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Visual Discomfort in the Built Environment: Leveraging Generative AI and Computational Analysis to Evaluate Predicted Visual Stress in Architectural Façades

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Abstract

The built environment is increasingly recognized as a critical determinant of human health, profoundly influencing neurophysiological and psychological well-being. Previous studies show that specific visual patterns can elicit cortical hyperexcitation and visual discomfort, particularly in individuals with a predisposition to cortical hyperexcitability. However, traditional approaches to examining visual stress have yet to capture the complexity of ways in which the built environment may contribute to visual discomfort. This study presents a novel, integrated analytical methodology that merges generative artificial intelligence (using Midjourney v6.1) with advanced Fourier-based computational analysis to quantify the impact of architectural façades on visual stress. By systematically varying contrast ratios, pattern periodicity, spatial frequency distribution, stylistic elements, and geometric curvature across nine façade designs, the research generated a diverse array of stimuli that were then analyzed using the Visual Stress Analysis Tool (ViStA). This tool employs Fourier spatial frequency decomposition to extract key metrics that are proxy indicators of potential cortical stress responses. The results revealed that façades with regularly spaced elements at approximately three cycles per degree exhibited the highest stress metrics, particularly when combined with high contrast ratios and consistent repetition. Vertical wooden slats and vertical metal screening elements produced the most pronounced indicators of visual stress, while more varied geometric compositions demonstrated substantially lower stress metrics. This methodology offers a scalable, reproducible approach for the evaluation of visual stress. The framework lays the groundwork for developing a more robust evidence base to support architectural design decision-making that proactively addresses the health impacts of the built environment.

Keywords: visual stress; allostatic load; generative AI; architectural neurophysiology; cortical hyperexcitability; neural processing

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1. Introduction

The built environment significantly influences human physiological and psychological responses, affecting both immediate neurophysiological reactions and long-term well-being [1,2]. Urban populations in industrialized economies spend approximately 95% of their time in or around constructed spaces [3]. The global increase in time spent within constructed microenvironments has prompted extensive research into the relationship between architectural environments and human health [4–9]. While the health effects of factors such as light, ventilation, and noise are relatively well established [10–13], the specific physiological impacts of visual exposure to the built environment remain underexplored.

Research demonstrates that natural landscapes exhibit statistical visual properties that facilitate optimal processing in the human visual cortex [14]. The luminance structure of these natural scenes shows strong alignment with efficient neural encoding mechanisms [15]. In contrast, many built environments, when analyzed through Fourier amplitude spectra, often display statistical properties that deviate from these "natural" visual parameters [16]. This architectural divergence from evolutionarily familiar visual characteristics has gained attention due to its association with visual discomfort and adverse neurophysiological outcomes [17]. These outcomes may be more common in certain neurodiverse groups [18–20]. In susceptible individuals, exposure to highly repetitive or statistically 'unnatural' spatial configurations can trigger severe physiological responses, including seizures and headaches [14,16,17,21–23]. This phenomenon is referred to as visual stress—a condition encompassing a spectrum of adverse responses, including discomfort, perceptual strain, and heightened physiological arousal, elicited by exposure to specific visual patterns [14,18].

Evidence indicates that regular, high-contrast patterns—a feature commonly used in contemporary architectural façades—may significantly increase visual discomfort [16,17]. The experience of visual discomfort is particularly acute when the observed spatial frequencies concentrate around three cycles per degree of visual angle—a frequency that corresponds with the peak sensitivity of the human visual system [17]. Computational models of visual cortical functioning suggest that this discomfort stems from inefficient neural processing [24]. This is manifested through increased haemodynamic responses that can be measured via non-invasive neuroimaging techniques, including functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) [14,24,25].

The scientific investigation of visual stress responses to the built environment is currently constrained by significant methodological limitations that impede both the advancement of theoretical understanding and the implementation of evidence-based design practices. Four predominant methodological paradigms were identified: simple synthetic patterns, architectural renderings, photography-based evaluations of existing buildings, and in situ evaluations. Each presents distinct trade-offs between internal validity, external validity, ecological validity, and face validity.

At present, two key methodological tensions persist in architectural visual perception research. First, approaches that maximize experimental control (e.g., visual exposure to simple patterns) fail to capture the complexity of architectural experience. While those that prioritize ecological validity (e.g., visual exposure to in situ evaluations) cannot systematically isolate the influence of specific design elements due to numerous confounding variables. Second, the prevalent reliance on subjective assessment instruments introduces potential response biases that complicate the establishment of objective design parameters.

These methodological constraints collectively generate a persistent epistemological dilemma: Researchers must choose between reductive controlled experiments or ecological complexity. These constraints constitute a significant impediment to the advancement of evidence-based architectural design practices that promote neurophysiological well-being, and there is currently a need for innovative methodological approaches that can bridge the gap between experimental rigor and real-world applicability.

The present study addresses these methodological constraints by developing an integrated research framework that combines generative artificial intelligence (AI) technologies with Fourier-based computational analysis (which serves as a proxy for visual stress responses) to systematically evaluate architectural façades. Rather than choosing between a methodological process of ecological realism or experimental control, this study proposes a novel approach that leverages generative AI to systematically alter architectural parameters—including formal composition, stylistic attributes, contrast relationships, repetitive elements, and orientational characteristics of high contrast linear elements—while maintaining the visual complexity that approximates authentic architectural environments.

The use of generative AI technologies in neuroarchitectural research offers new opportunities for the systematic exploration of the design of the built environment. By generating diverse architectural visualizations that systematically vary select specific parameters, this approach enables researchers to isolate the influence of individual design variables with precision previously unattainable in studies of complex architectural forms. This methodological innovation enhances internal validity without sacrificing the representational complexity necessary for ecological relevance.

The integration of Fourier-based computational metrics provides an objective, quantitative approach for identifying problematic spatial frequencies and high-contrast patterns most commonly associated with visual discomfort [17]. The proposed framework incorporates these two complementary methodological components that collectively address the limitations of existing research paradigms: (1) Generative AI-driven façade synthesis provides systematic manipulation of architectural parameters while preserving ecological complexity, thereby establishing an optimal balance between internal and external validity considerations; and (2) computational Fourier-based analysis implements objective quantitative metrics for identifying problematic spatial frequencies and high-contrast patterns, enabling the screening of large image datasets according to established neurophysiological criteria.

By combining the generative capabilities of artificial intelligence with established computational analysis in a controlled experimental paradigm, this study seeks to develop a methodological framework that advances both research rigor and practical applicability in the estimation of neurophysiological responses to architectural form. This innovative approach transcends the limitations of existing methodologies by enabling the systematic manipulation of complex architectural parameters while maintaining ecological relevance and experimental control. The resulting framework offers significant potential for informing evidence-based design practices that mitigate adverse neurophysiological responses and promote inclusive, health-supportive built environments across diverse populations.

2. Visual Exposure to Architectural Patterns and Visual Stress

An emerging body of interdisciplinary research underscores the importance of visual exposure in shaping physiological responses to the built environment. Architecture, and the design of the built environment more broadly, has been increasingly recognized as an influential factor in human well-being [4,5]. Within this broader framework, a growing field of research has developed that focuses on visual stress [14]. This emerging research builds on foundational evidence that unnatural spatial and chromatic structures can provoke heightened cortical responses, in turn contributing to subjective discomfort and potentially exacerbating broader physiological stress mechanisms [17].

Visual stress can be induced by exposure to regular, high-contrast patterns, the most uncomfortable being black and white stripes with a 50:50 duty cycle (where the black and the white stripes have equal width) in the region of 3–5 cycles per degree subtended on the retina. This is dependent on the size of the features and the viewing distance.

An example of this is shown in Figure 1. Similar patterns, with these properties, can be found in architectural features that can cause visual discomfort and potentially trigger neurophysiological stress responses. When the visual cortex encounters patterns it is not evolutionarily adapted to process, the required neural activity becomes more energetically demanding [16]. Migraine headaches and photosensitive seizures—particularly in susceptible individuals—are cited as extreme manifestations of this phenomenon [21,26]. These outcomes are also consistent with models of allostatic overload, wherein repeated or intense stressors (including ongoing exposure to discordant visual stimuli) can accumulate and tax the body's stress-response systems [27]. Although migraines and seizures have been more definitively linked to visual triggers [28], research has yet to fully characterize the ways in which subclinical levels of visual discomfort might contribute to chronic stress responses in the general population.

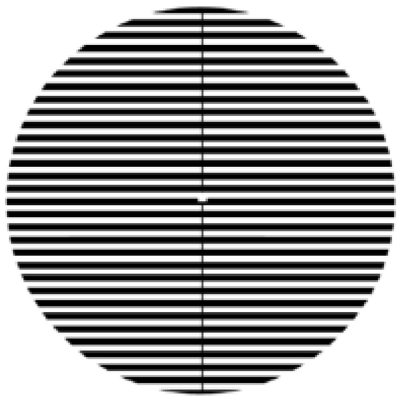

Figure 1. The Pattern Glare Test [24] Susceptibility to pattern glare is assessed by comparing the number of visual distortions reported when viewing the pattern.

A key lens through which visual stress can be understood is the characteristic shape of the spatial frequency distribution of most natural scenes, which approximates to 1/f [14,16]. The term "1/f" reflects the approximate inverse relationship between frequency and amplitude in the Fourier spectrum of natural images. As spatial frequencies increase, amplitudes diminish in a predictable, quasi-fractal manner. This statistical regularity is not confined to a single biome or and whether woodlands, deserts, or rainforests, natural scenes typically conform to an approximate 1/f structure [16]. The human visual system has evolved to efficiently process specific balances between spatial frequencies by activating only the neurons necessary for image processing. Such "sparse coding" is metabolically efficient, and demonstrates a clear evolutionary advantage by conserving energy and minimizing neural fatigue.

In contrast, urban environments often present visual stimuli that deviate from the 1/f distribution [17]. Repetitive high-contrast motifs—such as striped façades, geometric tilings, or strong architectural features (Figure 2)—are thought to generate dense, non-sparse neural firing patterns. This divergence is particularly problematic when architectural details concentrate contrast energy around mid-range spatial frequencies (approximately three cycles per degree)—a spatial frequency that coincides with the peak sensitivity of the human visual system [16]. Fernandez and Wilkins found that images rated as uncomfortable showed disproportionately greater amplitude at spatial frequencies within two octaves of three cycles per degree [29]. This finding was also supported by subsequent research from Juricevic et al. [30].

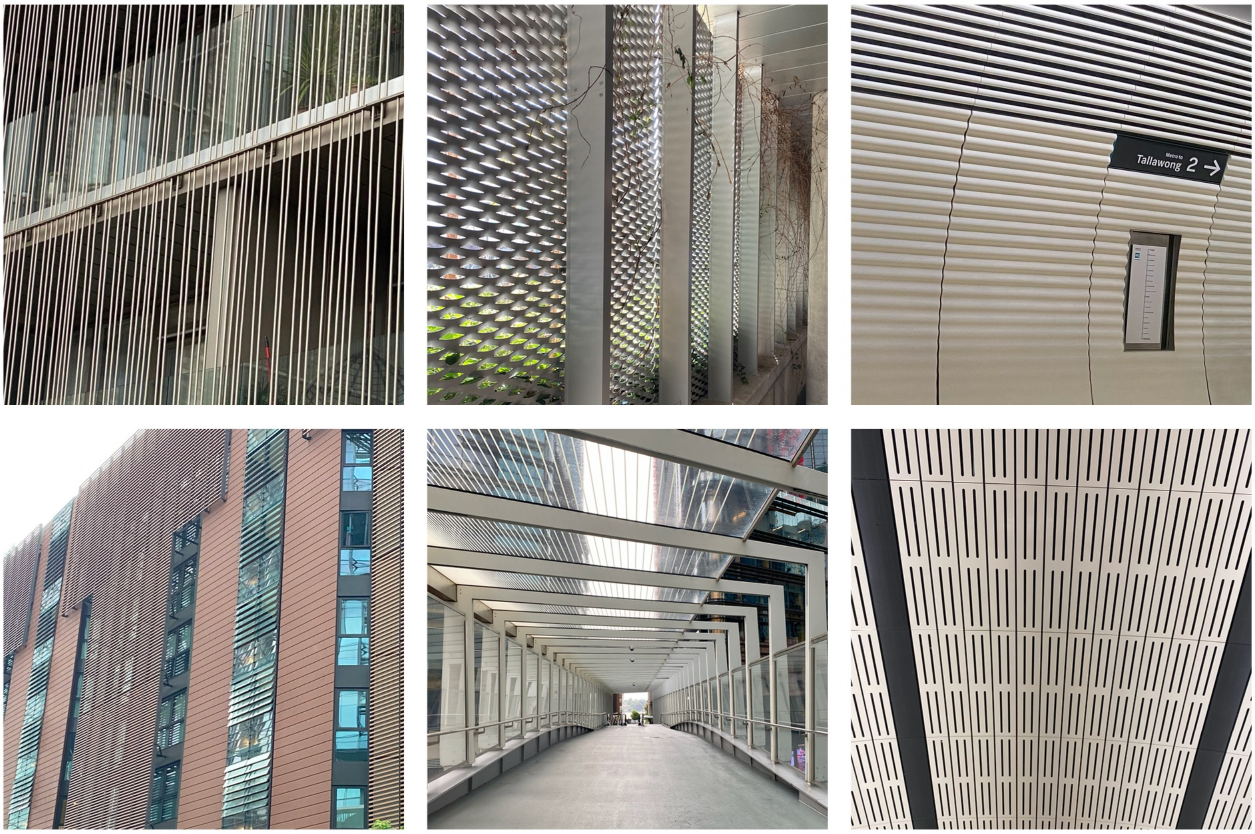

Figure 2. Examples of high-contrast regular repetitive visual patterns in the built environment. All photographs are the author's own.

In parallel, there is a growing recognition of individual differences in visual stress susceptibility [31–33]. For instance, certain individuals with neurodivergent profiles (e.g., those on the autism spectrum or with photosensitive epilepsy) report heightened responses to repetitive, high-contrast patterns [31–33]. Likewise, the presence of co-occurring anxiety or sensory processing disorders may exacerbate reactions to certain architectural forms [34–36]. Although preliminary studies indicate clear variation in range regarding discomfort glare, flicker sensitivity, and pattern glare, the precise underlying neurobiological mechanisms still remain poorly understood. Some evidence points to cortical hyperexcitability, where specific cortical regions display increased reactivity to visual patterns, but further neuroimaging work is needed to substantiate these observations across broader populations [24].

Furthermore, the relationship between visual discomfort and cumulative physiological stress has been relatively under-investigated. While recent efforts involve measuring physiological markers such as heart rate variability (HRV), functional near-infrared spectroscopy (fNIRS), and electroencephalography (EEG) to gauge cortical and autonomic arousal [14,17], consensus is lacking on which metrics best capture stress associated specifically with visual stimuli. This gap underscores the need for research protocols that systematically combine subjective assessments of discomfort with objective neurophysiological indicators to better elucidate the pathways through which visual stress may contribute to allostatic load.

3. Current Methodological Approaches to Measuring Visual Stress in Architectural Environments

As discussed, research on the visual stress-inducing properties of architectural façades currently employs one of four methodological approaches based on visual exposure to

(1) simple synthetic patterns, (2) renderings of designs, (3) photographs or videos of real-world buildings, or (4) in situ evaluation of built environments. Each strategy has distinct strengths and weaknesses in terms of internal validity, external validity, ecological validity, and face validity [37]. Before examining each methodological approach, it is essential to establish a clear conceptual framework regarding the various dimensions of validity that inform methodological assessment. The evaluation of research methodologies in architectural visual perception studies necessitates consideration of four distinct yet interrelated validity constructs [37]. Internal validity refers to the degree to which causal inferences can be drawn from a study's findings—specifically, the extent to which observed effects can be confidently attributed to the variables being examined rather than to extraneous factors. This dimension of validity is complemented by external validity, which pertains to the generalizability of research findings beyond the specific conditions, samples, and contexts in which they were obtained [37].

Equally significant is ecological validity, which has varying definitions, but which we define as the degree to which experimental procedures, materials, and settings approximate the real-world conditions they purport to represent [38]. In the context of neuroarchitectural research, this criterion assesses whether the experimental paradigm adequately captures the multisensory, embodied, and dynamic nature of experiences of the built environment—a particularly challenging aspect given the complexity of spatial perception.

Finally, face validity concerns the extent to which a research methodology appears, prima facie, to measure the construct it claims to measure [37]. Within visual perception studies of the built environment, face validity reflects whether the research approach intuitively corresponds to the actual experience of perceiving and responding to built environments, providing an immediate, though sometimes superficial, assessment of methodological appropriateness. Together, these four dimensions of validity provide a comprehensive framework for evaluating the strengths and limitations of diverse research approaches to examining visual perception within the built environment.

3.1. Approach 1: Visual Exposure to Simple Patterns

The use of simple geometric patterns, typically presented in black and white, offers researchers significant control over experimental variables (Table 1). These patterns are relatively straightforward to generate and analyze, focusing primarily on specific parameters such as spatial frequency, duty cycle, and angle of rotation. The Wilkins and Evans Pattern Glare Test exemplifies this approach, using three square wave gratings (0.5, 3, and 12 cycles per degree) with controlled parameters including a 50% duty cycle, high contrast, and horizontal orientation designed to mimic the striped effect of text [39]. Studies employing this approach generally target central vision, with the visual field necessarily limited by display size and viewing distance constraints [21,40].

The primary advantage of simple pattern studies lies in their high internal validity. By isolating specific visual properties and eliminating extraneous variables, researchers can establish robust causal connections between particular pattern characteristics and resultant stress responses. The Pattern Glare Test demonstrates this precision, with the three cycles per degree (cpd) grating specifically designed to maximally elicit pattern glare in susceptible individuals. The 3 cpd grating is based on extensive research that has demonstrated that this frequency is more likely to trigger visual perceptual distortions than other spatial frequencies [26].

However, this approach suffers from notable limitations in its external validity, as findings derived from simplified stimuli may not generalize effectively to the complex, heterogeneous characteristics present within the built environment. While Pattern Glare Test results correlate with conditions like visual discomfort and migraine, such tests do not map easily to the built environment. Architectural façades contain varied spatial frequencies, irregular patterns, and contextual elements absent in simple gratings such as the Pattern Glare Test. The ecological validity is similarly compromised, as the experimental conditions bear little resemblance to how individuals naturally encounter and perceive buildings in situ. The Pattern Glare Test's brief five-second viewing period and controlled lighting differ significantly from everyday architectural experiences involving extended exposure, movement, and variable environmental conditions. The face validity of this approach is correspondingly low; abstract geometric patterns do not intuitively correspond to architectural façades as experienced in quotidian contexts. This raises questions about whether the measured responses genuinely reflect the perception of the built environment rather than pattern recognition processes activated by the controlled stimuli used in tests such as the Pattern Glare Test.

Table 1. Approach 1: visual exposure to a simple geometric pattern.

Category	Description
Image generation	Simple geometric patterns, often black and white
Image analysis	Simple (e.g., spatial frequency, duty cycle, angle of rotation)
Visual field	Often central vision; limited by display size and viewing distance
Internal validity	High
External validity	Low
Ecological validity	Low
Face validity	Low

3.2. Approach 2: Visual Exposure to Renderings of Designs

Architectural renderings represent a methodological middle ground, offering greater realism than simple patterns while maintaining some degree of experimental control (Table 2). The generation of high-quality renderings requires substantial technical skill and can be resource-intensive. Renderings can potentially accommodate peripheral vision studies but generally remain unsuited for standard computer monitor presentation due to field-of-view limitations. For example, a 24″ monitor viewed at 60 cm would occupy around 47 and 28 degrees of the horizontal and vertical visual field respectively [calculated by 2 × (arctan(height/2)/viewing distance). This is compared with the full human visual field, which is approximately 190 degrees horizontally and 125 degrees vertically [41]. This approach achieves medium internal validity—researchers retain some control over design parameters but cannot isolate variables with the precision afforded by simple patterns. As such, this approach introduces potential confounding variables that may complicate causal inference. With this approach, there is a moderate level of external validity, as renderings more closely approximate reality while still representing idealized versions that may diverge from built environments in material properties, contextual integration, and phenomenological experience.

The ecological validity of rendering-based methodologies is similarly moderate. While renderings capture more architectural complexity than abstract patterns, they typically present static, decontextualized viewpoints that fail to encapsulate the multisensory, kinesthetic experience of moving through built environments. Face validity, however, is substantially enhanced when photorealistic, high-fidelity renderings are employed. Despite these advantages, rendering-based studies face significant constraints in that they tend to be labor-intensive and often examine only a narrow range of viewing angles or design variations. As such, they potentially overlook important aspects of how buildings are experienced in realistic contexts.

Table 2. Approach 2: Visual exposure to renderings of designs.

Category	Description
Image generation	Requires high skill level and can be cost-intensive
Image analysis	Complex (e.g., Fourier analysis)
Visual field	Can target peripheral vision but generally unsuited for standard computer monitors
Internal validity	Medium
External validity	Medium (limited to single or a few viewpoints)
Ecological validity	Medium (limited to single or a few viewpoints)
Face validity	Medium-high (assuming photorealistic, high-fidelity renderings)

3.3. Approach 3: Visual Exposure to Pictures of Buildings

Photography-based methodologies utilize images of existing buildings as experimental stimuli (Table 3). This approach is necessarily limited to the available building stock and requires complex analytical techniques similar to those used for renderings. Like renderings, photographs can potentially incorporate peripheral vision but their use faces practical limitations when presented on typical-sized computer monitors as discussed above.

The use of photographs achieves medium internal validity due to the presence of numerous uncontrolled variables including lighting conditions, viewing angles, and contextual elements that may confound the relationship between specific architectural features and observed visual stress responses. Le et al. [25] demonstrated this challenge in their study of discomfort from urban scenes. Within their study, careful photographic protocols were employed—taking un-posed images by "standing at the side of a curb and aiming a camera across the street" to capture building facades from consistent distances (5–12 m)—in an attempt to standardize the experimental stimuli. Additionally, while photographs capture existing structures, the selective framing, perspective, and technical qualities of photographic representations introduce potential distortions that may influence the generalizability of research findings.

Ecological validity in photography-based studies is enhanced relative to abstract patterns but remains limited by the static, two-dimensional nature of photographic representation, which cannot fully capture the embodied, multisensory experience of architectural environments. However, this approach offers high face validity, as participants encounter recognizable images of actual buildings rather than abstractions or simulations, fostering greater confidence that the measured responses reflect genuine reactions to architectural forms. Le et al. [25] validated this assumption in their fourth and fifth studies, where they found strong correlations (r = 0.89, $p < 0.001$ and r = 0.75, $p < 0.05$) between comfort ratings of real buildings when viewed in person and ratings of photographs of those same buildings, confirming that "photographs of scenes are a good surrogate for the scenes themselves".

The primary limitation of photography-based studies stems from their restriction to existing structures, which prevents systematic manipulation of architectural parameters and complicates the isolation of specific design elements that may contribute to visual stress. Le et al. [25] addressed this limitation by analyzing their photographic stimuli using an algorithm that measured how closely each image approximated the statistical properties of natural scenes (specifically the $1/f$ amplitude spectrum characteristic). This computational approach allowed them to objectively predict visual discomfort based on deviation from natural image statistics, finding that images with unnatural statistical properties produced both higher discomfort ratings and larger haemodynamic responses in the visual cortex. Furthermore, the presence of uncontrolled confounding variables—such as environmental context, material properties, and lighting conditions—introduces significant challenges for establishing robust causal relationships between specific architectural features and physiological responses.

Table 3. Approach 3: Visual exposure to pictures/videos of buildings.

Category	Description
Image generation	Photography-based, but limited to existing building stock
Image analysis	Complex (e.g., Fourier analysis)
Visual field	Can target peripheral vision but generally unsuited for standard computer monitors
Internal validity	Medium
External validity	Medium
Ecological validity	Medium
Face validity	High

3.4. Approach 4: Visual Exposure to In Situ Evaluations

In situ evaluations, arguably, represent the most ecologically valid approach to examining participants' responses within actual built environments (Table 4). This methodology is inherently limited to accessible existing buildings and locations. Analysis typically involves complex techniques applied to the architectural features present in these environments, with participants experiencing the full visual field of the surrounding space. The primary strength of in situ studies lies in their high external validity; findings derived from naturalistic environments are more readily generalizable to real-world architectural contexts than those obtained under artificial laboratory conditions. Srikantharajah and Ellard [42] demonstrated this advantage in their field studies conducted in London and Toronto, where they measured participants' physiological and affective responses to buildings with varying façade complexity. By bringing participants on walks through real urban environments and having them view pre-selected buildings for five minutes each, they captured authentic responses that laboratory simulations might have missed. The researchers noted that "findings from studies using simulations must be robust enough to be demonstrated in the real world, so they can usefully inform policy and practice in urban or architectural design" [42]. Similarly, there is a very high level of ecological validity, as participants encounter buildings in their complete environmental context, experiencing the full range of sensory inputs, spatial relationships, and contextual factors that constitute real-world architectural experiences. Srikantharajah and Ellard explicitly acknowledged this advantage, stating that "one major advantage of field research is that viewing stimuli in person is significantly more immersive than simulations in the laboratory" [42]. Their findings revealed that buildings with low visual complexity caused a significant decrease in skin conductance over time compared to high-complexity buildings, demonstrating measurable physiological effects that occur in authentic settings.

Face validity in in situ evaluations is exceptionally high, as the methodology directly engages with built environments as they are naturally perceived and experienced, rather than relying on abstractions or representations. In the Srikantharajah and Ellard [42] study, the researchers validated this approach by comparing participants' responses to real buildings versus photographs of those same buildings, finding strong correlations between ratings ($r = 0.89$ in London and $r = 0.75$ in Toronto). This confirms that "photographs of scenes are a good surrogate for the scenes themselves," [25] while still acknowledging the inherent value of direct experience with actual buildings.

However, the intrinsic complexity and heterogeneity of real-world environments render it exceedingly difficult to isolate specific variables or establish clear causal relationships between particular architectural features and observed visual stress responses. Srikantharajah and Ellard [42] faced this challenge directly, noting that "while isolating for certain variables (i.e., controlling for the weather or lighting) may provide more experimental power, the real world is inherently complicated and changing, especially urban environments.” Their study attempted to address this limitation by carefully selecting buildings that varied primarily in façade complexity, while measuring this variable through both mathematical means (fractal dimension and JPEG compression) and subjective reports.

Researchers must contend with numerous confounding factors—including lighting variations, acoustic properties, thermal conditions, temporal dynamics, and social context—that may influence participants’ responses independently of the architectural elements under investigation. These methodological constraints substantially limit researchers’ ability to identify with precision the specific design parameters that contribute to visual discomfort.

Table 4. Approach 4: Visual exposure to in situ evaluations.

Category	Description
Image generation	Limited to existing buildings and accessibility of varied locations
Image analysis	Complex (e.g., Fourier analysis)
Visual field	Full-vision
Internal validity	Low—hard to control across diverse physical environments
External validity	High
Ecological validity	High
Face validity	High

3.5. Bridging Methodological Approaches with Generative AI and Computational Analysis

The integrated methodology proposed in this study represents a novel hybrid approach that combines elements from existing methodological frameworks while addressing their inherent limitations. By leveraging generative artificial intelligence (Midjourney v6.1) in conjunction with computational Fourier-based analysis (ViStA), this framework extends the controlled parameter variation of simple pattern studies to that of more complex architectural forms. Unlike traditional renderings that typically require extensive technical expertise and resource investment for each design iteration, generative AI enables the systematic exploration of design spaces through iterative text prompts, producing diverse architectural visualizations that maintain internal consistency while selectively varying specific visual characteristics. This approach facilitates the creation of stimuli with controlled parameters—including contrast relationships, pattern periodicity, and spatial frequency distributions—while preserving visual complexity of built environments. The proposed framework achieves a balance between experimental control and ecological validity that has previously not been possible within visual perception research of the built environment. By enabling the controlled systematic variation of complex architectural parameters while maintaining experimental rigor and representational complexity, this hybrid methodology creates new possibilities for investigating the neurophysiological impact of the built environment.

The generation of façade variations through AI offers several distinct methodological advantages over traditional approaches. First, it enables precise control over specific visual parameters while maintaining a consistent baseline geometry across all stimuli, improving internal validity compared to photography-based methods. This systematic manipulation within a consistent framework allows researchers to isolate specific variables that might influence visual stress responses, facilitating more robust causal inferences than is possible with in situ evaluations. Additionally, the integration of computational Fourier-based analysis provides objective, quantitative metrics for evaluating the visual stress potential of image datasets—transcending the limitations of subjective assessment instruments commonly employed in architectural perception studies. This computational approach enables the identification of potentially problematic spatial frequencies and contrast relationships before resource-intensive testing with human subjects. By combining generative capabilities with established computational analytics, this methodology creates an iterative framework for design evaluation and refinement that bridges the gap between theoretical neuroscientific insights and practical architectural applications. This methodological innovation offers a scalable and reproducible approach for investigating how specific architectural parameters influence visual perception and neurophysiological response.

4. Methodology

4.1. Generative AI for Façade Variations (Midjourney)

Drawing from the Pattern Glare Test, which is the strongest known stimulus for visual stress, we examined architectural features that most closely resemble a high-contrast grating. Structural elements with strong directional emphasis and repetitive arrangements—such as slatted balustrades, privacy screens, and linear column arrays—have been associated with visual discomfort due to their regular, high-contrast patterning [16,17]. Similarly, perforated paneling used in acoustic treatments, security features, and cladding introduces regular spatial frequencies that can interfere with visual processing [17,43]. Geometric mesh and ventilation grills concentrate energy at specific spatial frequencies, much like the patterns known to induce pattern glare responses. Other elements, including highly patterned surfaces like ornate tilework or dense carpet motifs [28], as well as reflective materials that amplify luminance contrast and glare, further contribute to visual stress. Additionally, moiré effects from overlapping patterned elements—such as window films interacting with security screens—create interference patterns that compound the potential for discomfort. These findings indicate that common architectural features, often implemented to address other legitimate design concerns (security, privacy, acoustic treatment, and thermal regulation), may inadvertently create environments that induce visual stress [43]. This presents a significant challenge for designers, in balancing multiple functional requirements while considering the neurophysiological impact of their design decisions. The identification of these specific architectural elements that contribute to visual stress has important implications for architectural practice. Emerging evidence suggests that the adoption of evidence-based design approaches that incorporate knowledge of spatial frequency distributions and visual processing could potentially improve occupant well-being across various building typologies.

To ensure methodological rigor in stimulus generation, this investigation utilized Midjourney (version 6.1), to create nine systematically varied renditions of a single architectural façade. Midjourney is an advanced text-to-image generative artificial intelligence platform, and was selected for its efficiency in rapidly generating high-quality architectural visualizations through simple text prompts (Table 5). The text-to-image generation capability allowed for the precise linguistic specification of architectural features, enabling systematic variation of façade elements through carefully crafted prompt engineering. The experimental design deliberately maintained underlying structural coherence while methodically varying specific visual parameters to produce a comprehensive range of architecturally plausible variations for analysis.

The selection of architectural features was informed by established research on visual discomfort, with particular emphasis on high-contrast linear elements identified in prior literature [17,26,43]. These evidence-based considerations directly informed the development of text prompts for the generative AI system. This ensured that the resulting stimuli exhibited the specific visual characteristics identified within existing literature as potentially stress inducing. Five critical parameters were systematically manipulated across the stimulus set. First, contrast levels were precisely modulated to examine the potential relationship between differential luminance profiles and viewer perception. This manipulation permitted the investigation of how varying degrees of light–dark differentiation might influence visual comfort and processing efficiency. Second, pattern repetition was systematically varied along a continuum from minimally to moderately and highly repetitive configurations. This methodical progression facilitated the examination of how increasingly regularized design elements might differentially impact perceptual processing and cortical activation patterns. Third, spatial frequency distribution was carefully controlled through specific text prompts: "tight, narrow patterns" were employed to approximate mid-range spatial frequencies (approximately three cycles per degree), while "spread-out patterns" were utilized to generate lower spatial frequency distributions. The particular emphasis on mid-range frequencies [44] was informed by the existing body of research that documents the relationship of mid-range frequencies to visual discomfort and potential cortical hyperexcitability [16,26,45].

By employing seed control and iterative text prompts tailored to generate variations in design features, the study maintained a consistent base geometry for the façade, ensuring that only the targeted parameters were varied. A neutral "base façade" was first developed. This base facade was a two-story structure characterized by simple walls, generous natural light, and minimal ornamentation. All images were rendered at an aspect ratio of 91:51 using a 35 mm lens to standardize the field of view and perspective.

Systematic modifications focused on the second floor, using Midjourney's "highlight alter" function to introduce features such as slatted panels with differing spatial frequencies and contrast levels, variations in window and balcony treatments, and variations in the extent and geometry of fenestrations. In certain variations, angular elements were added to increase geometric complexity. This controlled yet flexible approach ensured that each façade was distinct yet comparable within a uniform visual framework, enabling the direct investigation of how contrast, repetition, and spatial frequency might influence visual stress and broader perceptual outcomes.

Table 5. Comparative overview of nine façade configurations illustrating progressive variations in contemporary architectural articulation.

Number	Description	Image
Image 1	Image 1 shows a minimalist white façade with a horizontal composition. The ground floor features a large glass window with black frames, divided into five sections with varying widths. Interior light creates a warm glow. The left side contains a recessed entrance with a black door and a small black panel mounted on the white wall. No upper-level windows are visible in this view.	
Image 2	Image 2 introduces a wooden slat screen on the upper level, creating a horizontal rectangular feature above the storefront. The wooden slats provide texture and warm tones, contrasting with the white walls. The ground floor remains consistently designed across all variations.	
Image 3	Image 3 presents a variation with vertical metal slats in the upper rectangular opening. These white-colored vertical elements are placed above a dark, unlit window creating a high degree of contrast. The ground floor remains consistently designed across all variations.	

Table 5. *Cont.*

Number	Description	Image
Image 4	Image 4 presents a wooden slat motif but shows it with light passing through and reflecting off the window behind. The light behind the slats adds depth and dimension to the façade, creating a variation in contrast. The ground floor remains consistently designed across all variations.	
Image 5	Image 5 shows a window arrangement with three evenly spaced rectangular windows on the upper level, contrasting with the modern storefront below.	
Image 6	Image 6 introduces recessed windows and balconies with galvanized metal, vertical bar railings. The vertical elements of the balcony railings create a subtle grid pattern.	
Image 7	Image 7 features three large arched windows on the upper level. These curves introduce a visual counterpoint to the rectangular geometry below.	
Image 8	Image 8 shows vertical metal screening elements on both the upper level windows and a recessed balcony. The consistent use of vertical lines creates a cohesive rhythm across the façade, while the varying depths and arrangements add visual depth to the façade. The warm lighting behind the screens creates an atmospheric effect.	
Image 9	Image 9 combines arched windows with a dramatic larger arch, creating a bold geometric statement. The larger arch encompasses a lit interior space, adding depth to the façade. This variation most strongly juxtaposes curved and rectangular forms.	

4.2. Visual Stress Analysis (ViStA)

The ViStA imaging pipeline (see Figure 3 below) is a refinement of the approach developed by Penacchio and Wilkins [16]. In that work, the deviation of an image's spatial luminance content from the statistics of natural images was estimated by first extracting the largest possible central square section of the image. The Fourier amplitude spectrum of this square image was then compared with an estimate of the average Fourier amplitude spectrum in natural images, based on a set of amplitude spectra of 350 natural images from a calibrated image database [46]. This reference spectrum forms an anisotropic cone in Fourier space—similar to a $1/f$ regular cone, but with excess power for cardinal orientation, as found in natural images [44].

For each image, deviation from natural statistics was computed by fitting its amplitude spectrum to the reference cone and summing the differences (residuals) in Fourier space, yielding a single scalar value. This value represents the deviation from the statistical properties of natural scenes and has been shown to be a good predictor of visual discomfort [16]. ViStA builds on this method, but rather than analyzing only the central square square region, it applies the same computation to a grid of square tiles that cover the full image. More precisely, in ViStA, an image is divided into squares of 2 degrees vertical field of view and resized to 64×64 pixels. Two degrees was chosen as this equates approximately to the size of the high acuity foveal region of the retina [47]. The squares have a 50% overlap to ensure that spatial features that span across the whole image are analyzed, and that pixels are equally weighted. The 64 × 64 pixel squares give 32 pixels per degree, which, in relation to the Nyquist frequency [48], means that spatial frequencies up to 16 cycles per degree are included. This ensures that spatial frequencies sufficiently beyond the peak of human contrast sensitivity (and, therefore, discomfort) are analyzed [21,26].

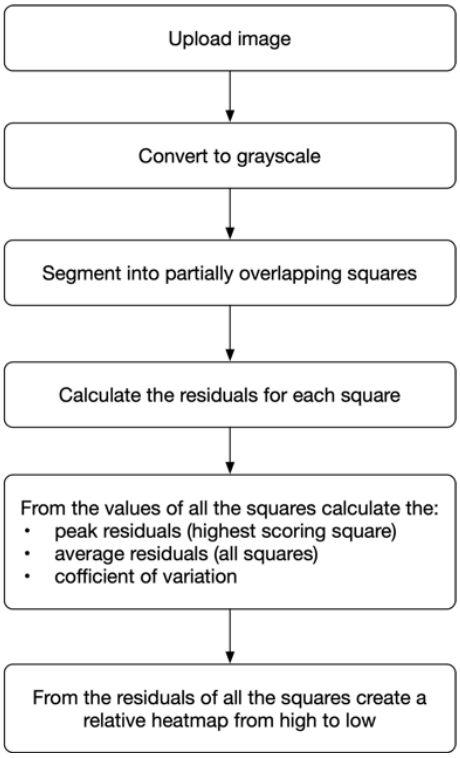

Figure 3. A basic outline of theViStA image processing pipeline.

ViStA adopts the version of the original algorithm proposed by Penacchio and Wilkins [16] that assigns greater weight to deviations from natural statistics at spatial frequencies to which humans are more visually sensitive. This is achieved by weighting the residuals according to the human contrast sensitivity function [49], following a formula developed by Mannos and Sakrison [50]. Currently, the approach provides a value for each tile of the set of tiles recovering the starting image. We refer to the maximum of these values as the peak residuals, the arithmetic mean of these values as the average residuals, and the coefficient of variation of these values simply as the coefficient of variation. Seventy-four images of building frontages from Le et al. [25] were used in a comparison of the results from the original algorithm of Penacchio and Wilkins [16] with those of the ViStA tool. Even though the latter analyzed multiple overlapping 2 × 2 degree images, the Spearman rank correlation between the mean residuals of the ViStA tool and the output from the original algorithm was 0.95.

5. Results

The computational analysis using the Visual Stress Analysis (ViStA) Tool revealed distinctive patterns in how the design of architectural façades might influence visual stress. The analysis of these results centered on three key metrics, each quantifying a different dimension of potential visual discomfort in the built environment. The peak residuals metric indicates the presence of strong, concentrated luminance contrast energy at one or more specific spatial frequencies within an image, with higher values suggesting more pronounced contrast features, whilst the average residuals metric measures the overall strength of luminance contrast energy across various frequencies. Elevated average residuals imply a higher predicted hemodynamic response (increased visual stress) [25].

The coefficient of variation assesses the variability in the contrast energy distribution, where values near 1.00 denote consistently high energy across frequencies, and values below 1.00 indicate more evenly distributed contrast energy. Images exhibiting high peak residuals or high average residuals values are likely to contain regular, high-contrast configurations that are known to induce visual discomfort, as supported by Penacchio and Wilkins [16] and Le et al. [25]. Conversely, lower values in these metrics signal fewer visual stressors and indicate a less fatiguing visual experience. Collectively, these metrics provide a framework for identifying and quantifying potential visual stressors in the built environment and provide a novel means by which to inform design strategies to enhance visual comfort and neuroarchitectural ergonomics. The computational analysis of the nine façade configurations revealed substantial variability in the observed visual stress metrics across the different design variations. The results below outline the visual stress metrics for each image individually (Table 6).

Image 1 served as the baseline condition, featuring a minimalist ground-floor glass storefront with black frames and no upper-level fenestration. The image 1 façade exhibited a peak residuals value of 2.00×10^9 and an average residuals value of 3.50×10^8, with a coefficient of variation of 1.20. No measurable spatial frequency was recorded, as the image lacked regular or repetitive elements. The recorded residuals values reflect the minimal contrast and geometric simplicity of the design.

The design configuration of Image 2 recorded the highest peak residuals (1.10×10^{10}) and average residuals (1.70×10^8) across all of the images examined and exhibited a coefficient of variation of 1.40. The spatial frequency of the vertical screening element on the upper story was calculated at exactly 3 cpd—a value that corresponds with the peak sensitivity of the human visual system. These results support existing evidence that built environment designs that incorporate elements that exhibit regular, high-contrast patterns at 3 cpd produce the most pronounced visual stress indicators [16].

Image 3 featured vertical metal slats set within a rectangular upper-level opening. While similar in design to Image 2, its observed spatial frequency (2 cpd) was lower. Correspondingly, Image 3 produced a peak residuals value of 3.90×10^9, an average residuals value of 8.30×10^8, and a coefficient of variation of 1.00, all lower than those of Image 2. The lower spatial frequency of Image 3 relative to Image 2 appears to mitigate, though not eliminate, the visual stress potential.

Image 4 introduced a wooden slat screen with visually permeable spacing that allows light to pass through and generates visual depth. Despite its repetitive vertical slat configuration, the spatial frequency measured 2.1 cpd. Image 4 yielded a peak residuals value of 3.20×10^9, an average residuals value of 8.50×10^8, and the lowest coefficient of variation among all the façades examined (0.84). The observed results for Image 4 are indicative of a more evenly distributed contrast profile and less visually demanding composition.

Image 5 featured three evenly spaced rectangular windows on the upper level. The Image 5 configuration had a spatial frequency of 1.8 cpd, and produced a peak residuals value of 2.00×10^9, an average residuals value of 4.30×10^8, and a coefficient of variation of 0.95. These observed values indicate low-to-moderate visual stress potential, likely due to the reduced repetition of visual elements and relatively subdued contrast levels.

Image 6 introduced balustrades with vertical bar railings, contributing to a strong expression of repeat linear elements within the façade. Despite a spatial frequency of 4.3 cpd—exceeding the hypothesized critical range—this façade generated a moderately high peak residuals value of 5.00×10^9 and an average residuals value of 7.50×10^8, with a coefficient of variation of 1.00. The interplay between the increased frequency of repeat linear elements, combined with reflective metallic materiality and spatial layering, amplified the contrast intensity, resulting in elevated visual stress metrics.

Image 7 featured three large arched windows on the upper level, introducing curved geometry in contrast to the predominantly rectilinear fenestration elements within the other façades examined. Due to the lack of repeated, frequent features, the spatial frequency for this image was very low and, therefore, well below the peak of the contrast sensitivity function. Image 7 registered a peak residuals value of 2.30×10^9, an average residuals value of 5.60×10^8, and a coefficient of variation of 0.99. The moderate residuals values observed for Image 7 suggest that geometric variation and curvature may potentially serve to diffuse contrast energy and reduce visual strain. Based on these results, the impact of geometric form on the visual stress-inducing potential of the built environment is an area that warrants further investigation.

Image 8 featured vertical metal screening over recessed balconies, producing a layering of repetitive linear elements and a high spatial frequency of 7.8 cpd. In the ViStA output for this façade, we recorded the second-highest peak residuals value (9.90×10^9) of the images examined, a high average residuals value (8.70×10^8), and a high coefficient of variation of 1.40. These values indicate that even at frequencies above the 3 cpd range, certain combinations of pattern regularity, material reflectance, and contrast layering can significantly increase the visual stress potential of building façades.

Image 9 combined a large central arch with multiple smaller arched windows, resulting in a mixed geometric composition that lacked a dominant repetitive element. As with Image 7, where there was a lack of repeated, frequent features, the spatial frequency for this image was very low and, therefore, well below the peak of the contrast sensitivity function. Façade 9 yielded a peak residuals value of 2.10×10^9, an average residuals value of 5.20×10^8, and a coefficient of variation of 0.97. The relative irregularity and gentle curvature likely contributed to the relatively low observed stress indicators when compared to the other façades examined.

Taken together, these results confirm that façades characterized by high contrast, consistent repetition, and spatial frequencies around 3 cpd (notably, Image 2) resulted in the highest visual stress metrics. However, façades exceeding 3 cpd (such as Image 8) were also observed to yield elevated stress metrics, suggesting that spatial frequency interacts with a range of variables—such as materiality, contrast layering, and geometric diversity—to influence the visual discomfort potential of the built environment. The interrelationship between the design of the built environment and visual stress, as well as the resultant implications for public health, are further explored in the following discussion.

Table 6. Comparative overview of nine architectural façade images, detailing primary features, pattern types, and visual stress metrics.

Image #	Primary Feature	Pattern Type	Peak Residual	Avg Residual	CoV	Cycles/°	> or <3 cpd
1	Blank upper wall	None	2.00×10^{9}	3.50×10^{8}	1.20×10^{0}	n/a	—
2	Horizontal slat screen	Horizontal repetition	1.10×10^{10}	1.70×10^{9}	1.40×10^{0}	3	equal
3	Vertical metal slats	Vertical repetition	3.90×10^{9}	8.30×10^{8}	1.00×10^{0}	2	less
4	Wooden slat screen	Vertical repetition	3.20×10^{9}	8.50×10^{8}	8.40×10^{-1}	2.1	less
5	Traditional windows	Regular spacing	2.00×10^{9}	4.30×10^{8}	9.50×10^{-1}	1.8	less
6	French balconies	Grid pattern	5.00×10^{9}	7.50×10^{8}	1.00×10^{0}	4.3	more
7	Arched windows	Curved repetition	2.30×10^{9}	5.60×10^{8}	9.90×10^{-1}	n/a	n/a
8	Vertical screening	Layered vertical	9.90×10^{9}	8.70×10^{8}	1.40×10^{0}	7.8	more
9	Large arch	Curved hierarchy	2.10×10^{9}	5.20×10^{8}	9.70×10^{-1}	n/a	n/a

6. Discussion

The analysis of visual stress indicators in architectural façades reveals complex relationships between spatial frequencies, architectural features, and neurophysiological responses. The findings demonstrate a notable correlation between cycles per degree (cpd) and visual stress metrics, with façades spatial frequencies within the 3 cpd range producing the most elevated stress indicators. However, the relationship is not strictly linear, and façades with higher spatial frequencies (as was observed with Image 8) also exhibited high stress metrics. Conversely, façades with spatial frequencies below 2 cpd generally showed lower potential visual stress levels, particularly when accompanied by varied patterning and moderate contrast. These results offer meaningful insights into how architectural design influences visual comfort and cognitive load in response to the built environment.

The highest peak residuals (1.10×10^{10}) and average residuals (1.70×10^{9}) values were observed in Image 2, which featured high-contrast vertical wooden slats at exactly 3 cpd. The findings suggest that regular patterns within the built environment with this frequency range are particularly problematic for visual processing. The combination of consistent spacing, high contrast between solid and void elements, and select critical spatial frequency ranges appears to create conditions that maximize the potential for visual stress.

Similarly, Image 8 exhibited the second-highest peak residuals value (9.90×10^{9}) with a spatial frequency of 7.8 cpd. Despite exceeding the spatial frequency critical range identified within the existing literature as most likely to induce visual stress [16], the consistent use of vertical metal screening elements, combined with the layering effect that was produced by the variation in facade depth and visual overlap of material elements, produced elevated stress metrics. Notably, both Images 2 and 8 shared the highest coefficient of variation (1.40). This finding is consistent with the elements of spatial frequency, duty cycle, and contrast amplitude that all contribute to the metric.

Repetitive high-contrast linear elements (Image 2) and layered high-contrast linear elements or patterns (Image 8) produced the highest stress indicators, sharing key characteristics: regular spacing, strong directional emphasis, and high-contrast relationships. Conversely, varied geometric compositions (Image 9) and curved elements (Image 7) generated substantially lower stress metrics. These findings suggest that pattern diversity and non-linear geometry may help to mitigate visual stress within the built environment.

Material selection emerged as another significant factor in visual stress. Metal elements in screening systems (Images 3 and 8) consistently produced higher stress indicators compared to timber elements with similar spatial organization and frequencies (Image 4). This suggests that the reflective properties of metallic surfaces may increase contrast and, hence, visual stress when combined with repetitive elements. Material choice appears to play a crucial role in modulating the severity of visual stressors, with more diffusive materials potentially offering advantages in stress mitigation.

Conventional window arrangements (Image 5) demonstrated relatively low stress metrics (peak residuals 2.00×10^{9}, 1.8 cpd) despite regular spacing. However, when similar rhythmic organizations were combined with additional elements, as in Image 6's balconies with vertical railings, the observed ViStA metrics increased substantially (peak residuals 5.00×10^{9}, 4.3 cpd). This suggests that visual layering of multiple regular patterns may compound stress effects.

The analysis reveals that the combination of regular patterns, critical spatial frequency ranges, and high-contrast materials produces substantially higher stress metrics than any single factor in isolation. This finding has significant implications for built environment design practices, suggesting that successful visual stress mitigation requires a comprehensive approach that takes into consideration the interconnected impact of multiple design factors on visual stress.

6.1. Implications for Architectural Design and Practice

The findings from this research have substantial implications for architectural practice to help support both the evaluation and design of reduced stress environments. The ViStA tool provides architects with a heat map identifying potential visual stressors, which are quantified with metrics—peak residuals, average residuals, and the coefficient of variation. This can help identify specific design elements that may induce visual stress, transforming abstract neuroscientific principles into readily applicable evaluations of architectural forms and materials. This analysis identifies several key architectural characteristics that correlate with elevated visual stress: elements with spatial frequencies around three cycles per degree, highly regular repetitive patterns, and the juxtaposition of high-contrast materials. By quantifying these elements, architects can evaluate the degree to which specific design features might be likely to induce visual stress when observed from typical viewing distances. The tool allows designers to identify potentially problematic design elements before finalizing the design.

The often siloed nature of research and practice means that valuable scientific knowledge frequently remains abstract and disconnected from real-world applications. The ViStA tool addresses this disconnect by enabling architects to systematically refine visual environments based on neuroarchitectural evidence. Specifically, it allows design teams to perform the following:

1. Identify potentially problematic visual elements and generate space-specific visual stress metrics;
2. Make focused design modifications rather than complete redesigns;
3. Re-analyze modified designs quickly to assess the impact of changes on visual stress;
4. Iterate systematically to reduce stress while preserving core design intent;
5. Assess visual stress both at the level of individual spaces and across broader interior or exterior zones.

By facilitating this form of direct interdisciplinary knowledge transfer, the methodology put forward within this paper creates a more cohesive and functional framework for embedding human well-being within the built environment design. Through successive rounds of evaluation and modification, architects and built environment designers can improve the visual comfort of the end design while balancing performance criteria and aesthetics. This iterative design feedback capability represents a significant advancement over traditional approaches, enabling neurophysiological considerations to be incorporated alongside aesthetics, functionality, constructability, and sustainability during active design processes.

The methodology developed within this paper and the ViStA tool also offer significant potential for collaboration with product manufacturers and suppliers. By quantifying how different materials and finishes affect visual stress, the research creates opportunities for the development of specification options that minimize neurophysiological stress and product lines that are specifically engineered to reduce visual stress and support well-being.

6.2. Limitations and Future Research

While this study advances methodological approaches to visual stress analysis in architecture, several important limitations must be acknowledged. The use of 2D static images differs fundamentally from dynamic real-world architectural experience, which involves continuous changes in perspective, viewing distance, and visual angle as individuals move through space. Additionally, the use of Midjourney for stimulus generation may produce artifacts or material representations that differ from actual built environments. The blackbox nature of commercial AI products such as Midjourney also represents issues in relation to the degree of control obtainable in the end images. As the base algorithms, code, and large language model learning inputs are unknown, there are a range of uncontrolled variables impacting on image production. Whilst the research team can control for the production of a consistent base image and systematic select variations through the prompt text utilized, unknown artifacts may be present in the research images generated.

The ViStA tool relies on computational Fourier-based analyses that would benefit from further validation through testing with human subjects to evaluate the impact of variations in individual susceptibility to visual stress [17]. The computational approach used within this research does not account for individual variability in sensitivity to visual stimuli. The metrics employed provide population-level predictions that may not accurately reflect the experiences of particularly vulnerable individuals, including neurodiverse populations who may experience heightened sensitivity to visual stimuli. Further research is needed to assess the impact of built environment design on visual stress in vulnerable populations.

At present, there is a lack of research addressing equity considerations in visual stress distribution. Current approaches do not adequately account for how visual stressors might disproportionately affect individuals with heightened sensitivity, nor how such stressors might be inequitably represented in neighborhoods with different socioeconomic backgrounds or demographic compositions, potentially contributing to environmental visual stress inequity at an urban scale.

This study represents the first phase of a larger research agenda aimed at understanding and mitigating visual stress within the built environment. Expanded research projects are currently being developed to focus on four primary areas:

1. **Empirical validation:** correlating computational predictions with neurophysiological responses measured through functional near-infrared spectroscopy (fNIRS) and heart rate variability (HRV) to strengthen the understanding of visual stress and the evidential basis for design recommendations.
2. **Parameter expansion:** examining a broader range of architectural parameters including color variation, lighting conditions, surface textures, and complex geometric relationships to provide a more comprehensive understanding of factors that impact on visual stress.
3. **Dynamic experience:** developing methodologies that capture the multi-sensory, embodied experience of architecture through immersive technologies and real-world testing environments.
4. **Inclusive design applications:** investigating the differential impact of visual stress on neurodiverse populations, vulnerable individuals with heightened sensitivities, and diverse demographic groups. This research stream will explore how visual stress considerations can be incorporated into inclusive design frameworks. Additionally, the potential exists to examine the geographic distribution of visual stressors across urban environments to address concerns in relation to environmental stress equity and well-being. Understanding these relationships will be crucial for developing design guidelines that create more inclusive, accessible environments for all users.

By addressing these limitations and expanding the research scope, it is hoped that future studies can further refine our understanding of the relationship between architectural form and neurophysiological responses, ultimately contributing to the development of more equitable, inclusive, and health-promoting built environments.

7. Conclusions

This study presents an integrated methodological framework that combines generative artificial intelligence with Fourier-based computational analysis to evaluate the visual stress potential of architectural façades. By systematically varying design parameters across nine façade iterations, this research has demonstrated the efficacy of this approach in identifying specific architectural features that may contribute to visual discomfort and heightened neurophysiological stress responses.

The quantitative analysis of visual stress metrics reveals that façades incorporating regular, high-contrast patterns at spatial frequencies of approximately three cycles/degree had the highest predicted visual stress values of the images examined. Configurations featuring repetitive vertical wooden slat screens (Image 2) and vertical metal screening elements (Image 8) with narrow spacing between the repeat linear elements generated peak residuals values of 1.10×10^{10} and 9.90×10^{9}, respectively, substantially exceeding the metrics observed in more varied compositional arrangements. These findings align with established research on cortical hyperexcitability while extending theoretical principles to examine architectural forms and built environment materiality.

The computational approach employed in this study addresses a significant methodological gap in built environment research by enabling the systematic assessment of complex design elements that have previously proven difficult to isolate and evaluate. The Visual Stress Analysis Tool (ViStA) provides a quantitative mechanism through which to evaluate the potential for designs to induce visual stress. This novel methodological framework offers architects an evidence-based process for design evaluation that complements traditional aesthetic and functional considerations.

This research contributes to an emerging interdisciplinary dialogue between neuroscience and architectural design through the translation of theoretical principles of visual processing into practical analytical tools that can be readily integrated into design workflows. By advancing methodological approaches to evaluating architectural visual stress within the built environment, this study provides both theoretical insights and practical tools for developing built environments that balance aesthetic expression with neurophysiological impact considerations. The findings presented within this research make inroads into developing a better understanding of the relationship between architectural form and neurophysiological responses to the built environment, and they represent an important step in informing design practices that better support visual comfort and cognitive well-being.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
EEG	Electroencephalography
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-Infrared Spectroscopy
HRV	Heart Rate Variability
ViStA	Visual Stress Analysis Tool
cpd	Cycles per Degree
1/f	Inverse Frequency (in spatial frequency spectra)
FFT	Fast Fourier Transform

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