instead of starting with empirical findings using those to logically develop intelligent design processes. Resultingly, managers of newly “opened” office spaces may be surprised by a subsequent dip in face-to-face interaction[22]. Research in neuroarchitecture has hardly progressed past suggesting that certain visual features are significant, or perhaps rebutting misguided design tropes. It is no closer to producing techniques or ways of thinking that can deliver progressive insights into extant structures, much less be integrated into a scientifically-augmented design process.

Not all issues relating to neuroarchitectural research are an extension of the field’s youth. In its current conception, there are several inherent factors that severely limit neuroarchitectural research and the potential for its findings to be applied to the design process. This is reflected in the limited quantity and questionable quality of much of the extant literature that explicitly deals with neuroarchitecture (for example, ‘bioenergy’ is a theme often explored, but seldom defined[23]. Let’s revisit our previous discussion on office design. Workplace design science has only applied experimental science to organization and questions of social interactions. It has made no mention of material form or materiality. This exclusion is not intentional—it is not an oversight, or some stubborn refusal to quantify what could be easily quantified. Rather, traditional experimental design cannot realistically test these features.

Unfortunately, the reasons for neuroarchitecture’s sparse applications are fundamental. It is nearly impossible to standardize aesthetic forms for objective experimentation. Basic (or even complex) geometric forms are generally not representative of real-world architectural motifs and patterns. Structures are composed of a nearly infinite array of highly complex forms, textures, and colors. In order to maintain a significant sample size for each permutation, a traditional participatory experiment would need to cull this variety to a very limited range of standardized types. In addition, experimentation cannot develop theories about aesthetic experience in three-dimensional space beyond what is unenlightening and apparent to the point of being trivial (i.e. that prolonged exposure to a windowless space has negative consequences on the human condition). It would be nearly impossible to standardize experiences for hundreds of people across thousands of spaces (likely scattered across a country, if not the globe) to glean statistically sound insights into subtly varied characteristics. Applied research in neuroarchitecture is absurdly cost-prohibitive. The nature of architecture is fundamentally resistant to experimental science. Even the Bernstein study, which did not deal with material or aesthetic choice (and is therefore hardly subject to the above constraints), was possible only through the support of the Harvard Business School and its infinite well of willing corporate partners and supporters[24].

However, opportunities exist for quantitative techniques to support architecture. We must first reframe our treatment of neuroarchitecture and its goals. Neuroarchitecture should not seek to develop generalizable principles-- not because it should not, but because it cannot. Quantitative approaches to architectural design can, however, support designers as they make specific material and formal choices in support of fostering a certain mood or sensation in a structure’s occupants. Through the creation of web-sourced artificial intelligence models (based on well-established concepts and practices) that can make simple decisions on the qualitative mood or affect of a sample, architects can explore a nearly infinite array of possibilities to develop an ideal, optimized form[25].

In the proposed framework, the architect designs the general form and situation of the structure as she normally would. But instead of choosing from a small swath of materials and textures with which to finish the interior and exterior surfaces of the building, architects can choose to input a visual sample (a sketch or material swath) into an algorithm. The architect chooses the subjective experience that it wishes to evoke with the material, be it contemplativeness, concentration, sociability, awe, or any other experiential state for which a model has been created. The algorithm randomizes elements of the sample to develop a tremendous number of possible “solutions” that are each evaluated for their fulfillment of the chosen subjective experience (hereby termed fitness criterion). Through a simple evolutionary algorithm, two samples are chosen for their fitness criterion, mated so that they exchange some of their characteristics, and again evaluated for fitness[26] (Figure 5). The algorithm continues until it reaches several solutions that fulfill the fitness criterion to a high degree. It can optionally “mutate” (introduce randomness to) each

# LIMITATIONS

mated sample to bolster simulated creativity. It presents a selection of these solutions to the architects, in addition to a few solutions that fulfill the fitness criterion to a reasonably high degree but boast a variety of unique and aesthetically diverse visual properties. The architect thus receives a number of novel, creative visual suggestions that can be drawn upon to make material and formal decisions in support of a specific space's program. She continues with the design process as usual.

This technique recognizes the impossibility of supplanting traditional architecture, or even using neuroarchitecture to fundamentally reshape buildings. It capitalizes upon the unique strengths of computational techniques in its complete comprehensiveness and infinite scalability. Architects can use the process to produce specific visual permutations for highly specific spaces and situations, like the corner of a room or the surface of a desk. The algorithm harnesses the collective decision-making of the uncountable hordes of internet users who have ever expressed a preference or reaction to an image, or who have ever associated that image with another. Of course, the algorithm is stupider than the architect—it makes no claim otherwise. Still, it does what the architect could never hope to do. It uses judgement gleaned from the prior behavior of everyone who has ever interacted with an image on the internet to explore every possibility for a space. For the foreseeable future, those interested in augmenting the design process should instead complement designers in specific situations where current practices are simply unable to match the computational prowess of massively parallel algorithmic design.

On the back of a considerable philosophical and historical foundation, the nascent field of neuroarchitecture has developed a useful framework for considering how the human mind processes aesthetic and architectural experiences. Despite this, successful integrations of neuroarchitecture into the world of design are few and far between. Current techniques in neuroarchitecture do not address the fundamental conflicts between architectural design and experimental science. To bring experimental science to design, a less conceptually ambitious and more scientifically sound approach must be taken. This approach must intelligently design around the experimental limitations of traditional neuroarchitecture, instead of blindly and arrogantly proceeding with pseudoscientific techniques. Computational techniques can enhance the process of textural and tonal material design. A computationally-enhanced materials selection framework based upon a artificial intelligence model of specific subjective experiences can produce designs that are finer in scale and potentially more effective in eliciting human emotional and mental condition by considering nearly-infinite possibilities. This conservative approach to integrating traditional and neuroarchitecture suppresses the shortcomings and preserves the strengths of both modes. This reformulation is necessary to fulfill neuroarchitecture's visions of crafting environments that fully satisfy multidimensional aspects of the human psyche.

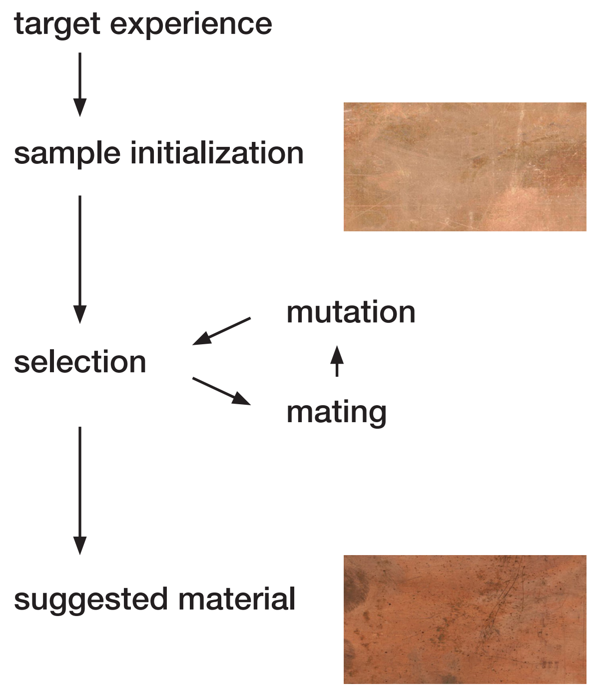


*Figure 5. Schematic of evolutionary material generation/selection algorithm.*

# DESIGN TO FULFILL THE HUMAN PSYCHE.

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