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The Integration of Color Psychology in the Construction Industry: A Multidisciplinary Review from Architectural, Civil Engineering, and MEP Perspectives

Integrasi Psikologi Warna dalam Industri Konstruksi: Tinjauan Multidisiplin Berbasis Arsitektur, Teknik Sipil, dan Sistem MEP

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ABSTRACT

The modern construction industry confronts complex challenges that require the built environment to transcend mere structural compliance and actively promote psychological well-being, productivity, and human safety. This study explores the integration of color psychology as a fundamental element in the engineering of the built environment through a multidisciplinary approach encompassing Architecture, Civil Engineering (specifically Occupational Health and Safety/OHS), and Mechanical, Electrical, and Plumbing (MEP) engineering. Drawing upon a systematic literature review following the PRISMA guidelines for structured article identification and screening, and conceptual synthesis, the findings indicate that color operates as a crucial neurobiological catalyst. Within architecture, color modulates cognition, emotion, and thermal perception (examining the hue-heat hypothesis and thermal reflectance index). In civil engineering and OHS, standardized color coding elicits heuristic responses for instantaneous hazard mitigation on-site, specifically serving to minimize visual work fatigue. Furthermore, in MEP engineering, color is utilized as an ontological mapping system to navigate critical infrastructure; this is subsequently integrated with Building Information Modeling (BIM) to facilitate spatial conflict resolution. The synergy of these disciplines, further supported by Human-Centric Lighting (HCL), is proposed as a holistic framework for optimizing the building life cycle and ensuring worker safety.

Keywords: *Color Psychology; Construction Industry; Occupational Health and Safety; Built Environment; Building Information Modeling (BIM); Thermal Comfort; Human-Centric Lighting.*

ABSTRAK

Industri konstruksi modern menghadapi tantangan kompleks yang menuntut lingkungan binaan untuk tidak sekadar memenuhi standar struktural, melainkan juga mendukung kesejahteraan psikologis, produktivitas, dan keselamatan manusia. Penelitian ini mengeksplorasi integrasi psikologi warna sebagai elemen fundamental dalam rekayasa lingkungan binaan melalui pendekatan multidisiplin yang mencakup Arsitektur, Teknik Sipil (Keselamatan dan Kesehatan Kerja/K3), serta rekayasa Mechanical, Electrical, and Plumbing (MEP). Berdasarkan tinjauan literatur sistematis yang mengikuti panduan PRISMA untuk identifikasi dan penyaringan artikel secara terstruktur, serta sintesis konseptual, temuan menunjukkan bahwa warna berfungsi sebagai katalisator neurobiologis yang krusial. Dalam arsitektur, warna memodulasi kognisi, emosi, dan persepsi termal (menguji hue-heat hypothesis dan indeks reflektansi termal). Pada teknik sipil dan K3, standar pengkodean warna memicu reaksi heuristik untuk mitigasi bahaya secara instan di lapangan, khususnya guna meminimalisasi visual work fatigue. Sementara itu, pada rekayasa MEP, warna difungsikan sebagai sistem pemetaan ontologis untuk navigasi infrastruktur kritis, yang diintegrasikan lebih jauh melalui Building Information Modeling (BIM) untuk resolusi konflik spasial. Sinergi seluruh disiplin ini, yang turut

didukung oleh pencahayaan Human-Centric Lighting (HCL), diusulkan sebagai kerangka kerja holistik untuk mengoptimalkan siklus hidup bangunan dan keselamatan pekerja.
Keywords: *Psikologi Warna, Industri Konstruksi, Keselamatan Kerja, Lingkungan Binaan, Building Information Modeling, Kenyamanan Termal, Pencahayaan Berpusat pada Manusia.*

Introduction

The global construction industry is currently undergoing a fundamental transformation. With its market capitalisation projected to exceed USD 15.5 trillion by 2030 (National Institutes of Health, 2024), the architecture, engineering, and construction (AEC) sector can no longer be managed merely as a rigid, mechanistic assembly of structural materials. Conversely, modern paradigms necessitate the recognition of the built environment as an interface that interacts directly with human cognition, physiology, and psychological well-being.

Among the vast spectrum of design elements, safety engineering, and material innovations that constitute a building, colour occupies a position that is both paramount and frequently misinterpreted. Transcending its primitive function as a mere aesthetic coating, colour serves as an environmental signal that functions as a neurobiological catalyst. The processing of colour by the human central nervous system directly influences emotional responses, regulates levels of alertness, modulates the perception of spatial thermal efficiency, and dictates on-site productivity and occupational safety.

Psychologist Carl Jung postulated that colour represents the 'mother tongue' of the human unconscious (WorkDesign Magazine, 2025); given that the subconscious governs 95% of cognitive functions and processes up to 20 million environmental stimuli per second, colour acts as a vital signal regulating stress hormones such as cortisol and adrenaline. A comprehensive analysis of colour spectrum applications within the construction landscape reveals that various disciplinary pillars—primarily Architecture, Civil Engineering (encompassing Occupational Health and Safety, or OHS), and MEP (Mechanical, Electrical, and Plumbing) engineering—possess distinct epistemological foundations and tactical approaches, yet remain fundamentally interdependent. The objective of this paper is to formulate a novel conceptual framework regarding the significance of holistic colour management in modern built environment engineering by bridging the interdisciplinary silos between these technical fields.

Research Methods

This study employs a methodology comprising a Systematic Literature Review (SLR) adhering to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and conceptual synthesis. The PRISMA framework was utilized to ensure a transparent and reproducible process in identifying, screening, and including relevant literature. Data were sourced from a diverse range of academic literature. Data were sourced from a diverse range of academic literature, neurobiological empirical studies, international and national regulatory standards (such as OSHA, ANSI, ASME, and the Indonesian National Standard/SNI), and Building Information Modelling (BIM) implementation guidelines. The analysis focuses on mapping the functions and impacts of colour across three primary construction disciplines:

(1) Architecture, with an emphasis on spatial psychology and building physics thermodynamics;

(2) Civil Engineering, focusing on operational Occupational Health and Safety (OHS) management;

and (3) Mechanical, Electrical, and Plumbing (MEP) Engineering, centred on spatial utility navigation. Subsequently, an interdisciplinary synthesis was developed to evaluate how the intersections of these three disciplines are coordinated through digital technologies and the manipulation of spatial illumination.

Results and discussion

1.1 Structured Summary of Reviewed Literature

To establish a consistent evidence base for the multidisciplinary integration of color psychology, this study systematically reviewed key literature. A summary of the primary studies supporting the conclusions in this manuscript is presented in Table

Table 1

Author(s) & Year	**Discipline Focus**	**Objective**	**Key Findings / Evidence Base**
Yi et al. (2012)	Civil / OHS (Occupational Health and Safety)	To suggest color schemes reducing perception-related accidents.	Specific color modifications on site facilities mitigate cognitive fatigue and restore spatial orientation.
Levinson et al. (2019)	Architecture	To evaluate benefits of solar-reflective cool walls.	High-albedo colors reflect radiation, but climate-specific adaptations are

			needed for thermal efficiency.
Rhamadana (2022)	Architecture	To analyze the effect of room color on thermal comfort.	Spatial color manipulation directly influences microclimate perception and worker productivity.
Putri & Albyn (2026)	Civil / OHS (Occupational Health and Safety)	To review OHS human resource completeness in safety systems.	Competent OHS personnel are vital for ensuring visual safety codes are consistently understood.

1.2 The Neurobiological Underpinnings and Cognitive Processing of Colour Signals

An understanding of the function and significance of colour within the built environment must originate from fundamental human anatomical and neurobiological foundations. Light enters the eye through the cornea, where the iris muscles regulate the quantity of photons reaching the retina; this structure houses photoreceptor cells, specifically rods for low-light conditions and cones for chromatic variations. Decoded optical signals are subsequently transmitted to the visual cortex, which instantaneously channels the data to be integrated with emotional, mnemonic, and cognitive cues. The human brain responds to the built environment by scanning colour signals long before rational analytical processes are formed, a reaction triggered within 90 seconds of initial exposure. Furthermore, prolonged exposure to environments featuring destabilizing colours has been demonstrated to stimulate the adrenal glands to release adrenaline and cortisol, potentially leading to chronic anxiety and clinical depression.

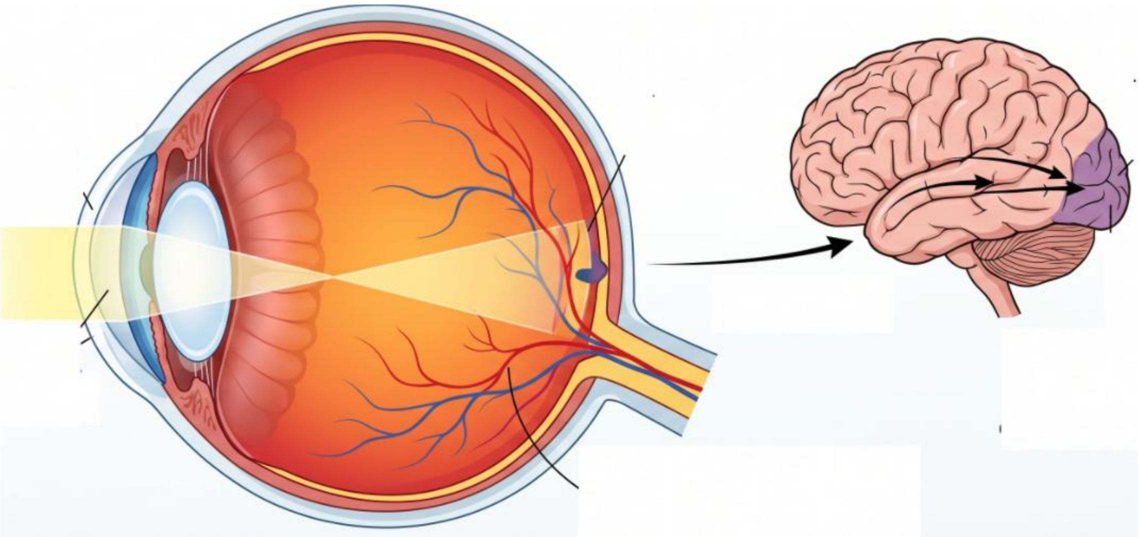

Figure 1.1. The fundamental neurobiological basis of color processing, from the eye to the brain. The illustration depicts how light enters the cornea and is decoded by photoreceptors into variations of hue
(Source. Corporate Environments, n.d.).

Beyond immediate stress hormone responses, imbalances in colour and lighting stimuli within the built environment contribute significantly to the accumulation of occupational fatigue. Disruptions to circadian rhythms resulting from inappropriate visual stimuli not only diminish productivity but also correlate closely with impaired sleep quality and chronic fatigue among workers (Sandi, 2026). Consequently, the regulation of the colour spectrum in architecture serves as a medical preventive measure to maintain the cognitive homeostasis of employees.

In the future, neurobiological analyses of colour exposure will no longer rely solely on post-construction observation; rather, they may be projected through neurochemistry-based computational modelling. This computational approach enables engineers to map and simulate the dynamics of neural network interactions—such as fluctuations in stress hormone release induced by specific visual colour exposures—within a virtual system (Ramadhan et al., 2025). By integrating this neurochemical modelling framework into spatial engineering, the potential for anxiety or mental fatigue in construction workers can be quantitatively predicted from the pre-construction phase.

1.3 Architectural Dimensions: Psychology of Space, Functional Aesthetics, and Thermal Environment

In the field of architecture, colour functions as an instrument for manipulating spatial perception, wayfinding, and physiological stimuli. Functional Magnetic Resonance Imaging (fMRI) research reveals that warm colours, such as red, activate the amygdala, thereby increasing heart rate and alertness. Conversely, cool colours (blue/green) engage the prefrontal cortex, which facilitates analytical thinking and the mitigation of mental fatigue.

Beyond the emotional dimension, colour influences the perception of physical microclimates through the hue-heat hypothesis. However, research conducted by the Master of Architecture Programme at the Institut Teknologi Bandung (ITB) in Indonesia indicates that the public does not rigidly adhere to this hypothesis; purple, for instance, was evaluated as a hue that evokes warmth. The same study asserts that for these perceptions to function effectively, a space necessitates an adequate level of illumination—recommended to be above the 350–400 lux standard—to ensure optimal optical identification.

Regarding building exteriors, Solar Reflectance Index (SRI) and Albedo values are critical determinants of HVAC cooling loads. The selection of roofing and facade materials significantly influences the Urban Heat Island (UHI) phenomenon. Although white roofs effectively reflect solar radiation, contemporary research indicates the necessity for climate-specific approaches (such as the use of EPDM membrane roofing) in cold climates (ASHRAE Zones 4–8) to prevent internal heating deficits that increase fossil fuel consumption during winter.

Psychological well-being within construction and corporate environments results from the complex interaction between physical environmental factors and an individual's internal condition. Research demonstrates that occupational burnout has a significant correlation with stress levels and the quality of rest (Sandi, 2026). This reinforces the premise that the manipulation of spatial colour to induce tranquillity—specifically through the use of cool tones to activate the prefrontal cortex—constitutes a clinical necessity in modern spatial engineering.

1.4 Architectural Dimensions: Spatial Psychology, Functional Aesthetics, and Thermal Comfort

The construction industry represents an environment of extreme hazard volume. Two out of every five construction workers on heavy infrastructure sites frequently experience symptoms of depression and anxiety, which correlate linearly with impaired motor reflexes and occupational accidents. Within this context, the discipline of Civil Engineering utilises colour as a proactive mitigation tool.

Table 2

Safety Colour Classification

Colour	Significance	Application
Yellow	Alert; enhancing situational awareness	Barriers and high-exposure zones

Colour	Significance	Application
Red	Safety hazards and restrictions; emergency protocols	Emergency stop, Fire extinguisher
Green	Safe; calming effects	Evacuation route, Assembly point

Note: Safety colors comply with OSHA, ANSI Z535.1, and SNI 13-6351-2000 standards, which account for human visual and psychological responses to color.

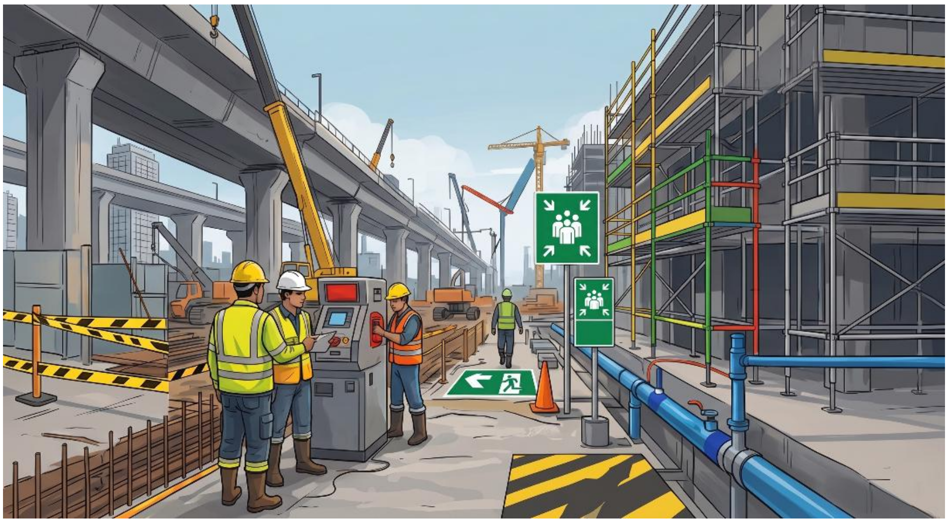

Figure 1.2 Illustration of an active physical construction site featuring heavy infrastructure, where safety color standards are applied for proactive hazard mitigation (Source. Yi et al., 2012).

In project sites characterized by environmental homogeneity and the prevalence of visual work fatigue syndrome, chromatic intervention is imperative. A seminal study by June-Seong Yi et al. demonstrates that specific color palette modifications applied to five temporary construction facilities workwear, safety nets, gondolas, scaffolding, and walkways effectively mitigate the degradation of cognitive rhythms and restore workers' spatial orientation. Furthermore, considering that corneal lens degeneration in veteran workers often results in yellowing, which impairs the perception of the blue spectrum, safety palettes must avoid a reliance on bluish hues in rugged field environments.

Moreover, the successful implementation of these safety color codes is inextricably linked to the competence and supervisory capabilities of Occupational Health and Safety (OHS) personnel. As emphasized in recent literature, the adequacy and readiness of OHS human resources constitute the primary pillars in enhancing the effectiveness of Safety Management Systems (SMS) and mitigating risks within high-level operational environments (Putri & Albyn, 2026). Within the context of construction engineering, the OHS function utilizes color as a proactive mitigation tool. Consequently, competent OHS personnel are essential to ensure that such chromatic visual instruments not only meet regulatory compliance standards but are also consistently understood and correctly acted upon by field workers.

1.5 Mechanical, Electrical, and Plumbing (MEP) Engineering

Mechanical, Electrical, and Plumbing (MEP) systems typically account for 20% to 40% of the aggregate project budget, functioning as a concealed labyrinth that transports vital yet potentially destructive utilities in close proximity. Absent the codification of infrastructural piping hierarchies—such as those prescribed by ASME/ANSI A13.1-2020 and SNI 19-3778-1995—technicians are confronted with a perilous maze. In this context, color serves as a heuristic shortcut command for the brain's instantaneous biological identification system:

- Yellow Background with Black Text: Highly flammable and extreme-risk gases.
- Safety Blue: Potable water utility lines.
- Purple or Faded Green: Non-potable degraded water, designated to mitigate the risk of cross-contamination catastrophes.
- Blood Red: High-pressure fire suppression residue conduits.

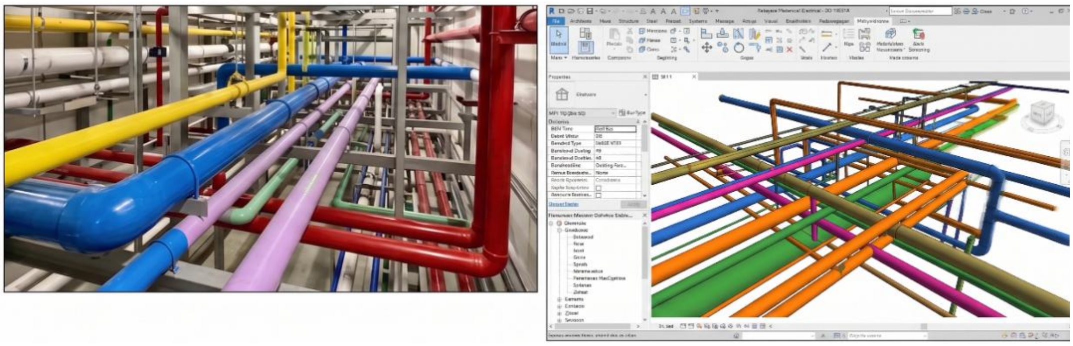

Figure 1.3 Illustration of Piping Design Planning
(Source. General Services Administration, 2021)

Modern design is frequently impeded by spatial conflicts between architectural, civil, and MEP disciplines, a phenomenon known as the Silo Fragmentation Dilemma. To mitigate this, centralised Building Information Modeling (BIM) methodologies—governed by standards such as ISO 19650—are implemented. BIM integrates a Parametric RGB Color Mapping scheme, wherein piping systems are represented through absolute RGB coordinates (e.g., Sanitary Sewerage designated as RGB 255,127,0). This allows visual algorithms to immediately highlight virtual element collisions (clash detection resolution), bypassing the delay of semantic translation within the operative's cognition.

The efficacy of this material colour spectrum is highly contingent upon lighting intervention. In the contemporary era, construction activities are increasingly shifted to nocturnal shifts to facilitate Nighttime Highway Construction Congestion Relief. Human-Centric Lighting (HCL) addresses the circadian fatigue syndrome of night workers by emitting a sharp, blue-spectrum Correlated Color Temperature (CCT) during the early morning hours. This manipulation of CCT suppresses melatonin secretion and sustains worker alertness, thereby enhancing safety and productivity to levels commensurate with diurnal rhythm standards.

Conclusion

The integration of the psychological, anatomical, and physiological roles of color within the logistical framework of contemporary architectural and construction engineering has transcended mere aesthetic supplementation; it now constitutes an essential interdisciplinary conceptual approach to ensuring building longevity and operational viability. The dynamics of chromatic utility necessitate a cross-sectoral fusion: Architecture manipulates emotion and thermodynamics; Civil and Occupational Health and Safety (OHS) infrastructure leverages primate heuristic reactions through standardized warning colors for life-safety mitigation; and MEP Engineering employs color as a logical mapping tool to avert utility-related catastrophes. Ultimately, this holistic collaboration must be consolidated within high-resolution virtual environments (BIM) and physiologically synchronized via circadian rhythm interventions from Human-Centric Lighting systems. This multidisciplinary understanding is the cornerstone of a future in design and construction that is not only efficient but fundamentally human-centric.

Suggestion

Based on the synthesis of the literature review and the multidisciplinary findings of this study, several critical areas requiring exploration and development in future research have been identified:

- Integration of Artificial Intelligence (AI) and Computer Vision in OHS Colour Monitoring: The supervision of Personal Protective Equipment (PPE) compliance can no longer rely exclusively on human inspection. Further development is required in computer vision algorithms—such as YOLOv8 models or alternative deep learning approaches—specifically trained to detect high-visibility colours of helmets and vests in real-time. This technological innovation offers significant prospects for providing automated alerts regarding anomalies or violations within construction 'red zones'.

- Inclusive Construction Safety Design (CVD Accessibility): Given that approximately 300 million people worldwide experience Color Vision Deficiency (CVD), Occupational Health and Safety (OHS) warning signs and piping layouts must transcend reliance on colour as the sole signifier. Future research is encouraged to develop visual engineering standards that combine adaptive contrast ratios with cue redundancy (such as hatching patterns and distinct geometric iconography), ensuring safety elements are accurately interpreted by workers with colour vision impairments.
- Optimisation of Integrated Human-Centric Lighting (HCL) in Extreme Environments: The physiological impact of dynamic lighting—characterised by fluctuating light intensity and daily Correlated Colour Temperature (CCT) variables—has not been fully explored within physical construction sites. Further empirical studies are necessitated, particularly in extreme infrastructure projects isolated from natural daylight (e.g., underground tunnelling), to measure correlations between lighting, post-shift sleep quality, worker energy levels, and productivity index fluctuations.
- Examination of Moderating and Cross-Cultural Variables: The implementation of interior colour schemes is frequently influenced by demographic and social biases. Future interior design research should synthesise colour application guidelines that account for moderating variables, including regional cultural contexts, specific saturation adjustments, and the impact of varied lighting combinations across diverse demographic groups.
- Conflict Resolution Management in BIM Ecosystems via Network Analysis: Although Building Information Modelling (BIM)—utilising RGB colour-coded mapping standards—promises seamless visualisation, fundamental issues persist regarding coordination levels, interdisciplinary trust (Architecture vs. Civil vs. MEP), and role identification. Studies employing mixed-review methods and quantitative approaches, such as Social Network Analysis (SNA), are highly recommended to deconstruct and enhance the collaborative ecosystem among stakeholders during project implementation.
- Computational Modelling for Neurobiological Worker Simulation: Future multidisciplinary research must bridge the gap between architectural intervention and computational engineering. Subsequent studies are expected to develop algorithmic models that specifically simulate the interaction between colour spectrum (RGB) variations in BIM models and the projected neurochemical responses of users (Ramadhan et al., 2025). This trajectory holds the potential to generate advanced Digital Twin ecosystems

that not only detect spatial utility clashes but also calculate and mitigate potential psychological 'clashes' among workers.

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