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Features of Visual Perception of Volumetric Wall Panels Depending on Lighting Scenarios

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Abstract

Volumetric wall panels occupy a unique position between architectural surfaces and sculptural reliefs, where visual perception strongly depends on lighting scenarios. The article examines how the direction, intensity, distribution, and colour temperature of light influence the perceived depth, texture legibility, and material qualities of three-dimensional wall panels, with an emphasis on gypsum relief compositions. The study synthesises recent findings from vision science, environmental psychology and interior design on shape-from-shading, material perception, visual comfort and spatial appraisal. Within this framework, the work analyses how grazing, directional, diffuse and mixed lighting schemes enhance or suppress relief articulation, modify the reading of concavities and convexities, and alter impressions of warmth, softness and visual complexity. The goal is to formulate design-oriented recommendations for selecting lighting scenarios that reveal volumetric panels without visual fatigue or perceptual distortions. The article will be helpful for interior designers, lighting designers, sculptors working with architectural relief, and researchers studying the interaction between light, surface geometry and human perception.

Keywords: *Volumetric Wall Panels, Sculptural Relief, Lighting Scenarios, Visual Perception, Depth Perception, Material Perception, Indoor Visual Environment, Spatial Perception, Gypsum Panels, Interior Lighting.*

INTRODUCTION

Three-dimensional wall panels combine functional surface treatment with expressive sculptural modelling, transforming a flat plane into a complex relief that interacts with light, shadow and human perception. In contemporary interiors, such panels operate not only as decorative accents but as spatial regulators that guide movement, define zones and shape emotional responses. For such elements, the perception of depth, plasticity, and material quality is determined less by physical dimensions than by the lighting environment, which reveals or hides the relief structure.

Modern lighting technologies enable the flexible control of luminous flux, direction, distribution, and spectral composition, allowing a single relief composition to appear either sharply plastic and dramatic or almost flat and neutral, depending on the chosen scenario. This sensitivity becomes especially pronounced for gypsum and similar matte materials, where subtle variations of shading and penumbra define the legibility of sculptural modelling. Design practice confirms that errors in lighting configuration often produce visual discomfort, false reading of depth, or excessive contrast that tires the eye, even when the relief itself is executed with high craftsmanship.

The purpose of the article is to provide a theoretical and applied analysis of how different lighting scenarios affect the visual perception of volumetric wall panels in interior spaces. The work pursues three interrelated tasks: first, to summarise current scientific knowledge about perception of three-dimensional shape, surface material and indoor visual environment relevant to sculptural wall treatments; second, to interpret these results for typical lighting schemes used for relief panels, including frontal, grazing, side and mixed lighting with variable colour temperature; third, to derive design recommendations for configuring lighting so that sculptural panels preserve articulate depth, balanced contrast and stable material impression without reducing visual comfort.

Novelty of the article stems from the targeted integration of experimental findings from vision science, environmental psychology, and interior design in relation to a specific object

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type – volumetric wall panels. Existing literature usually considers shape-from-shading and material perception in abstract stimuli or addresses interior lighting in terms of general visual comfort and spatial appraisal. Here, these directions are systematically connected with the practical issue of presenting sculptural relief in architectural interiors, which enables the formulation of more precise criteria for evaluating lighting scenarios for such panels.

MATERIALS AND METHODS

The analysis relies on recent studies that examine depth cues from shadows and shading, material and colour perception, psychological responses to interior material combinations, and characteristics of indoor visual environments. P. Cavanagh, R. Casati and J. H. Elder investigated how offset and blur of cast shadows influence perceived separation between an object and the background surface, establishing a near-linear relationship between shadow displacement and judged depth [1]. E. A. Cooper, R. Casati, H. Farid and P. Cavanagh analysed artistic and experimental strategies for making objects appear to rest on or float above surfaces through manipulation of cast shadows and supporting planes [2]. T. Huang, C. Zhou, X. Wang, and J. Kaner investigated how the colour and texture of reconstituted decorative veneer affect the visual perception of surface samples, including attractiveness, naturalness, and complexity ratings [3].

Z. J. Isherwood and co-authors examined how variations of surface gloss, texture and illumination alter perceived colour, showing strong interactions between photometric structure and chromatic appearance [4]. S. Kwak and K. Choi assessed psychological and physiological responses to wood-integrated material combinations in interior material boards, focusing on warmth, softness and arousal appraisals under controlled lighting [5]. P. J. Marlow and B. L. Anderson demonstrated that image information can simultaneously specify three-dimensional shape and material properties for translucent surfaces, revealing joint coding of geometry and material cues [6]. In a subsequent study, P. J. Marlow, B. Prior de Heer and B. L. Anderson analysed the contribution of self-occluding contours to discrimination between opaque and translucent materials, emphasising the diagnostic power of contour curvature for material judgments [7].

X. Meng, M. Zhang and M. Wang conducted a systematic review of how indoor visual environments in schools, including lighting and visual features, influence health-related outcomes, summarising evidence on visual comfort and well-being in educational interiors [8]. S. Stefanopoulou explored how different lighting configurations in public interiors change perceived depth and affordances, paying special attention to vertical surfaces and their articulation through luminous gradients [9]. J. T. Todd, Y. Yu, and F. Phillips investigated the qualitative perception of three-dimensional shape from patterns of luminance curvature, showing that concave regions of the luminance field reliably guide the detection of concavities on smooth surfaces across varying illumination conditions [10]. These sources provide the theoretical basis for understanding how volumetric wall panels are visually perceived under various lighting scenarios.

The article uses comparative analysis and synthesis of empirical findings from the selected studies, correlating them with typical design situations involving volumetric wall panels. The method of theoretical modelling is applied to extrapolate results obtained on simplified stimuli (laboratory shapes, material samples, psychophysical scenes) to sculptural wall reliefs in authentic interiors. Typological grouping is used to classify lighting scenarios and relief morphologies according to their expected perceptual effects. Additionally, a visual-analytical assessment of representative photographic examples of relief panels under various lighting schemes is employed to verify the applicability of theoretical conclusions to design practice.

RESULTS

The synthesis of the selected research enables a structured representation of how lighting scenarios influence the visual perception of volumetric wall panels, particularly in relation to depth perception, material impression and visual comfort. For sculptural reliefs executed in gypsum or similar matte materials, three clusters of parameters are decisive: the geometry of illumination (direction, grazing angle, and presence of cast shadows), photometric characteristics (intensity distribution, contrast, and shadow softness), and spectral composition (colour temperature and rendering).

Experimental work on depth from shadows indicates that the visual system uses the offset between an object and its cast shadow as a robust cue for perceived separation from the background surface. P. Cavanagh and co-authors demonstrated that increasing shadow offset results in a nearly linear increase in judged distance. In contrast, variations in shadow blur and light direction have a secondary influence [1]. For volumetric wall panels, this result implies that directed lighting that produces distinct cast shadows from protruding elements reinforces perception of relief height even when the absolute depth is modest. Conversely, configurations that minimise shadow-background offset, such as diffuse ceiling lighting, compress the perceived depth range and make sculptural modelling appear flatter.

Figure 1 schematically summarises the relationship described by Cavanagh and colleagues. As the centre of a cast shadow moves away from the base of a protrusion on a patterned wall, the perceived separation between protrusion and background grows approximately linearly, with only weak dependence on penumbra width [1].

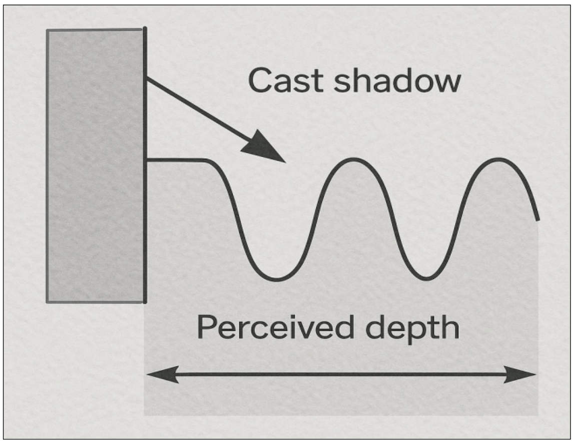

Figure 1. Schematic relationship between cast shadow offset and perceived depth for a rectangular protrusion on a textured wall panel (compiled by the author based on his own research)

Empirical findings on anchoring and floating objects relative to support surfaces refine this picture. E. A. Cooper and co-authors demonstrated that even without explicit cast shadows, surfaces rich in texture and orientation cues can visually support objects, whereas ambiguous backgrounds promote the impression of floating; cast shadows then reliably reattach objects to the ground plane [2]. For sculptural wall panels, this mechanism means that relief blocks or fragments, when illuminated so that their cast shadows clearly connect to the surrounding wall texture, are interpreted as firmly integrated in the plane of the wall. Suppose shadows are displaced in a way that visually detaches them from the underlying surface, for example, through complex overlapping lighting. In that case, relief elements acquire an ambiguous status closer to separate objects than to a continuous architectural surface.

Vision science literature on shape-from-shading and material perception clarifies how shading gradients on relief panels interact with lighting direction. J. T. Todd and co-authors showed that observers use patterns of luminance curvature—rather than absolute luminance levels—to infer surface concavities and convexities on smoothly curved shapes [10]. Concave regions of the luminance field tend to be interpreted as geometrically concave, despite changes in illumination and material properties, which grants a degree of constancy to qualitative shape perception. Applied to wall panels with smoothly modelled waves or draperies, this finding suggests that lighting setups should preserve coherent luminance curvature along principal relief directions; irregular, multi-directional lighting that produces conflicting curvature patterns introduces perceptual noise and destabilises the reading of the sculptural form.

Research by P. J. Marlow and B. L. Anderson on light-permeable materials demonstrates that the visual system exploits specific image features that jointly indicate material and three-dimensional shape [6]. In their studies, observers inferred both the geometry and translucency of objects from correlated variations of shading and internal light scatter. While gypsum panels do not exhibit strong subsurface scattering comparable to that of translucent media, analogous interactions arise between micro-texture, small-scale shading, and overall relief depth. If lighting eliminates subtle internal gradients through overly uniform illumination, the panel visually approaches a two-dimensional graphic pattern. Strategic directional lighting that preserves minor contrast variations allows the eye to integrate material and shape into a coherent volumetric impression.

The importance of contour structure for material perception, demonstrated by P. J. Marlow and co-authors, has direct consequences for relief design and lighting [7]. Self-occluding contours—where the surface curves out of view—carry photometric signatures that help distinguish between opaque and translucent, as well as between glossy and matte materials. In sculptural panels, such contours arise at ridges, deep grooves and overlaps of volumes. Lighting that emphasises contour curvature through controlled rim highlights and consistent shadow boundaries supports the correct classification of the relief as a solid architectural surface. Overly diffused lighting, which erases contour-based cues, reduces the clarity of the material impression and can even produce unintended ambiguity between a flat graphic pattern and proper relief.

Studies on surface properties and colour perception expand this picture. Z. J. Isherwood and co-authors showed that interactions between diffuse and specular components of reflection significantly influence perceived colour and that manipulating gloss and texture under varying illumination leads to complex shifts in appearance [4]. For gypsum panels finished with paint or coatings of different sheen, this means that light direction and intensity not only reveal relief but also modulate hue and saturation of coloured elements. Intense grazing light can darken recesses and desaturate highlights, while frontal soft illumination brings perceived colour closer to the physical pigment. Designers working with polychrome reliefs, therefore, need to calibrate lighting so that desired chromatic relationships are preserved in the target viewing position.

Material studies oriented toward interior design provide evidence of how people evaluate composite material surfaces in realistic settings. T. Huang and co-authors, analysing reconstituted decorative veneer samples, documented that combinations of colour and texture significantly affect ratings of naturalness, visual comfort and complexity [3]. Experiments by S. Kwak and K. Choi demonstrated that increasing wood coverage on material boards resulted in higher perceived warmth, and that the brightness level strongly influenced softness and arousal impressions [5]. These results imply that volumetric panels that visually emulate wood grain or integrate wooden inserts will be perceived differently under warm versus neutral colour temperatures and under high-contrast versus low-contrast lighting. Warm, moderately bright light tends to reinforce impressions of warmth and softness, whereas cooler, higher contrast light emphasises texture sharpness and stimulates arousal.

Environmental psychology and interior design confirm that the indoor visual environment has a significant impact on comfort and health-related outcomes. The systematic review by X. Meng and co-authors identified lighting, access to nature, window characteristics, environmental aesthetics and spatial arrangement as main visual themes influencing children's health in school environments [8]. Evidence from this review suggests that balanced lighting with reduced glare, adequate vertical illuminance and visually coherent surfaces contributes to comfort and well-being. For volumetric wall panels used in educational or other functionally demanding interiors, lighting scenarios that generate extreme contrast and specular glare on protruding elements should therefore be avoided in favour of solutions that maintain legible relief while limiting visual strain.

Design-oriented research on lighting and spatial perception supports this conclusion. S. Stefanopoulou's exploration of depth and affordances in public interiors showed that directional lighting of vertical surfaces alters perceived depth stratification and navigational cues, while carefully calibrated gradients guide movement and attention without disorientation [9]. For sculptural panels, such gradients can be used to accentuate certain zones—entrances, focal walls, circulation paths—without overloading the field of view. By incrementally varying intensity across the panel, designers can introduce perceived depth progression that aligns with the spatial hierarchy of the interior.

Based on these results, lighting scenarios for volumetric wall panels can be categorised into several typical configurations. Narrow-beam grazing light from above or the side generates strong relief articulation with pronounced cast shadows and high local contrast. According to depth-from-shadow research, such arrangements maximise perceived relief height, but risk exaggeration when shadow offsets exceed physical proportions [1]. Wider-beam directional light from a moderate angle produces more moderate shadow offsets and softer gradients; in combination with matte surfaces, this solution provides articulate volume without harsh transitions. Diffuse lighting from large luminous surfaces significantly reduces cast shadows and compresses perceived depth; panels under such illumination operate more as subtle textural backgrounds than as strong focal elements. Mixed schemes, where directional accent lighting is superimposed on a diffuse base level, offer the most flexible control, allowing sculptural zones to be highlighted while maintaining general visual comfort. The interaction between lighting and panel morphology deserves separate consideration. Research on luminance curvature and qualitative shape perception implies that reliefs composed of broad, smoothly transitioning forms are less sensitive to precise light direction than those dominated by fine, high-frequency details [10]. For wave-like or draped compositions, even moderate changes in light position preserve the overall pattern of concavities and convexities, although the perceived curvature may be slightly distorted. Panels constructed from sharp facets, deep grooves, and small protrusions, in contrast, show a stronger dependence on the incidence angle, as tiny changes in shadow placement can transform the apparent structure. In such cases, lighting design should be coordinated with the sculptor to ensure that critical edges and intersections receive stable shading, independent of minor variations in luminaire positioning.

Finally, the combined evidence on indoor visual comfort indicates that lighting for volumetric panels must be evaluated not only in terms of relief visibility but also in relation to the surrounding tasks and user groups. The review by X. Meng and colleagues emphasises that excessive contrast, glare and unstable luminance patterns negatively influence comfort and health outcomes, especially for children [8]. When panels are installed near work zones, desks, or circulation routes, accent lighting should be adjusted to avoid direct views of bright sources and to maintain reasonable luminance ratios between the panel, adjacent walls, and work surfaces. In leisure or representative areas, a higher contrast range is acceptable, but even there, dynamic control of intensity and colour temperature enables adaptation to different activities and emotional scenarios.

DISCUSSION

The synthesised results highlight a complex interaction between the physical parameters of lighting, the geometric structure of relief panels, and the perceptual mechanisms of shape and material interpretation. Depth from cast shadows and luminance curvature offer particularly robust cues that can either be harnessed or inadvertently distorted by lighting design. Where shadow offset and curvature are consistent with the intended geometry of the panel, observers obtain a stable impression of layered volumes integrated into the wall plane; when these cues conflict—for example, through overlapping light directions or contradictory gradients—the relief appears visually noisy or ambiguously detached from the background.

Studies by P. Cavanagh and co-authors, together with the artistic-experimental analysis of E. A. Cooper and colleagues, suggest that volumetric wall panels should be approached not merely as decorative backgrounds but as active participants in the system of support and floating relationships within the interior [1, 2]. When accent light produces transparent contact shadows at the base of protruding elements, the panel contributes to a legible stratification of surfaces, enhancing orientation and spatial coherence. If, conversely, shadows fall in directions inconsistent with other surfaces, or detach from the supporting wall texture, the relief may introduce local ambiguity that conflicts with the global depth organisation of the room.

A useful conceptual bridge between laboratory findings and sculptural panels is provided by J. T. Todd's work on luminance curvature and P. J. Marlow's analyses of self-occluding contours [7, 10]. Relief compositions often combine smooth transitions and sharp edges within the same panel. Grazing light from a single dominant direction tends to generate luminance profiles whose concavities align with physical concavities of the relief, thereby reinforcing volumetric reading. When multiple spotlights with differing directions are used without coordination, the resulting luminance curvature can misalign with geometric structure, creating regions where concave intensity patterns correspond to convex surface patches and vice versa. In such cases, observers experience subtle perceptual tension: the eye recognises the sculptural form through occlusion contours yet receives conflicting shading information.

Figure 2 illustrates this interaction schematically, adapting the logic of Todd's experiments to a relief panel: along a horizontal section through a wavy gypsum panel, concave segments of the luminance curve under single-direction grazing light reliably coincide with physical grooves, whereas under cross-lighting, additional luminance concavities appear over convex ridges, potentially leading to false concavity impressions [10].

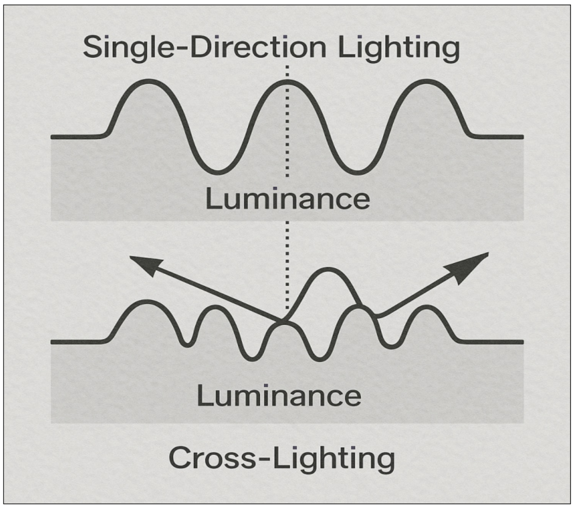

Figure 2. Schematic correspondence and mismatch between luminance curvature and surface concavity on a wavy wall panel under single-direction and cross-lighting (compiled by the author based on his own research)

Material-oriented studies refine the understanding of how viewers experience such panels once shape cues are established. Work by T. Huang and by S. Kwak and K. Choi demonstrates that colour, texture and material combinations strongly modulate impressions of naturalness, warmth, softness and arousal [3, 5]. When volumetric panels employ wood, wood-like finishes, or warm-toned coatings, lighting with a warmer colour temperature and controlled brightness gradients tends to align the perceived warmth of the material with its expected tactile qualities. Cooler, high-intensity light, even if it reveals relief clearly, may reduce the perceived naturalness of wood surfaces and accentuate every irregularity in gypsum, producing a more technical and less welcoming atmosphere.

Figure 3 generalises these results for relief applications: increasing proportion of warm-toned, wood-textured areas on a panel corresponds to higher ratings of warmth and trendiness up to a certain threshold, beyond which visual complexity rises and can cause overstimulation; brightness level modulates this relationship so that brighter scenes shift evaluations toward softness and comfort, whereas darker yet contrast-rich scenes enhance stimulation and drama [3, 5].

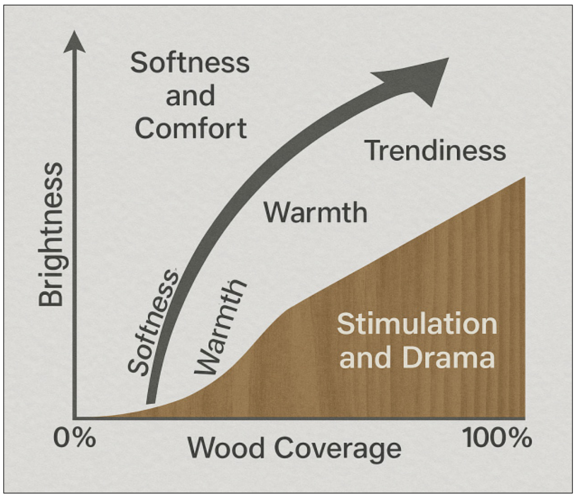

Figure 3. Conceptual dependence of perceived warmth, softness and arousal on wood coverage and brightness level for wall-integrated relief compositions (compiled by the author based on his own research)

Evidence from the systematic review of school visual environments and from studies on lighting and spatial perception, broadens the perspective from local surface evaluation to global spatial behaviour [8, 9]. Balanced lighting of vertical boundaries has been shown to contribute to orientation, comfort and health-related outcomes in educational settings, while strong visual accents, if placed strategically, can guide movement and attention. For volumetric wall panels, this implies that lighting design should consider not only the panel itself but its function in the spatial narrative: leading users toward focal points, articulating thresholds or providing calm background structure. Directional lighting of relief should therefore be integrated into a hierarchy of luminance levels across the interior rather than treated as an isolated effect.

At the same time, visual comfort literature warns that exaggerated contrast and glare are detrimental across user groups, especially when tasks demand sustained attention [8]. Panels with deeply modelled relief, when illuminated by high-intensity grazing spotlights, can introduce glitter-like highlights on sharp edges and deep shadows in grooves, creating stressful luminance distributions. The art-historical and experimental insights of E. A. Cooper and colleagues show that artists have long exploited such contrasts to create expressive illusions of floating objects and strong chiaroscuro [2]. In functional interiors, such strategies need moderation: dramatic lighting that would be appropriate for a gallery-type setting may overload workspaces or educational environments.

A further implication arises from the research of Z. J. Isherwood and co-authors on interactions between gloss, texture and colour [4]. Even when panels are nominally matte, slight differences in coating or surface finish introduce micro-specularities that behave differently under various lighting angles. Raking light accentuates these micro-highlights, sometimes fragmenting the perceived material unity of the panel, whereas softer, more frontal illumination supports stable colour appearance closer to the intended pigment. When sculptural panels are partially glazed or combined with polished inserts, lighting design must anticipate such interactions to avoid incoherent patches of excessive sparkle against otherwise soft relief.

Considering these findings together suggests a set of design-oriented interpretations. For panels intended as strong focal elements—for example, behind a reception desk or in an exhibition space—a combination of directional grazing light with carefully tuned intensity can emphasise depth and accentuate the narrative content of the relief, drawing on principles of depth scaling from shadow offset and the expressive use of cast shadows documented in visual experiments [1, 2]. For panels located in areas of prolonged stay, such as living rooms, classrooms or lounges, more moderate directional components superimposed on diffuse base lighting are preferable, so that the relief remains legible without dominating the visual field or introducing excessive flicker during movement.

The thesis by S. Stefanopoulou on lighting and spatial perception reinforces the idea that gradual luminance gradients on vertical surfaces support intuitive navigation and depth appraisal [9]. When volumetric panels extend over large wall areas, using linear wall-washers or continuous cove lighting that creates smooth vertical or horizontal gradients aligns with these findings, mainly if accent spots are used sparingly at compositional centres. Such arrangements allow the sculptural relief to contribute to perceived spaciousness and depth without fragmenting the interior into isolated bright and dark patches.

Ultimately, the reviewed literature emphasises the importance of considering volumetric wall panels as a testing ground for applying insights from vision science in practical design. Experiments on shape-from-shading, luminance curvature and material cues were typically conducted on abstract stimuli; transferring their logic to architectural relief encourages more precise control over how panels will be perceived across different vantage points. When designers treat light not as a secondary accessory but as an integral component of the sculptural composition, guided by empirically grounded principles, the resulting interiors achieve a more stable and predictable relation between physical modelling and subjective visual experience.

CONCLUSION

The conducted analytical study shows that the perception of volumetric wall panels strongly depends on how lighting scenarios structure information about shadows, shading gradients, contours and material cues. Depth judgments rely on cast shadow offset and luminance curvature, so directed lighting that generates coherent gradients and transparent contact shadows enhances perceived relief height. In contrast, diffuse illumination compresses depth and reduces sculptural expressiveness. Material and colour evaluations respond to combinations of surface texture, gloss, and spectral composition of light. Warm, moderately bright lighting supports impressions of warmth and softness for wood-like or gypsum surfaces, while cooler and more contrast-rich configurations emphasise texture and stimulation.

Evidence on indoor visual environments and spatial perception indicates that such effects cannot be considered in isolation from visual comfort and spatial hierarchy. Balanced luminance distributions with controlled contrast and absence of glare contribute to comfort and health-related outcomes. At the same time, targeted accents on relief panels guide attention and orientation when integrated into a consistent luminance hierarchy.

From a practical standpoint, the results justify several design recommendations. First, lighting for sculptural panels should be planned in conjunction with relief morphology, ensuring that critical concavities, convexities, and self-occluding contours receive stable shading consistent with the intended geometry, rather than relying on post-hoc placement of luminaires. Second, accent lighting should use directions and intensities that preserve coherent luminance curvature and avoid conflicting gradients produced by uncoordinated cross-lighting. Third, selection of colour temperature and brightness needs to account for the material character of the panel and the functional profile of the space, balancing the expressiveness of relief with the requirements of visual comfort.

Such an approach connects theoretical insights from vision science with everyday design decisions, enabling interior and lighting designers, as well as sculptors working with architectural relief, to predict how specific lighting scenarios will shape visual perception of volumetric wall panels and to use this knowledge in creating interiors where sculptural surfaces and light form a unified perceptual whole.

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