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Methodological Analysis of Color Research in the Built Environment

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Abstract

Color in the built environment is a fundamental environmental variable that directly shapes human psychology, physiology, and spatial perception processes. Based on an original quantitative matrix compiled from 54 empirical articles published between 1990 and 2025, this study analyzes the methodological evolution and structural patterns of research examining color parameters in the built environment over the past thirty-five years. Within the scope of the collected dataset, descriptive frequency and multiple-response cross-tabulation analyses were conducted using SPSS.The findings reveal a significant chronological acceleration in color studies, heavily concentrated on educational and office typologies. Methodologically, a structural transition is documented from traditional full-scale mock-ups toward immersive virtual reality environments, accompanied by a shift from subjective psychological scales to objective neurophysiological measurements such as EEG. Statistical analysis confirms that user-oriented emotional and affective dimensions represent a time-independent, dominant core outcome, whereas spatial perception and direct behavioral variables constitute chronic literature gaps. Finally, a widespread reporting omission regarding international color standardization systems is identified, undermining methodological replicability in environmental design.

Keywords: *Color Research, Built Environment, Empirical Research Methods, Methodological Analysis, Color Effects.*

Yapılı Çevre Renk Araştırmalarında Kullanılan Yöntemlerin Analizi

Öz

Yapılı çevrede renk, insan psikolojisi, fizyolojisi ve mekânsal algı süreçlerini doğrudan biçimlendiren temel bir çevresel değişkendir. Bu çalışma, 1990–2025 yılları arasında yayınlanmış 54 ampirik makaleden derlenen özgün bir nicel matris üzerinden, yapılı çevrede renk parametrelerini inceleyen araştırmaların son otuz beş yıllık metodolojik evrimini ve yapısal örüntülerini analiz etmektedir. Toplanan veri seti kapsamında SPSS ortamında betimsel frekans ve çoklu tepki çapraz analizleri yürütülmüştür. Bulgular, renk çalışmalarında kronolojik olarak bir ivmelenme olduğunu ve bu çalışmaların ağırlıklı olarak eğitim ve ofis tipolojilerinde yoğunlaştığını ortaya koymaktadır. Metodolojik açıdan, geleneksel tam ölçekli deneysel odalardan (mock-up) sanal gerçeklik ortamlarına doğru yapısal bir geçiş belgelenmiş, bu sürece öznel psikolojik ölçeklerden EEG gibi nesnel nörofizyolojik ölçümlere doğru bir kayma eşlik etmiştir. İstatistiki analizler, kullanıcı odaklı duyuşsal ve duygusal boyutların dönemlerden bağımsız, baskın bir temel sonuç olduğunu, mekansal algı ve doğrudan davranışsal değişkenlerin ise kronik literatür boşlukları oluşturduğunu göstermektedir. Son olarak, uluslararası renk standardizasyon sistemlerine ilişkin yaygın bir raporlama eksikliği tespit edilmiş olup, bu durum çevresel tasarımda metodolojik tekrarlanabilirliği zayıflatmaktadır.

Anahtar kelimeler: *Renk Araştırmaları, Yapılı Çevre, Deneysel Araştırma Yöntemleri, Metedolojik Analiz, Renk Etkisi.*

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1. Introduction

Sommer (1969) emphasized the reciprocal relationship between humans and the built environment, arguing that individuals shape their living environments according to their needs and aspirations, while the transformed physical environment, in turn, plays a decisive role in shaping human perceptions, attitudes, and behavioral patterns. Among the various components of the built environment, color is undoubtedly one of the most influential. The remarkable ability of the human visual system to discriminate approximately 2.5 million different color shades (Linhares et al., 2008) enhances the potential of color to create unique, dynamic, and multilayered effects on architectural surfaces and within three-dimensional spaces.

Color is a dynamic phenomenon that encompasses multifaceted functions across both the physical and psychological dimensions of human experience, serving as a signifier and a mechanism of impact across a broad spectrum ranging from visual value generation to wayfinding, the shaping of affective states to cognitive focus, and the appreciation of spatial quality to human behavior (Elliot&Maier, 2014; Valdez & Mehrabian, 1994). Color, which enhances spatial diversity, facilitates the differentiation of architectural elements, and highlights specific areas, serves as a fundamental instrument in constructing the intended atmosphere and mood within a design. (Güneş & Olguntürk, 2020; Jaglarz, 2024).

In this context, research on color effects spans a broad and interdisciplinary literature encompassing many fields such as psychology, neurophysiology, architecture, and interior design (Hurlbert & Ling, 2007; Elliot & Maier, 2014). Drawing from diverse scientific methods, these studies start from different fundamental questions and utilize different techniques and conceptual tools (Anter & Billger, 2010). One of the most dynamic domains where this interdisciplinary theoretical framework materializes and directly intersects with human experience is architectural interiors. When abstract color theories at the macro scale are translated into the interior scale, wall surfaces in particular transform into environmental stimuli, becoming objects of rational empirical research. At this point, the 'contextual role' of color in interior color research comes to the fore as a critical distinction in terms of empirical validity. Because a color experience within an architectural context with a specific function (office, classroom, hospital room, etc.) produces different results than an isolated color stimulus in a laboratory environment. Therefore, the individual's exposure to environmental colors possessing a specific context directly directs their psychological well-being, mood, attention level, and spatial performance (Aksoy & Hidayetoğlu, 2019; Jonauskaite & Mohr, 2025). Indeed, in current interior-oriented empirical studies, the role of color is handled multi-dimensionally, and besides the affective relationships and behavioral orientations of color on human attitudes, its direct somatic effects on neurophysiological processes such as blood pressure, heart rate, and brain activities are comprehensively documented (Küller et al., 2006; Al-Ayashi et al., 2016; Llinares et al., 2021; Bower et al., 2022; Liu et al., 2022).

1.1. Historical Development of Color Research in the Built Environment

The empirical investigation of the effects of color stimuli on human psychology and physiology has a well-established experimental history spanning for over 100 years. Féré (1885; 1887) pioneered the field by conducting the first quantitative studies explicitly examining the influence of color on psychological and physiological functioning. Subsequently, Baldwin (1893) investigated how color stimuli elicited fundamental motor responses during early childhood, while Cohn (1894) carried out some of the earliest quantitative experiments exploring the positive and negative emotional responses evoked by different colors.

Early psychological studies on color perception and affective meanings are theoretically grounded in Wundt's (1897) dimensions of responses to stimuli, namely "pleasure, tension, and inhibition." These conceptual categories later provided a foundation for experimental research demonstrating that human judgments and environmental experiences are organized along the "pleasure, arousal, and dominance" (PAD) framework (Mehrabian & Russell, 1974). Eysenck (1941), in turn, documented this early historical accumulation of knowledge by presenting a comprehensive literature review spanning approximately forty to fifty years of experimental research and incorporating over 20,000 ratings.

Studies on the effects of environmental color have developed in parallel with the effects of space and environmental evaluations on people. Pressey (1921) found that there was no difference in the responses of warm and cold colors on the autonomic nervous system, whereas luminance increased performance speed. Guilford & Smith (1959), who examined the experimental background of color perception and preferences, were the first researchers to systematically study hue, value, and chroma parameters in order to measure affective component. Despite Guilford's approach, much of the color research conducted until 2010–2015 focused primarily on "hue," the most dominant dimension of color. However, current research proves that value (lightness) and saturation (chroma) also play equally critical roles in modifying psychological and physiological responses to environmental conditions, and that color effects can only be understood through the multiple interaction of these three dimensions (Elliot & Maier, 2014; Duyan & Işık, 2022; Liu, 2022; Duyan & Şener, 2025).

Since the second half of the 20th century onwards, measurement tools have diversified, and with the development of the Semantic Differential Scale by Osgood et al. (1957), interior colors have begun to be analyzed multi-dimensionally within this framework. Utilizing the Semantic Differential Scale (SDS), Sivik (1969) revealed the relationships between the perceptual dimensions of colors and their associative meanings. Similarly, Hogg (1969) employed the SDS to measure user perception in interiors, defining the dimensions of *dynamism, spatial quality, emotional tone, evaluation*, and *complexity.* During the same period, Inui (1969) advanced the empirical study of interior color by systematically documenting color characteristics in diverse interior environments, including hospitals, schools, hotels, cinemas, and residential spaces, using the Munsell system and subjective evaluations of color schemes. Küller (1972), on the other hand, developed new descriptive dimensions for evaluating environment and space through factor analysis. Tikkanen (1976) investigated the effects of color changes in school environments on students' emotions.Ruttenberg (1988) defended the role of color on environmental atmosphere and emotional balance, while Willumsen (1988) conceptualized the spatial effect of color at three levels as information/communication, emotional response, and aesthetic perception.

These pioneering researches presented in a chronological flow clearly show that the effects of the color stimulus on human psychology and physiology do not consist of a uni-dimensional preference norm, rather, they are shaped in a multi-layered structure hosting perceptual, cognitive, and somatic processes together. Therefore, grasping these versatile effects created by color components in the built environment on the user within a holistic theoretical framework prepares an appropriate ground for the examination of integrated 'attitude' models, which is one of the fundamental areas of environmental psychology.

1.2. Attitudes Towards Environmental Color Stimuli

Research in the field of interior environmental perception clearly demonstrates that spaces are not merely passive physical backdrops, rather, they function as active environmental stimuli capable of directly influencing users' behaviors, emotional states, and cognitive processes (Mehrabian & Russell, 1974; Evans, 2003; Bower et al., 2022). According to the Mehrabian and Russell (M-R) model developed within this framework, stimuli originating from the physical environment (such as color, light, and texture) play a central role in generating emotional states that, in turn, shape individuals' behavioral intentions, specifically approach or avoidance responses.

Human responses to the built environment and particularly to color stimuli as one of its most dominant components are conceptually framed within the attitude construct in social psychology and environmental psychology literature. "Attitude" is defined as a learned evaluative and response tendency toward a specific object, person, institution, or event. Environmental attitudes, in turn, refer to psychological orientations through which components of the built environment are perceived and evaluated as either positive or negative (Milfont & Duckitt, 2010). According to the "*Tripartite Model of Attitudes"* developed by theorists such as Allport (1954), Rosenberg & Hovland (1960), Hilgard (1980), and Ajzen (1993), responses to a stimulus are examined across three primary dimensions: affective, cognitive, and behavioral.

"The affective component" encompasses the emotional reactions an individual experiences toward color stimuli, such as liking or disliking, feelings of comfort, anxiety, and similar responses. For example, it is well documented that warm colors with high saturation tend to evoke feelings of arousal, alertness, and discomfort, whereas cool colors such as blue and green are associated with calmness, coolness, and relaxation (Küller et al., 2009; Siamionava et al., 2018; Büker & Kaynakçı Elinç, 2023). "*The cognitive component"* involves an individual's thoughts, perceptions, and mental evaluations of color stimuli, and it directly influences processes such as concentration, attention, and task performance. In the context of educational environments, cognitive capacity refers to students' ways of perceiving lectures, maintaining attention, and processing memory and comprehension (Dzulkifli & Mustafar, 2013). "*The behavioral component"* refers to actions performed within a space as a result of color stimuli, as well as performance outcomes and decisions to prefer or avoid a given environment.

A wide variety of experimental setups have been constructed in the literature of architecture, interior design, and psychology to measure these attitudes. The Semantic Differential Scale, developed by Charles E. Osgood and colleagues, has been widely used to quantitatively measure both the affective and cognitive dimensions of perception through bipolar adjective pairs (Osgood et al., 1957). In studies conducted along these lines, researchers have resorted to diverse data collection instruments and spatial simulation methods to evaluate user attitudes. For instance, in investigations carried out within full-scale (mock-up) experimental offices and workspaces, Ainsworth et al. (1993) examined job performance, anxiety, and arousal levels through standard office tests and psychological scales, while Kwallek et al. (1996) explored the effects of wall colors on mood and performance, and Stone & English (1998) alongside Stone (2001) researched the role of red and blue walls calibrated on reading comprehension success and spatial satisfaction. Similarly utilizing full-scale experimental spaces, Read et al. (1999) revealed the impact of different wall colors on the collaborative behaviors of children aged 3–5 in a preschool play environment through systematic video observations, whereas Küller et al. (2009) validated the emotional effects of office colors on users in a full-scale experimental room (mock-up) using neurophysiological methods such as pioneering EEG and ECG measurements. Wang & Russ (2008) examined the relationship between students' classroom wall color preferences and personality types by applying 15 different colors to the walls of a computer-simulated classroom, whereas Baytin et al. (2005), who conducted their study in-situ experiment, applied 32 different colors to the walls of an architectural studio on a weekly basis and monitored changes in students' performance and attention levels. Yıldırım et al. (2007) measured perceptual responses to wall color in a cafe-pastry shop atmosphere using the Semantic Differential Scale, and Genschow et al. (2015) analyzed the effect of Baker-Miller pink on prisoners' aggression levels in a real-world prison field study using institutional staff observation logs.

With the integration of neurophysiological methods, the relationships between color stimuli and somatic responses have been established on a more objective empirical basis. Consequently, physiological indicators such as autonomic nervous system activity, galvanic skin response (GSR), heart rate (ECG), electroencephalography (EEG) and respiratory rate have been increasingly employed to assess the effects of color stimuli (Al-Ayashi, 2016; Jacobs & Hustmyer, 1974).

Today, the influence of color in interior design is considered a significant variable that shapes a user's attitude towards the built environment through factors such as comfort, satisfaction, perceived spatial quality, and behavioral tendencies (purchasing, approach, etc.) (Bellizzi & Hite, 1992). Beyond the Tripartite Model of Attitudes, it is also methodologically important to distinguish two constructs that are frequently examined in the literature: "color preference" and "the effects of color on spatial perception". Color preference represents an individual's subjective evaluation of, satisfaction with, and aesthetic appreciation for a particular color stimulus or spatial color composition. As such, it can be regarded as an affective construct that reflects the pleasure dimension of emotional responses (Ou et al., 2004). On the other hand, spatial perception, which encompasses the optical and geometric effects of color within a space, refers to the cognitive capacity through which individuals process and interpret physical spatial attributes such as depth, spaciousness, width, and height based on visual

information. From this perspective, spatial perception can be conceptualized as a fundamentally cognitive process and a mechanism of spatial evaluation within the field of environmental psychology (Aksoy & Hidayetoğlu, 2019). Accordingly, empirical research on color typically treats color preference as an affective–aesthetic outcome, whereas changes in spatial perception are regarded as cognitive–spatial functions, thereby providing a comprehensive framework for understanding users' attitudes toward the built environment.

1.3. Aim and Scope of the Study

Despite the existence of a rich literature investigating the effects of colors on human reactions, these studies exibit a very large diversity and a fragmented structure from a methodological perspective. Researchers utilize controlled laboratory experiments, questionnaire-based field researches, full-scale mock-ups, and in recent years, digital simulation techniques extending from computer visualizations to immersive virtual reality (VR) environments. Although this methodological diversity enriches the field, it causes a lack of standardization in the operational definitions of colors (differences between color systems such as NCS, Munsell), the control level of environmental variables such as data collection tools (psychometric scales, performance tasks, or neurophysiological tools). This state of affairs restricts the comparability and generalizability of the findings (Elliot & Maier, 2014).

An examination of the existing literature reveals that reviews have predominantly been conducted from thematic perspectives, such as color-emotion relationships, functional spatial interactions, or general historical contexts (Savavibool & Moorapun, 2017; Elliot & Maier, 2007; Elliot, 2019; Coutinho & Akbay, 2023; Jonauskaite & Mohr, 2025). However, systematic reviews that comprehensively classify the strengths and limitations of the methodological approaches, data collection instruments, and spatial representation techniques used in built environment color research have not yet matured, leaving a gap in the literature with a methodological framework waiting to be clarified. Addressed in this direction, this study aims to fill this methodological gap by examining it through a structural lens, thereby contributing to the literature by providing a holistic guide for future empirical research.

The main objective of this study is to classify, compare, and analyze the methodological trends of data collection tools, spatial color presentation environments, and spatial functions used in empirical research methods examining the effect of color in the built environment. The historical progression of interior color research indicates that, with technological advancements, it has evolved from simple effect measurements towards more rational and multi-dimensional measurements. Accordingly, the study covers works published between the years 1990 and 2025 a period characterized by the qualitative and quantitative development of research techniques and accelerated scientific production conducted strictly within the contexts of diverse spatial functions (office, education, commercial, residential, etc.). The classification matrix has been constructed according to the attitudes of users (affective, behavioral, cognitive), the data collection tools utilized (task completion, psychometric scales, neurophysiological measurements), and spatial color representation methods (real space, mock-up, computer-aided visualization, virtual reality).

Since the focus of this research is on the methods employed in studies on the effects of interior colors, user-derived personal and demographic variables such as gender, occupation, and cultural background, which are frequently encountered in empirical studies, were excluded from the scope of this study. With this in mind, rather than a direct comparison of the quantitative results of the studies examined, this study aims to provide a structural analysis of the methodological designs, simulation techniques, and data collection tools applied.

2. Material and Method

This study investigates the methodological evolution and structural patterns of empirical color research in the built environment over a specific thirty-five-year period (1990–2025). A comprehensive literature review was conducted using databases such as Scopus, Web of Science (WoS), and Google Scholar. The search utilized the following keyword combinations: "color in interior space", "environmental color perception", "color effect", "color psychology built environment", "color and user behavior", and "color perception".In the first stage, publications retrieved from the databases

were screened, and only studies employing experimental designs were retained. In the second stage, each study was assessed to determine whether it investigated user perception, attitudes, or performance within a physical or simulated interior environment. Ultimately, 54 original research articles that met the inclusion and exclusion criteria and focused on different spatial functions and empirical measurement methods were included in the final dataset.To analyze the structural trends within this dataset, an original quantitative coding and matrix system was developed. The methodological characteristics of the selected 54 articles—including spatial functions, presentation formats, measured dependent variables, and data collection instruments—were transformed into standardized categorical data. This compiled matrix was then transferred to SPSS software to perform advanced quantitative evaluation. Descriptive frequency analyses were conducted to map chronological shifts, and multi-response crosstabulation (multiple response analysis) combined with Pearson Chi-Square (χ^2) independence tests was executed to detect statistically significant correlations between historical periods, spatial mediums, and investigated user outcomes (Figure 1).

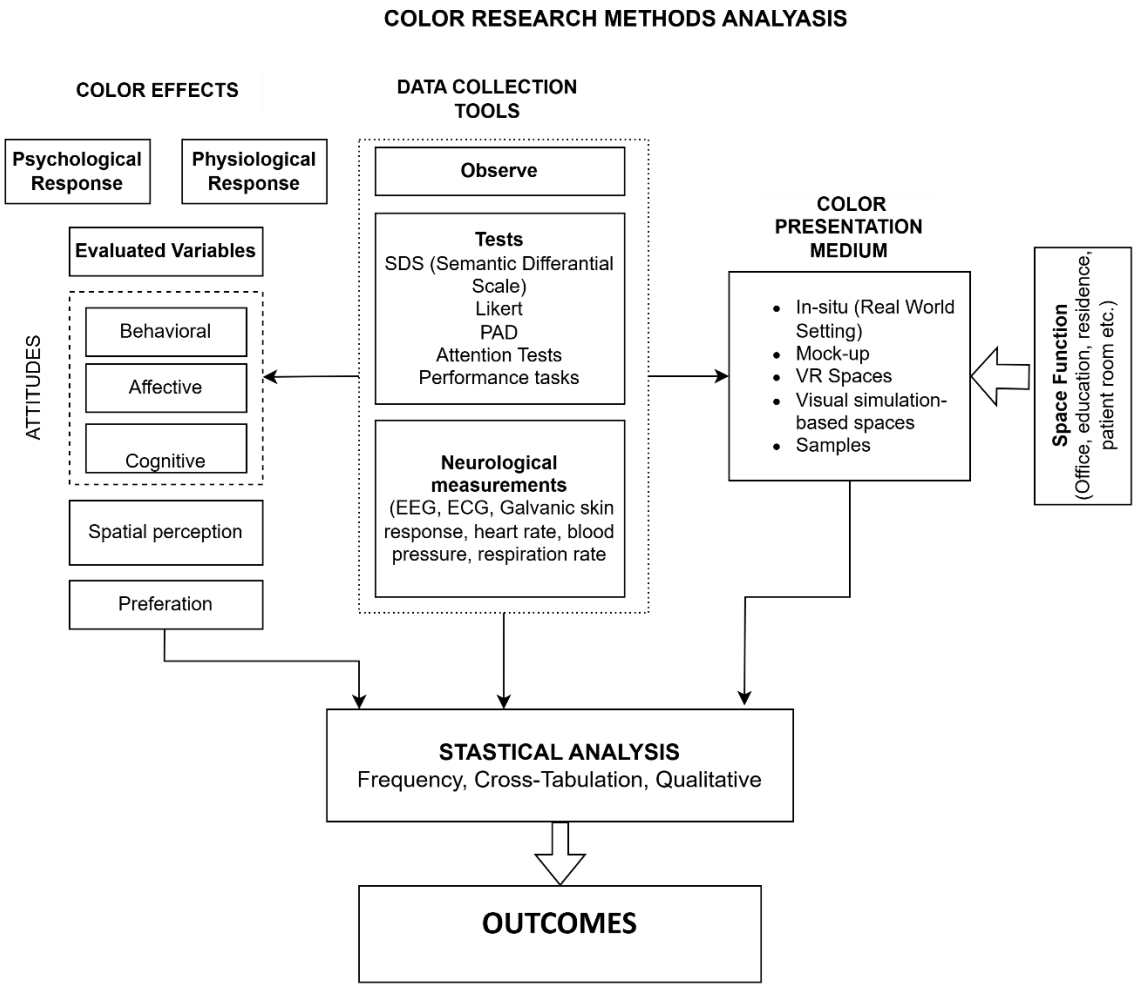


Figure 1. Conceptual framework of methodological trends and variables in built environment color Research analysis (Created by the author)

2.1. Spatial Color Evaluation and Presentation Methods

Experimental methods in color research are designed to isolate causal relationships between color stimuli as independent variables and human responses as dependent variables under controlled environments. The selected studies implement these approaches across four primary presentation mediums:

In Situ (Field Studies / Real-World Settings): Conducted in real-world settings to examine the natural interaction between users and spatial colors. While offering the highest ecological validity, its presence

is relatively limited in the dataset due to operational challenges in controlling ambient lighting and environmental parameters.

Mock-Up and Controlled Laboratory Settings: Studies where researchers systematically manipulate color attributes (hue, value, chroma) in standardized physical spaces or color booths while holding confounding variables (CCT, CRI, acoustics, air quality) constant.

Visual Simulation-Based Environments and Virtual Reality (VR): Digital 3D modeling (e.g., 3ds Max) where color schemes are applied to virtual surfaces. Participants experience these environments via screen projections or immersive VR headsets, simulating spatial presence and real-time movement.

Isolated Color Samples and Standardized Color Charts (Swatches): Studies relying on physical color chips or standardized systems (e.g., Munsell, NCS, RAL) associated with contextual, cognitively imagined spatial scenarios.

2.2. Data Collection Instruments

The data collection instruments analyzed within the research matrix are categorized based on the subjectivity/objectivity of the measured user responses and the targeted psychological or physical dimensions:

2.2.1. Affective measurement methods (affective measurements: mood, emotion, and color preference)

Structured psychometric instruments are commonly employed to measure users' subjective evaluations, psychological attitudes, and preferences toward specific interior color conditions.

Semantic Differential Scale (SDS): Participants rate color conditions using bipolar adjective pairs (e.g., Warm–Cool, Spacious–Confined) on 5- or 7-point scales to transform semantic spatial dimensions into quantitative data (Osgood et al.; 1957).

Likert Scales: These consist of structured statements designed to measure users' levels of agreement regarding color preference, perceived spatial comfort, and environmental experience, ranging from *"strongly disagree"* to *"strongly agree."*

Emotional Response and Mood Scales (PAD and Profile-Based Instruments): Standardized instruments including the PAD (Pleasure–Arousal–Dominance) emotional state model, (Mehrabian & Russell; 1974), POMS (Profile of Mood States), and choice-oriented ranking tests to capture affective fluctuations across different spatial functions.

Color Preference and Choice-Oriented Measures: These are ranking or preference tests that identify users' aesthetic preference patterns and emotional associations by determining which color or color composition they associate with specific spatial functions (e.g., hospitals, residential settings, or workplaces).

2.2.2. Performance-oriented methods (task performance and attention)

Attention Tests and Task Performance methods are designed to measure the effects of color stimuli on individuals' cognitive capacity. Participants are asked to complete tasks such as attention tests, reading comprehension exercises, visual search tasks, proofreading, or standardized office-related tasks in controlled colored environments. Objective performance outcomes are then assessed, including concentration levels, error rates, and task completion speed.

2.2.3. Behavior-oriented methods (behavioral observations)

This approach investigates users' natural behavioral patterns in existing environments characterized by specific color schemes. For example, the impact of wall colors on customers' dwell time in retail spaces or the effects of color on concentration duration in educational settings can be identified through direct observation or video analysis conducted in ways that minimize observer effects. By capturing behavior as it occurs in real-world contexts, observational studies provide valuable insights into the practical and behavioral consequences of color applications in spatial environments.

2.2.4. Neurophysiological Methods (Neurological and Physiological Measurements)

These are advanced laboratory-based methods that measure the involuntary, objective, and biological responses of the human nervous system to color stimuli, with the aim of eliminating potential response biases in self-report measures (e.g., social desirability bias).

- EEG (Electroencephalography): During exposure to specific color compositions, brainwave activity (alpha, beta, theta, and delta) is recorded in real time using electrodes placed on the scalp.
- ECG (Electrocardiogram) and Heart Rate Variability (HRV): This method analyzes fluctuations in cardiac rhythm and HRV parameters to measure the direct effects of color tones on the autonomic nervous system, particularly the balance between sympathetic and parasympathetic activity. It provides objective physiological datasets related to anxiety, arousal, or relaxation states elicited by different colors.
- Blood Pressure and Pulse Measurements: Participants' blood pressure and real-time pulse rates are recorded either during exposure to spatial environments designed with specific color schemes or immediately after exposure to color stimuli. This method provides objective and direct physiological data to verify the effects of color on arousal or relaxation through hemodynamic responses of the cardiovascular system.
- Galvanic Skin Response (GSR): By monitoring instantaneous changes in skin conductance, the GSR method is used to record emotional arousal and stress levels induced by color stimuli through sweat gland activity, providing real-time and objective measurements of autonomic nervous system responses.

3. Findings and Discussion

Following preliminary screening conducted through database searches, the abstracts and full texts of approximately 180 studies were reviewed. In line with the inclusion and exclusion criteria, a total of 54 empirical studies were included in the qualitative and quantitative synthesis. Considering the chronological distribution of the articles within the scope of the review (1990–2025), a marked acceleration in publication frequency has been observed particularly after 2010. This trend indicates a growing body of empirical research focusing on the effects of built environment components and spatial color parameters on user experience.

To describe the methodological boundaries, variable networks, and data collection instruments of color-focused research in the built environment, two main tables were constructed. Accordingly, the methodological distribution matrix of the 54 empirical studies classified according to spatial typology, mode of presentation, and dependent variable groups in a chronological framework is presented in Table 1 (Methodological Distribution Matrix). In addition, detailed parametric information of these studies, including sample sizes, specific color/lighting parameters tested, and data collection instruments used, is synthesized in Table 2 (Data Extraction Table).

Table 1. Methodological Distribution Matrix of the 54 Reviewed Empirical Articles by Typology, Medium, and Variables (Chronological Order)

Authors	Year	Function Typology	Presentation Medium					Evaluated Variables					Data Collection Instruments					
									Affective		Cognitive							
			In-situ (Real World Setting)	Mock-Up	VR Spaces	Visual simulation-based spaces	Samples	Behavioral	Preference	Mood, Well-being, Emotional States	Spatial Perception	Attention, Performance, Arousal	Observe	SDS (Semantic Differential Scale)	Likert	Attention Tests, Task performance	Neurological measurements	Survey/ Other Tests
Kwallek & Lewis	1990	Office		●						●								●
Ainsworth et al.	1993	Office		●						●		●				●		●
Kwallek et al.	1996	Office		●					●	●		●			●	●		●
Stone & English	1998	Office								●		●				●		
Read et al.	1999	Education		●				●					●					●
Stone	2001	Office		●						●		●				●		●
Babin et al.	2003	Shopping					●	●		●					●			●
Edge	2003	Patient room	●							●								●
Baytin et al.	2005	Education	●						●	●		●		●		●		●
Yıldırım et al.	2007	Shop	●							●	●			●				
Kwallek et al.	2007	Office		●								●				●		●
Manav	2007	Residence					●		●	●								●
Dijkstra et al.	2008	Patient room				●				●								●
Küller et al.	2009	Office		●						●		●		●		●	●	
Kamaruzzaman & Zawawi	2010	Office					●		●	●								●
Yıldırım et al.	2011	Living room				●				●	●			●				
Yıldırım et al.	2012	Hairdressing Salon				●				●				●				
Öztürk et al.	2012	Office		●						●		●		●		●		
Jalil et al.	2013	Education					●		●			●			●			
Park J.	2013	Livig room		●					●	●								●
Bakker et al.	2013	Office	●							●	●	●				●		●
Genschow et al.	2015	Prison cell	●					●		●			●		●			●
Yıldırım et al.	2015	Education				●				●				●				
Tantanatewin & Inkarojrit	2016	Bank Sub-branch				●				●	●			●				
Duyan & Unver	2016	Education	●					●		●		●	●	●	●	●		●
Al-Ayash et al.	2016	Education		●						●		●					●	●
Çağatay & Hidayetoğlu	2016	Education	●							●	●			●				
Savavibool & Moorapun	2017	Office				●				●	●			●				
Müezzinoğlu	2018	Education	●								●					●		
Siamionava et al.	2018	Contexless			●					●								●
von Castell et al.	2018	Contexless		●						●		●				●		●
Yıldırım et al.	2019	Education			●					●	●			●				
Güneş & Olguntürk	2020	Living room		●		●				●								●

Cha et al.	2020	Contexless			●				●		●		●		●	●	●
Pourbagher et al.	2020	Education				●			●		●			●			●
Ulusot et al.	2020	Bedroom		●			●		●	●							●
Baper et al.	2021	Education					●		●	●							●
Lipson-Simith et al.	2021	Living room, Hospital, Contexless			●				●	●							●
Llinares et al.	2021	Education				●						●			●	●	●
Bower et al.	2022	Contexless		●	●					●						●	●
Liu *et al*	2022	Education			●					●		●				●	●
Duyan & Ünver	2022	Education	●					●	●	●	●	●	●	●	●		
Oh & Park	2022	Contexless		●						●				●	●	●	
Xu et al.	2022	Hotel room			●				●	●				●			●
Akbay & Demirbaş	2023	Contexless/ Library				●				●					●		●
Weijs et al.	2023	Contexless		●						●		●				●	●
Duyan & Işık	2024	Education				●				●	●	●		●	●		●
Ulusoy	2024	Bedroom				●				●							●
Sun et al.	2024	Education	●							●	●				●		●
Aydoğdu	2024	Patient room				●			●	●	●			●	●		●
Duyan & Şener	2025	Home-office				●				●	●	●		●	●		●
Yüksektepe & Küçükkılıç	2025	Patient room			●				●	●					●		●
Bölükbaşı & Uç	2025	Patient room			●					●					●		●
Hendi & Mazaherian	2025	Therapy room			●					●							●

Table 2. Detailed Data Extraction and Parametric Overview of the Reviewed Studies: Sample Sizes, Color Systems, and Measurement Instruments

	Author (s)/ Year	Functional Typology	Stimulus Presentation Mode	Dependent Variables (Outcomes)	Veri Toplama Araçları	Tested Colours	Color System	Participants
1	Kwallek & Lewis (1990)	Office	Full scale Mock-up	*Affective*	Profile of Mood States(POMS)	Red, green, white	Munsell	222
2	Ainsworth et al. (1993)	Office	Full scale Mock-up	*Affective and cognitive (arousal level)*	State Anxiety Inventory, Multiple Affect Adjective Check List (MAACL), office task.	Red, Blue-Green, White		36 Adults
3	Kwallek et al. (1996)	Office	Full scale Mock-up	*Preference, affective, cognitive (task performance)*	POMS (Profile of Mood States), self-report fo preferation	Nine schemes featuring red, blue, and white, including their different value and saturation tones.	Munsell	94 Adults
4	Stone & English (1998)	Office	Mock-up	Preference, Affective, Cognitive (task performance)	Multiple Affect Adjective Check List (MAACL),	Red, blue	Munsell	112 participants
5	Read et al. (1999)	Education	Mock-up	Behavioral	Parten's Social Participation Scale	Purple, blue, green, Yellow, orange and red	Munsell	Children (3-5 Aged)
6	Stone (2001)	Learning environment	Mock-up	Preference, Affective, Cognitive (task performance)	Multiple Affect Adjective Check List (MAACL), performance tasks, surveys	Red, blue		26 male, 32 female

7	Babin et al. (2003)	Shop	Samples	*Affective*	Likert	Hot and cold colors, blue, orange		141
8	Edge (2003)	Patient room	In-situ	*Affective*		Purple, green, orange, beige		19 female, 20 male, 26-89 (Aged)
9	Baytin et al. (2005)	Education	In-situ	*Affective, attention*	State-Trait Anxiety Inventory	Purple, green, orange, beige		19 female, 20 male (39 participants)
10	Yıldırım et al. (2007)	Shop	In-situ	*Affective, Perception*	SDS	Yellow, purple		250
11	Kwallek et al. (2007)	Office	Mock-up	*Cognitive (Performance)*	Performance tasks, Eysenck Personality Inventory, PAD, (QMSSA)	White, red, blue-green		67 female, 23 male (90 participants)
12	Manav (2007)	Residence	Samples	Affective, preference	Frequency	41 colors		50 (30 female, 20 male)
13	Dijkstra et al. (2008)	Patient room	Visualization	Affective	Stress Arousal Checklist	orange, green		38 male, 51 female
14	Küller et al. (2009)	Office		Affective, *Cognitive (Performance)*	EEG,	Red, blue, Comlexity		Ex.1. 6 female, 6 male (17-28), Ex.2. 17 female, 8 male (20-31), Ex. 3. 20 female, 20 male (21-62)
15	Kamaruzzaman & Zawawi (2010)	Office	Samples	Affective	Questionaire	Blue, yellow, grey		**50**
16	Yıldırım et al., (2011)	Living Room	Visualization	Affective	SDS	Red, blue	Lab	150
17	Yıldırım (2012)	Hairdressing	Digital Visualization	Affective	SDS	Cream, lilac, orange		70 participants (30-60 Aged)
18	Öztürk et al. (2012)	Office	Mock-up	Affective	Clerical tasks, SDS	Yellow, grey	NCS	60 participants
19	Jalil et al. (2013)	Learning environment	Samples	Affective/ Preferation	Likert	Red, blue,green, pink, purple, brown, orange, yellow, white, black, grey	Munsell	798 (19-27 Aged)
20	Park (2013)	Living Room	Mock-up (1/2 scaled)	Affective/ Preferation	Preference	45 colors	Munsell	Children (37-11 Aged) 63 participants
21	Bakker et al. (2013)	Office	In-situ	Affective, perceive, performance	Questionaire	Red and Blue		52 (26-52 Aged)
22	Genschow et al. (2015)	Prison cell	Field Experiment / In-situ	Behavioral	Observe	Baker_Miller Pink		59 Adults (19-46 Aged)
23	Yıldırım et al. (2015)	Education	Visualization	Affective	SDS	Cream, blue, pink		Male s
24	Tantanatewin & Inkarojrit (2016)	Bank sub-branch	Visualization	Affective	SDS	Yellow-orange, grey-white		144
25	Duyan & Unver (2016)	Learning envronment	In-Situ	Attention	Attention test	Red, Yellow, Green, Blue, Purple	Munsell	8-9 aged
26	Al-Ayashi et al. (2016)	Learning envronment	Mock-up	Affective, ccognitive	SAT comprehension test, neurophysiological tests	Red, yellow, blue	NCS	24
27	Çağatay & Hidayetoğlu (2016)	Education	In-situ	Affective	SDS	Cream, blue, green	RGB	939 male (15-19 Aged)
28	Savavibool & Moorapun (2017)	Office	Visualization	Affective, perception	SDS, questionnaire	Blue, complexity, neutral		80

29	Müezzinoğlu (2018)	Education	In-situ	Affective, Cognitive, perception	SDS, Performance, attention tests	Yellow, blue, neutral	Munsell	80female, 80 male (160)
30	Siamionava et al. (2018)	Hotel room	VR	Affective, perceive	PAD	Red, blue		76 female, 63 male (139)
31	von Castell et al. (2018)	Contexless	Mock-up	Affective, performance	LMT (Lern- und Merkfähigkeitstest), self assestment	Pink, red, blue, white		170
32	Yıldırım et al. (2019)	Education/ Classroom	VR	Affective	SDS	Light/medium red, light/ medium blue, grey	NCS, RGB	113 Adults
33	Güneş & Olguntürk (2020)	Living room	Visualization	Affective	Emotion matching	Red, green, blue, grey	RGB	180 (90 female, 90 male) (17-26)
34	Cha et al. (2020)	Contexless	VR	Affective , cognitive	SDS, SAT, neurophysiological tests	Red, green, blue, white		55
35	Pourbagher et al. (2020)	Education/ Classroom	Visualization	Affective, Attention	Likert	Green, blue, red, yellow, white		275 (20-24 Aged)
36	Ulusoy et al. (2020)	Bedroom	Mock-up	Affevtive, preference	Questionnaire	42 colors	Munsell	20 Adults
37	Baper et al. (2021)	Education	Samples	Affevtive, preference	Questionnaire	Yellow, green, blue, purple, white, and black, grey	Munsell	36 female, 29 male (65)
38	Lipson-Smith et al. (2021)	Living room, hospital, contexless	VR	Affective, preferation		40 colors		745
39	Llinares et al. (2021)	Education	Visuliation	Attention, performance	EKG, EEG, heart rate	24 colors		160
40	Bower et al., (2022)	Contexless	Mock-up/ VR (HMD)	Cognitive	EKG, respiratory belt transducer, SCR finger plate electrodes	Blue, white		18-55 Aged (18 Adults)
41	Liu et al. (2022)	Education	VR	Affective, attention	EEG, ECG	Yellow, red, white, blue, and green, while	RGB	30
42	Duyan & Unver (2022)	Education/ Classroom	In-situ	Cognitive	Attention test (Bourdon)	5R 7/8 Red, 5YR 7/8 Orange, 5Y 7/8	Munsell	8-9 aged (43 Children)
43	Oh & Park (2022)	Contexless	Mock-up	Affective		12 green, blue colors		24 (9 m, 15 f)
44	Xu et al. (2022).	Hotel room	VR	Affective	Questionnaire	Yellow, blue, grey		112
45	Akbay & Demirbaş (2023)	Contexless	Visualization	Affective	International Personality Item Pool (IPIP)	Black, grey, white, Yellow, orange, red, pink, Purple, black, blue, and green	NCS	37 female, 18 male (18-36 Aged)
46	Weijs et al. (2023)	Contexless	Mock-up	Affectice, Arousal	Self assestment, GSR	Red, blue		60 (39 female, 21 male)
47	Duyan & Işık (2024)	Education	Visualization	Affective, perceiving	SDS	Red, blue-green, purple	Munsell	52 (24 female, 28 male)
48	Ulusoy (2024)	Bedroom	Visualization	Affective, preferetion		Purple, brown, orange, yellow, blue, green, pink, red		100
49	Sun et al. (2024)	Education	In-situ	Affective	PANAS-C	Hot (red, yellow), cold (blue, green)		123
50	Aydoğdu (2024)	Patient room	Visualization (In-situ)	Affective, ppreference	SDS, Likert	Light-medium, saturated (Red, green-	Munsell	69 (43 female, 26 male), 18-65 Aged

						yellow, blue, Purple), grey, white (14 Colors)		
51	Duyan &Şener (2025)	Office	Visualization	Affective, perceiving	SDS	Light-saturated-dark (Red, red-purple, blue, green-yellow), (12 Colors)	Munsell	51 (24 female, 27 male)
52	Yüksektepe & Küçükkılıç Özcan (2025)	Patient room	VR	Affective, preference	SDS, Likert	Light, very slightly saturated-light, slightly saturated-light, moderately saturated (Red, Yellow, green, blue, Purple) neutral (16 colors)	Munsell	70
53	Bölükbaşı & Uç (2025)	Patient room	VR	Affective	PAD	Orange, blue	RGB	41 female-39 male, 18-67 Aged
54	Hendi & Mazaherian (2025)	Therapy room	VR	Affective	Self-Assessment Manikin (SAM), PAD	17 colors		57

All data were analyzed using descriptive and inferential statistical methods in the SPSS program. Initially, descriptive frequency analyses were performed to determine the distribution of categorical variables. Subsequently, the relationships between parameters were evaluated using the Crosstabs tool, complemented by a qualitative content analysis to systematically categorize the non-numerical methodological insights extracted from the articles. The conceptual schema for the study's analysis is shown in Figure 2.

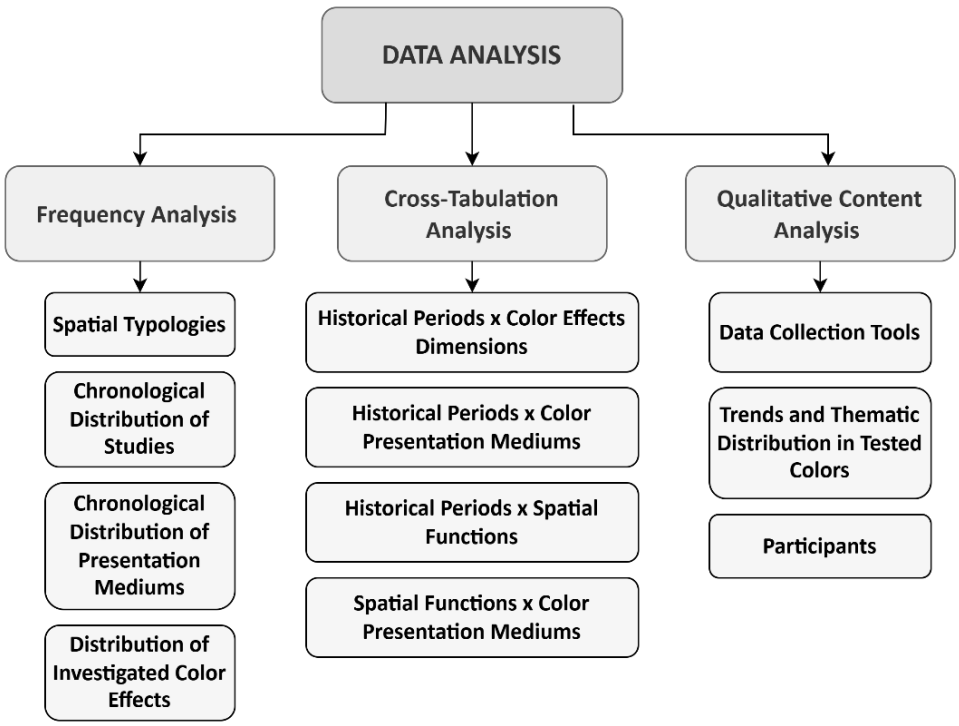


Figure 2. Conceptual schema of data analysis (Created by the author)

3.1. Frequency Analysis

Descriptive frequency analyses were conducted to reveal the general methodological structure, temporal trends, and architectural functions focused on by empirical research examining color parameters in the built environment. Accordingly, the publication years, spatial typologies, color presentation environments, and tested dependent variable dimensions of the 54 studies included in the systematic review were structured using frequency (f) and percentage (%) distributions calculated via SPSS software.

3.1.1. Spatial typologies

Across the 54 analyzed empirical studies, it was observed that the research tends to concentrate on specific spatial typologies. Notably, the most heavily investigated functions are clustered around Educational (29.6%) and Office environments (22.2%). These are followed respectively by Context-Independent experimental setups (13.0%), Residential settings (11.1%) (e.g., living rooms and bedrooms), and Patient rooms (9.3%). In contrast, studies conducted in more specialized Environments such as bank branches, hotel rooms, therapy rooms, hair salons, and prison cells remain highly limited in number and are aggregated under the 'Other' category (14.8%). This distribution demonstrates that color research in the built environment is predominantly focused on learning and work-related contexts, highlighting significant research gaps in environments associated with more diverse user profiles and specialized functions (Table 3).

3.1.2. Chronological distribution of studies

The 54 analyzed studies were categorized into a total of 7 periods consisting of 5-year intervals to accurately reflect the 35-year temporal span. The distribution pattern reveals that environmental color research remained highly limited during the early periods of 1990–1995 ($3.7\%, f = 2$) and 1996–2000 ($5.6\%, f = 3$) (Table 3). Descriptive analysis verifies that the primary turning point and growth momentum of the literature initiated after 2016 ($f = 13, 24.1\%$), reaching its peak in the final period (2021–2025) with 18 studies (33.3%).

Table 3. Frequency analysis of chronological periods, spatial functions, and color presentation mediums.

Varables	Category	Frequency (f)	Percentage (%)
Publication year	1990-1995	2	3,7
	1996-2000	3	5,6
	2001-2005	4	7,4
	2006-2010	6	11,1
	2011-2015	8	14,8
	2016-2020	13	24,1
	2021-2025	18	33,3
Spatal function	Education	16	29,6
	Office	12	22,2
	Contexless	7	13
	Residence	6	11,1
	Patient Room	5	9,3
	Others (Hair dressing salon, shop, bank branch, etc.)	8	14,8
Color presentation Medium	Mock-up	15	27,8
	Visualization	14	25,9
	In-situ	11	20,4
	VR (Virtual reality)	9	16,7
	Samples	5	9,3
Total		**54**	**100**

3.1.3. Chronological Distribution of Presentation Mediums

An investigation of the color presentation mediums used in the analyzed studies reveals that early research was predominantly conducted in in-situ environments ($f = 11,\ 20.4\%$) and full-scale experimental settings (Mock-ups, 27.8%). With the advancement of computer-based visualization techniques, two-dimensional digital representations became increasingly prevalent ($f = 14, 25.9\%$), and in recent years, the utilization of Virtual Reality (VR) applications has reached a remarkable level ($f = 9, 16.7\%,$) (Bölükbaşı & Uç, 2025; Bower et al., 2022; Cha et al., 2020; Hendi & Mazaherian, 2025; Liu et al., 2022; Xu et al., 2022; Yüksektepe & Küçükkılıç, 2025).

VR has become a vital component of contemporary research by replacing the cost and control limitations of in-situ studies with an immersive experience comparable to mock-up accuracy (Heydarian et al., 2015). Additionally, some studies directly utilized standardized color charts/swatches (Samples, $9.3\%, f = 5$) for evaluation purposes (Table 3). Overall, this trend clearly demonstrates a methodological-technological shift toward increasing experimental control and the sense of immersion in environmental color research (Babin et al., 2003; Jalil et al., 2013; Manav, 2007).

3.1.4. Distribution of Investigated Color Effects

The analysis of the psychological and perceptual effect types investigated in the analyzed studies reveals that the vast majority of research conducted in architectural environments (f = 48, 88.9%) focuses on affective effects, including mood, psychological comfort, and semantic evaluations. This is followed respectively by cognitive effects ($f = 18, 33.3\%$) and color preferences ($f = 12, 22.2\%$). In contrast, empirical studies investigating the effects of color on spatial perception ($f = 7,\ 13.0\%$) and direct user behavior ($f = 3, 5.6\%$) are determined to remain highly limited in the literature (Table 4).

To identify the dimensions in which the included studies address color parameters and the psychophysical outcomes they focus on, a Multiple Response Frequencies analysis was conducted using the SPSS statistical software. Within the scope of the analysis, a dichotomous variable set was defined, taking into account that a single study could simultaneously investigate multiple dependent variables or effects.

Table 4. Frequency distribution of investigated color effects.

Color Effects Dimensions	Frequency (n)	Usage rate Percentage (%)*
Emotional/Affective	48	88,9
Cognitive	18	33,3
Color Preference	12	22,2
Spatial Perception	7	13
Behavioral	3	5,6
Total Responses	**88**	**163**

*Because a multiple response analysis was applied, the sum of percentages exceeds 100%, and the total number of responses exceeds the total number of articles ($N = 54 < 88$). Percentages were calculated based on the total number of articles.

The analysis results indicate that articles could test more than one effect simultaneously. According to the obtained multiple response frequency distributions, emotional and affective effects represent by far the most heavily focused area in architectural color studies, with a dominant rate of 88.9%. Affective effects are followed by cognitive effects with a frequency of 33.3% and direct color preferences with 22.2%. On the other hand, the spatial/volumetric effects of color on spatial perception (13.0%) and its direct behavioral outcomes (5.6%) have been found to be investigated to a highly limited extent in the literature (Babin et al., 2003; Duyan & Unver, 2016; Genschow et al., 2015; Read et al., 1999). The operational difficulty of observing or measuring individuals' direct physical behaviors (e.g., purchasing behavior, spatial dwell time, and social interaction) in response to color, compared to administering standard questionnaires, has created a relative research gap in the literature.

The distribution of color effect parameters demonstrates that architectural color research heavily concentrates on users' emotional states and perceptual responses; however, the behavioral and spatial simulation dimensions of color still constitute a significant research gap waiting to be addressed in the literature.

3.2. Cross-Tabulation Analysis of Methodological Parameters

To reveal the structural and methodological relationships, historical trends, and patterns among the 54 empirical studies included in the analysis, two-way crosstabulation analyses were conducted. Within this scope, the projections of chronological processes (historical periods) on the measured dimensions of color effects, preferred spatial functions, and utilized color presentation mediums were examined. Additionally, to decode the methodological correlations and tendencies between spatial functions and color presentation mediums, Chi-Square (χ^2) independence tests between categorical variables were executed. These multidimensional analyses present the 35-year methodological transformation of the color literature, the dominant trends in the field, and potential research gaps for future studies within a holistic framework.

3.2.1. Cross-tabulation analysis of historical periods and color effects dimensions

Multiple Response Crosstabulation, conducted to determine which empirical outcomes are measured on users and the historical trends of these measurements over time in built environment color research, reveals the multidimensional structure of the literature (Table 5, Figure 3). It was found that a total of 88 impact dimensions were tested in 54 independent scientific publications included in the review. It was observed that the studies performed an average of 1.63 different impact measurements per article, and due to this experimental diversity, the overall usage rate reached 163.0% of the total number of articles.

A holistic examination of the last 35 years reveals that affective effects have consistently been the primary focus of research. Of the 54 studies included in the review, 88.9% (f = 48) examined the effects of color on human psychology, mood, and psychological comfort. In particular, affective outcomes formed the empirical basis in 92.3% (f=12) of the 13 empirical studies published between 2016-2020 and in 88.9% (f=16) of the 18 articles in the most recent period, 2021-2025. Pearson Chi-Square analysis confirms that the research trend of affective effects does not show a statistically significant difference between periods (χ^2=2.607, df=6, p=0.856). This proves that the affective dimension has always been a focal point in the literature, regardless of the historical process.

Cognitive effects, which examine the influence of color parameters on work and learning performance, concentration, and attention, were investigated in 33.3% of the reviewed studies (f = 18). A period-based analysis showed that cognitive effects accounted for 50.0% of the studies (f = 1) during the 1990–1995 period. As the volume of the literature expanded, this proportion remained relatively stable, reaching 30.8% (f = 4) in 2016–2020 and 33.3% (f = 6) in 2021–2025. No statistically significant association was found between publication period and the frequency with which cognitive effects were investigated (χ^2 = 3.851, df = 6, p = 0.697).

Color preference was examined in 22.2% of the reviewed studies (f = 12). A temporal analysis indicated that color preference was investigated in 66.7% of the studies (f = 2) during the 1996–2000 period, whereas this proportion declined to 22.2% (f = 4) in the most recent period (2021–2025). However, no statistically significant association was identified between publication period and the selection of color preference as an empirical dependent variable (χ^2 = 5.607, df = 6, p = 0.469).

Spatial perception, which encompasses studies examining three-dimensional spatial boundaries, perceived depth, volumetric illusions, and the perception of ceilings and walls, accounted for 13.0% of the reviewed studies (f = 7). The most notable increase in research on spatial perception was observed during the 2016–2020 period, when digital representations and three-dimensional modeling became increasingly prevalent, with 30.8% of the studies published during this period (f = 4) focusing on this topic. In the most recent period (2021–2025), this proportion declined to 11.1% (f = 2). No statistically significant association was found between publication period and the distribution of studies investigating spatial perception (χ^2 = 7.639, df = 6, p = 0.266).

Behavioral effects, which examine the direct influence of color on users' behavior, represented only 5.6% of the reviewed studies (f = 3), making them the least investigated research domain over the past 35 years. Historically, behavioral effects were examined only sporadically, appearing in the 1996–2000 (f = 1, 33.3%), 2011–2015 (f = 1, 12.5%), and 2021–2025 (f = 1, 5.6%) periods. No statistically significant association was identified between publication period and the frequency with which behavioral effects were investigated (χ^2 = 6.618, df = 6, p = 0.358). This finding suggests a persistent and time-independent research gap, likely attributable to the methodological challenges associated with measuring individuals' direct behavioral responses to color.

Table 5. Distribution of color effects in built environment research by years (1990–2025)

Periods	Totaly Researchs (N)	Affective Effect n (%)	Cognitive Effect n (%)	Color Preference n (%)	Spatial Perceive n (%)	Behavioral Effect n (%)
1990-1995	**2**	2 (%100,0)	1 (%50,0)	0 (%0,0)	0 (%0,0)	0 (%0,0)
1996-2000	**3**	3 (%100,0)	2(%66,7)	2 (%66,7)	0 (%0,0)	1 (%33,3)
2001-2005	**4**	3 (%75,0)	2 (%50,0)	1 (%25,0)	0 (%0,0)	0 (%0,0)
2006-2010	**6**	5 (%83,3)	2 (%33,3)	1 (%16,7)	0 (%0,0)	0 (%0,0)
2011-2015	**8**	7 (%87,5)	1 (%12,5)	2 (%25,0)	1 (%12,5)	1 (%12,5)
2016-2020	**13**	12 (%92,3)	4 (%30,8)	2 (%15,4)	4 (%30,8)	0 (%0,0)
2021-2025	**18**	16 (%88,9)	6 (%33,3)	4(%22,2)	2 (%11,1)	1 (%5,6)
Totaly	**54**	**48 (%88,9)**	**18 (%33,3)**	**12 (%22,2)**	**7 (%13)**	**3(%5,6)**

*Because a multiple response analysis was applied, the sum of percentages exceeds 100%, and the total number of responses exceeds the total number of articles ($N = 54 < 88$). Percentages were calculated based on the total number of articles.

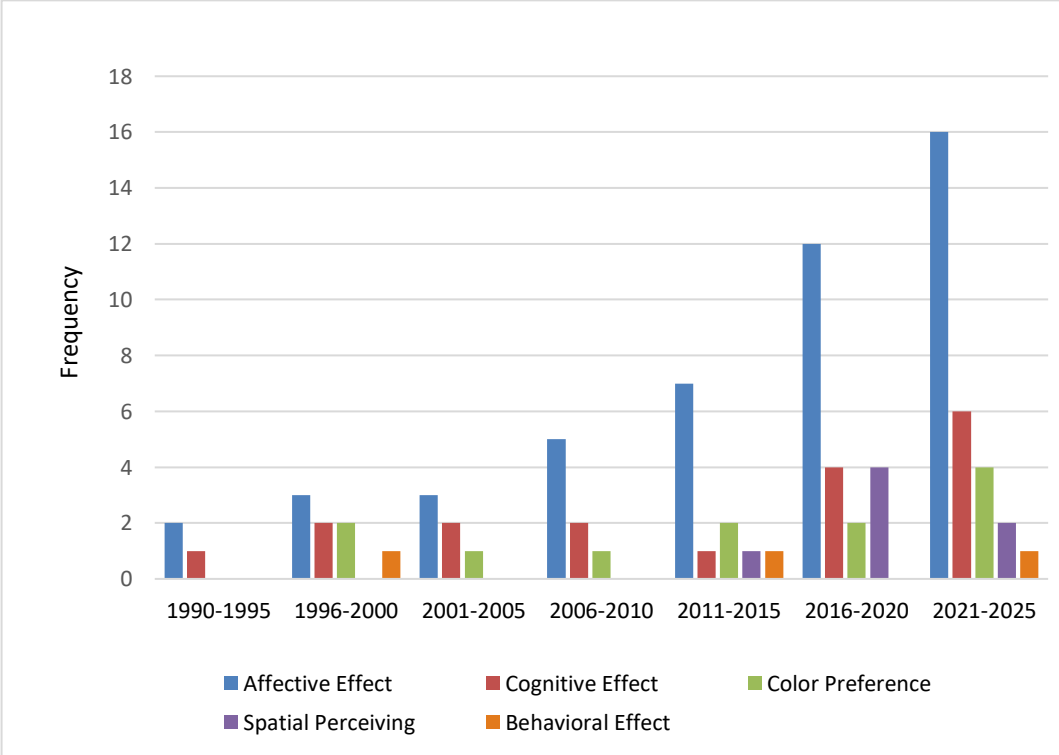


Figure 3. Distribution of investigated color effects in built environment research by years (1990–2025) (Created by the author)

3.2.2. Cross-tabulation analysis of historical periods and color presentation mediums

A Pearson's chi-square test was conducted to examine the relationship between historical periods and the color presentation mediums employed in empirical studies. The results indicated no statistically significant categorical association between the two variables ($\chi^2 = 33.237,\ df = 24,\ p = 0.099,\ V = 0.392$). Although the overall association did not reach the conventional level of statistical significance ($p \leq 0.05$), the obtained Cramer's *V* value (0.392) indicates a moderate effect size, suggesting a meaningful methodological trend. This finding implies that the relatively small sample size (N = 54) may have limited the statistical power of the chi-square test, preventing the association from reaching statistical significance despite the presence of practically meaningful temporal patterns. An examination of the period-specific frequency distributions and row and column percentages reveals a clear methodological transition toward digital color presentation environments over time (Table 6).

During the 1990–1995 period, all studies (100.0%, f = 2) employed mock-up environments. Similarly, mock-up methods were used in 66.7% (f = 2) of the studies published between 1996 and 2000 and in 50.0% (f = 2) of those published during 2001–2005. These findings reflect the methodological constraints of the early research period, when immersive digital simulation technologies such as virtual reality (VR) were either unavailable or not sufficiently accessible for experimental applications. Consequently, researchers relied primarily on full-scale physical mock-ups and controlled laboratory settings to investigate the effects of color parameters. Despite the subsequent emergence of digital technologies, the mock-up approach has maintained a stable presence throughout the study period.

In-situ studies conducted in real architectural environments also represented a consistently employed research method across the reviewed literature. Their temporal distribution demonstrates relatively stable usage throughout the intermediate periods, accounting for 33.3% of the studies in 1996–2000, 25.0% in 2001–2005, 37.5% in 2011–2015, and 23.1% in 2016–2020. These findings indicate that field-based investigations remained an important methodological approach for evaluating users' responses to color in environmental settings.

The visualization approach, encompassing two-dimensional digital images, rendered scenes, and computer-generated visualizations, first emerged in the literature during the 2006–2010 period, representing 33.3% of the studies published during that interval. Its adoption increased substantially over time, accounting for 38.9% (f = 7) of the studies published between 2021 and 2025, thereby becoming one of the two most frequently employed color presentation methods. This trend suggests that continuous improvements in rendering technologies, display quality, and screen calibration have encouraged researchers to adopt flexible digital visualization techniques while reducing the cost and logistical complexity associated with constructing physical experimental environments.

The introduction of virtual reality (VR) marked the most notable methodological transformation in recent years. No VR-based color presentation studies were identified before 2016. However, VR accounted for 23.1% (f = 3) of the studies conducted during the 2016–2020 period and increased further to 33.3% (f = 6) in 2021–2025, making it one of the two most frequently adopted presentation methods in the most recent period.

Conversely, the proportion of in-situ studies declined markedly, decreasing from 37.5% during 2011–2015 to only 11.1% in the 2021–2025 period. This shift indicates that contemporary researchers increasingly favor digital presentation environments, particularly visualization techniques and VR, over physical field experiments or mock-up settings because of their advantages in experimental control, flexibility, cost efficiency, and the ability to standardize environmental conditions across participants.

Table 6. Distribution and Trends in Color Presentation Media by Period

Publication Year	In-situ f (%)	Mock-up f (%)	Visualization f (%)	VR f (%)	Samples f (%)	Total f (%)
1990-1995	0 (0,0%)	2 (100,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	2 (3,7%)
1996-2000	0 (0,0%)	3 (100,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	3(5,6)%
2001-2005	2 (50,0%)	1(25,0%)	0 (0,0%)	0 (0,0%)	1 (25,0%)	4 (7,4%)
2006-2010	1 (16,7%)	1 (16,7%)	2 (33,3%)	0 (0,0%)	2 (33,3%)	6 (11,1%)
2011-2015	3 (37,5%)	2 (25,0%)	2 (25,0%)	0 (0,0%)	1 (12,5%)	8 (14,8%)
2016-2020	3 (23,1%)	3 (23,1%)	3 (23,1%)	3 (23,1%)	1 (7,7%)	13 (24,1%)
2021-2025	2 (11,1%)	3 (16,7%)	7 (38,9%)	6 (33,3%)	0 (0,0%)	18 (33,3%)
Total (f)	11	15	14	9	5	54
General Rate (%)	20,40%	27,80%	25,90%	16,70%	9,30%	100,00%

3.2.3. Cross-tabulation analysis of historical periods and spatial functions

To examine the historical development and temporal trends of the spatial functions (typologies) investigated in color research, cross-tabulation and chi-square analyses were conducted between publication periods (grouped into five-year intervals) and spatial function categories.

The statistical analyses yielded a Pearson's chi-square value*, χ^2= 62,619, (df = 60, p = 0.383),* and a Cramer's *V* of 0.440. Although these results indicate no statistically significant categorical association between publication period and spatial function ($p > 0.05$), the *Linear-by-Linear Association* statistic was statistically significant ($\chi^2 = 6.701$, $p = 0.010$). This finding demonstrates a significant linear temporal trend, indicating that the types and diversity of spatial functions investigated have changed systematically over time rather than by chance. The Cramer's *V* value (0.440) further suggests that this structural trend represents a moderate-to-strong association.

The frequency distribution of the 54 reviewed studies across publication periods (1990–1995: 2; 1996–2000: 3; 2001–2005: 4; 2006–2010: 6; 2011–2015: 8; 2016–2020: 13; 2021–2025: 18) demonstrates a substantial expansion of the literature during the last decade, with 57.4% of all studies published after 2015. Accompanying this growth, notable shifts in the spatial typologies investigated were observed (Table 7). Office environments dominated the early literature, accounting for 100.0% of the studies published during 1990–1995 ($f = 2$), 66.7% during 1996–2000 ($f = 2$), and 50.0% during 2006–2010 ($f = 3$). These findings suggest that early color research primarily focused on optimizing workplace productivity, computer-based work performance, visual comfort, and environmental stress within office settings.

Educational environments constituted the largest spatial category in the overall dataset, representing 29.6% of the reviewed studies (f = 16). However, their temporal distribution reveals that 12 of these 16 studies (75.0%) were published after 2015, with six studies (46.2%) conducted during 2016–2020 and another six studies (33.3%) during 2021–2025. This pattern confirms that, over the past decade, the relationship between color, lighting, and environmental comfort in learner-centered educational environments has become a major focus of research, reflecting the growing emphasis on active learning, flexible educational spaces, and student well-being.

Table 7. Distribution of Spatial Functions by Period

Periods	Office (n)	Education (n)	Residence (n)	Patient Room (n)	Contexless (n)	Other Functions * (n)	Period Total (N / %)
1990-1995	2 (100%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	**2** (%3,7)
1996-2000	2 (66,6%)	1 (33,3%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	**3** (%5,6)
2001-2005	1 (25,0%)	1 (25,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)	2 (50,0%)	**4** (%7,4)
2006-2010	3 (50%)	0 (0,0%)	1 (16,7%)	1 (16,7%)	0 (0,0%)	1 (16,7%)	**6** (%11,1)
2011-2015	2 (25%)	2 (25%)	2 (25%)	0 (0,0%)	0 (0,0%)	2 (25%)	**8** *(%14,8)*
2016-2020	1 (7,7%)	6 (46,2%)	2 (15,4%)	0 (0,0%)	3 (23,1%)	1 (7,7%)	**13** *(%24,1)*
2021-2025	1 (5,6%)	6 (33,3%)	1 (5,6%)	4 (22,2%)	4 (22,2%)	2 (11,2%)	**18** *(%33,3)*
Total (n / %)	**12** *(%22,2)*	**16** *(%29,6)*	**6** *(%11,1)*	**5** *(%9,3)*	**7** *(%13,0)*	**8** *(%14,8)*	**54** *(%100,0)*

Other Functions*: Hairdressing, Shop, Prison cell, Hotel room, Library

Of the five studies investigating patient rooms included in the dataset, 80.0% (*f* = 4) were published during the most recent period (2021–2025), representing 22.2% of the studies conducted within that period. This marked increase may be interpreted as reflecting the growing influence of healing environments, evidence-based design, and post-pandemic design approaches emphasizing user health and well-being within the field of environment–behavior research.

Whereas the early literature focused primarily on a limited range of spatial typologies, such as offices, educational environments, and retail spaces, studies published after 2015 expanded to include more specialized settings, including hotel rooms, libraries, and prison cells. One of the most notable findings is that 57.1% (*f* = 4) of the seven *contexless* studies were published during the 2021–2025 period. This trend suggests that recent advances in digital technologies, particularly virtual reality (VR), have enabled researchers to isolate spatial variables and conduct more controlled experiments focusing directly on the fundamental effects of color parameters, independent of specific architectural contexts.

3.2.4. Cross-Tabulation Analysis of Spatial Functions and Color Presentation Mediums

To examine the relationship between spatial functions (spatial typologies) and the color presentation mediums used to deliver color stimuli to participants, a cross-tabulation analysis and Pearson's chi-square test of independence were conducted on the 54 empirical studies included in this review. The results revealed a statistically significant association between the spatial function investigated and the color presentation medium employed ($\chi^2 = 56.630$, df = 40, p = 0.042, Cramer's V = 0.512). Since the p-value was below the conventional significance threshold ($p < 0.05$), the findings indicate that the selection of color presentation mediums varies systematically according to the spatial typology being investigated rather than occurring by chance.

An examination of the overall distribution of spatial functions and presentation mediums shows that the literature has primarily focused on educational environments (29.6%) and office environments (22.2%). Regarding presentation methods, mock-up environments (27.8%) and visualization techniques (25.9%) were the most frequently employed approaches.

Among the 12 studies focusing on office environments, more than half (58.3%) used mock-up environments, consisting of full-scale physical models or controlled laboratory settings, to present color stimuli. Furthermore, 46.7% of all mock-up studies (15 studies in total) were conducted in office settings. This pattern may be explained by the fact that office-based color research frequently investigates long-term cognitive performance, concentration, and productivity, which require highly

controlled experimental conditions. Full-scale physical environments minimize potential confounding factors associated with digital displays, such as color distortion and screen flicker, thereby providing a more natural and reliable representation of color.

Educational environments exhibited the greatest methodological diversity, encompassing 16 studies employing multiple presentation mediums. Of these, 37.5% were conducted as in-situ experiments in real educational settings, while 31.3% employed visualization techniques. More than half (54.5%) of the 11 in-situ studies in the dataset were carried out in educational environments. The widespread use of field experiments in schools and university classrooms is likely attributable to the ease of accessing participants, existing lighting systems, and authentic learning environments, making these settings particularly suitable for evaluating users' responses to color under real-world conditions.

A clear preference for digital simulation techniques was observed in spatial typologies with more restricted accessibility, particularly residential environments (6 studies) and patient rooms (5 studies). Half of the residential studies (50.0%) employed visualization techniques, whereas studies involving patient rooms relied equally on visualization (40.0%) and virtual reality (VR) (40.0%). In healthcare settings, where infection control, patient safety, and psychological well-being are critical considerations, the logistical and ethical constraints associated with physical interventions through in-situ experiments or mock-up environments appear to have encouraged researchers to adopt digital presentation methods capable of evaluating alternative color schemes under highly controlled conditions without disrupting clinical environments (Table 8).

Tablo 8. Distribution of Color Presentation Mediums According to Spatial Functions

Function	In-situ (n)	Mock-up (n)	Visualization (n)	VR (n)	Samples (n)	Total Function (N / %)
Education	6	3	5	1	1	**16** *(%29,6)*
Office	0	7	3	1	1	**12** *(%22,2)*
Contexless	0	3	0	4	0	**7** *(%13,0)*
Residence	1	0	3	0	2	**6** *(%11,1)*
Hasta Odası	1	0	2	2	0	**5** *(%9,3)*
Other Functions*	3	2	1	1	1	**8** *(%14,8)*
Toplam (n / %)	**11** *(%20,4)*	**15** *(%27,8)*	**14** *(%25,9)*	**9** *(%16,7)*	**5** *(%9,3)*	**54** *(%100,0)*

Other Functions*: Hairdressing, Shop, Prison cell, Hotel room, Library

Virtual Reality (VR) was used in 57.1% of the 7 “Context-Free” studies, which did not define a specific spatial function and aimed to isolate the direct abstract psychological/emotional effects of color. Nearly half (44.4%) of the total 9 VR studies fall into this category. This data confirms the flexibility that VR technology offers researchers in creating isolated laboratory environments stripped of spatial cues, where external stimuli are completely controlled.

3.3. Qualitative Content Analysis

Due to the high diversity of color variations in the studies, the combined use of heterogeneous systems based on verbal (e.g., “hot/cold,” “complexity”) or numerical criteria instead of standard codes, and the fact that data collection tools varied depending on the measured variables, it was not possible to create a quantitative matrix in SPSS. To overcome this methodological limitation and gain a holistic view of the structural trends in literature, the parameters of the 54 studies included in the research were subjected to qualitative content analysis. Accordingly, systematic thematic coding was performed based on color stimulus characteristics, the color systems used, data collection tools, and participant profiles.

3.3.1. Data collection tools

The data collection instruments employed to assess users' responses to color varied according to the empirical depth of the studies, the dependent variables investigated, and the historical evolution of research methodologies. Across the reviewed literature, the Semantic Differential Scale (SDS) emerged as the most frequently used instrument. In particular, studies by Yıldırım et al. (2007), Yıldırım et al. (2011), Yıldırım et al. (2012), Yıldırım et al. (2019), Duyan & Unver (2016), Duyan & Işık (2024), Duyan & Şener (2025), Öztürk (2012), Tantanatewin & Inkarojrit (2016), and Müezzinoğlu (2018) adopted the SDS as the primary tool for evaluating users' perceptions of color, spatial impressions, and affective responses. In addition, several standardized psychological assessment instruments were employed to measure mood and emotional states, including the Profile of Mood States (POMS) (Kwallek & Lewis, 1990; Kwallek et al., 1996), the Multiple Affect Adjective Check List (MAACL) (Ainsworth et al., 1993; Stone & English, 1998; Stone, 2001), the Pleasure–Arousal–Dominance (PAD) scale (Siamionava et al., 2018; Bölükbaşı & Uç, 2025; Hendi & Mazaherian, 2025), and the Positive and Negative Affect Schedule for Children (PANAS-C) (Sun et al., 2024).

Studies investigating the effects of color on cognitive outcomes, such as work performance, learning, and concentration, relied on objective performance measures in addition to self-reported assessments. To evaluate attention, learning, and cognitive performance, researchers employed instruments including the Bourdon Attention Test (Duyan & Ünver, 2022), the Lern- und Merkfähigkeitstest (LMT) (von Castell et al., 2018), Scholastic Assessment Test (SAT) comprehension tasks (Al-Ayashi et al., 2016; Cha et al., 2020), and a variety of clerical and office-based performance tasks (Ainsworth et al., 1993; Kwallek et al., 2007).

In recent years, advanced physiological measurement technologies capable of capturing participants' immediate and involuntary responses have become increasingly integrated into color research. Küller et al. (2016), Llinares et al. (2021), and Liu et al. (2022) employed electroencephalography (EEG) and electrocardiography (ECG) to record brain activity and cardiac responses. Similarly, Bower et al. (2022) combined ECG with a respiratory belt transducer and skin conductance response (SCR) finger electrodes, whereas Weijs et al. (2023) utilized galvanic skin response (GSR) sensors to monitor autonomic nervous system activity. The integration of these neurophysiological measurement techniques has enabled researchers to obtain objective indicators of individuals' responses to color, complementing traditional self-report measures and reducing reliance on subjective evaluations.

The relatively small number of studies examining the influence of color on users' observable behavior and social interaction primarily relied on observational methodologies. Read et al. (1999), for example, employed the Parten Social Participation Scale to code children's social behaviors in play environments. Likewise, Duyan and Ünver used a structured teacher observation form to document the behavioral responses of primary school children aged 8–9 years under different classroom wall color conditions. Similarly, Genschow et al. (2015), who investigated the effects of color in prison cells, validated their findings through structured behavioral observation.

3.3.2. Characteristics of Tested Color Stimuli

The characteristics of the color stimuli employed in empirical studies have changed over time. A qualitative examination of the reviewed literature reveals clear trends in color selection, the number of colors tested, and the methods used to specify color stimuli.

From the early years of the literature to the present, most researchers have favored primary and contrasting color combinations in laboratory and digital experimental settings in order to reduce experimental complexity. In particular, the red–blue color pair, either alone or combined with green and white, has remained one of the most frequently employed color schemes (e.g., Kwallek & Lewis, 1990; Stone & English, 1998; Bakker et al., 2013; Weijs et al., 2023).

In contrast, several studies adopted substantially larger color sets to capture users' responses across a broader range of color stimuli. Manav (2007) and Park (2013) investigated 41 and 45 colors, respectively, while Ulusoy (2020) evaluated 42 colors and Lipson-Smith et al. (2021) employed 40 colors to maximize visual diversity within the experimental environment. More recent studies have

continued this trend by utilizing multiple color stimuli, including Aydoğdu (2024) with 14 colors, Yüksektepe & Küçükkılıç (2025) with 16 colors, and Hendi & Mazaherian (2025) with 17 colors.

The reviewed studies also demonstrate increasing attention to specifying colors not only by their common names but also according to their hue, value, and chroma. For example, Kwallek et al. (1996) evaluated nine color schemes composed of different shades of red, blue, and white, whereas Duyan & Ünver (2022) specified color stimuli using precise Munsell notations, such as 5R 7/8 Red and 5Y 7/8 Yellow. Similarly, Yüksektepe & Küçükkılıç (2025), Duyan & Işık (2024), and Duyan & Şener (2025) systematically classified color stimuli according to variations in hue, value, and chroma before presenting them to participants.

The qualitative analysis further reveals a lack of methodological consistency in the standardization of color stimuli across empirical studies. The Munsell Color System constitutes the most widely adopted and scientifically established framework for defining hue, value, and chroma in environment–behavior research (Kwallek & Lewis, 1990; Stone & English, 1998; Duyan & Ünver, 2022; Aydoğdu, 2024; Duyan & Şener, 2025; Yüksektepe & Küçükkılıç, 2025). However, several studies employed the Natural Color System (NCS) (Öztürk, 2012; Al-Ayashi et al., 2016; Akbay & Demirbaş, 2023), while the increasing use of digital visualization and virtual reality technologies has led to the adoption of RGB color specifications in screen-based experiments (Çağatay & Hidayetoğlu, 2016; Cha et al., 2020; Bölükbaşı & Uç, 2025). Nevertheless, a considerable proportion of the 54 reviewed studies did not report any internationally recognized color specification system (e.g., Munsell, NCS, or RAL). This lack of technical reporting represents a notable methodological limitation that restricts the reproducibility and comparability of empirical color research.

3.3.3. Sample characteristics and participant profiles

Sample characteristics constitute a fundamental methodological component of empirical color research, as they directly influence the reliability, generalizability, and contextual relevance of research findings. The reviewed studies exhibit considerable diversity in terms of sample size, age groups, and demographic characteristics. Nevertheless, participant selection appears to vary according to the research setting, spatial function, and experimental methodology employed, while also revealing several consistent methodological patterns across the literature.

Sample sizes ranged from laboratory-based micro-samples consisting of only 18 participants (Bower et al., 2022) to large-scale studies involving as many as 939 participants (Çağatay & Hidayetoğlu, 2016). Studies employing digital visualization and computer-based presentation techniques generally achieved substantially larger sample sizes than those conducted in controlled physical environments. For example, Jalil et al. (2013) recruited 798 participants, whereas Pourbagher et al. (2020) included 275 participants. Despite this variability, the majority of empirical studies employed sample sizes ranging between 50 and 150 participants to ensure adequate experimental control while maintaining manageable data collection procedures (e.g., Dijkstra et al., 2008 [89 participants]; Yıldırım, 2012 [70 participants]; Savavibool & Moorapun, 2017 [80 participants]; Duyan & Işık, 2024 [52 participants]; Aydoğdu, 2024 [69 participants]).

With regard to participant profiles, the reviewed literature predominantly relied on university students and adult participants. However, the age composition of the samples varied according to the spatial function and target user group under investigation. For example, Read et al. (1999) examined children aged 3–5 years in studies of educational environments, whereas Duyan & Ünver (2016, 2022) investigated the responses of primary school children aged 8–9 years to different classroom color conditions. In contrast, Edge (2003), who examined patient rooms in healthcare settings, included participants ranging in age from 26 to 89 years, thereby encompassing older adults as well. Furthermore, many recent studies have sought to maintain a balanced representation of female and male participants, reflecting an increasing emphasis on demographic balance to enhance the empirical validity and representativeness of research findings.

4. Conclusion and Suggestions

This study systematically reviewed 54 empirical studies on color in the built environment published between 1990 and 2025, providing a comprehensive overview of the methodological development of the field over the past 35 years. Unlike previous review studies, which primarily summarize empirical findings, the present study focused exclusively on the methodological characteristics of the reviewed research. The selected studies were systematically analyzed and compared in terms of spatial functions, types of effects investigated, color presentation media, data collection instruments, color specification systems, and participant characteristics. Accordingly, this study presents a comprehensive methodological framework that illustrates the historical evolution of empirical color research in the built environment.

The findings indicate a substantial increase in the number of empirical color studies over the last decade, accompanied by considerable methodological diversification driven by advances in digital technologies. Nevertheless, the fundamental research directions have remained relatively consistent over time. Most studies have focused on the effects of color on mood, psychological comfort, and spatial perception, whereas investigations addressing behavioral responses remain remarkably limited. This finding suggests that significant research gaps still exist, particularly regarding the cognitive and, more importantly, the behavioral effects of color within built environments.

From the perspective of spatial functions, early studies predominantly focused on office environments, whereas educational settings have emerged as the most extensively investigated spatial typology in recent years. Furthermore, the increasing inclusion of specialized settings, such as patient rooms, hotel rooms, libraries, and contextless experimental environments, reflects the growing interdisciplinary and user-centered nature of color research.

One of the most notable methodological transformations identified in this review concerns the evolution of color presentation media. While early studies primarily relied on physical mock-up environments and in-situ experiments, recent research has increasingly adopted computer-based visualizations and, particularly, virtual reality (VR) technologies. The enhanced experimental control, flexibility, cost-effectiveness, and standardized testing conditions offered by digital presentation media have encouraged researchers to adopt these approaches more frequently. Parallel to this development, the integration of neurophysiological measurement techniques—including electroencephalography (EEG), electrocardiography (ECG), and galvanic skin response (GSR)—has enabled researchers to objectively assess participants' physiological responses alongside conventional subjective evaluations.

Despite these methodological advances, the reviewed studies also revealed several important methodological limitations. In particular, the absence of internationally recognized color specification systems (e.g., Munsell, NCS, or RAL), insufficient reporting of lighting conditions, and the inadequate description of the technical properties of color stimuli in a considerable number of studies limit both the reproducibility and the comparability of empirical findings. Likewise, the predominance of university students and young adults as research participants restricts the generalizability of existing findings to broader user populations and different age groups.

Based on these findings, future empirical studies should adopt internationally recognized color specification systems and report not only hue but also value and chroma as essential attributes of color stimuli. In addition, systematically documenting technical parameters such as illuminance levels, correlated color temperature (CCT), color rendering index (CRI), screen calibration, and other characteristics of the experimental environment is recommended to enhance methodological rigor and facilitate replication. Future research would also benefit from placing greater emphasis on behavioral responses to color, validating findings obtained in virtual reality environments through comparisons with real-world settings, integrating neurophysiological measurements with subjective assessment scales, and recruiting more diverse participant samples representing children, older adults, and other user groups.

In conclusion, this study systematically analyzed the methodological characteristics and historical evolution of empirical color research in the built environment. By synthesizing methodological trends across spatial functions, investigated effect types, color presentation media, data collection instruments, color specification systems, and participant characteristics, the study provides a comprehensive methodological framework for the field. This framework is expected to serve as a valuable reference for the design of future empirical color studies and to promote more standardized, comparable, and reproducible research in the built environment.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

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This study was written by a single author. There is no conflict of interest.

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