

## Article

# Lighting as a Spatial Mediator in Museum Interior Architecture: A Theoretical Framework

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## Abstract

Museum lighting has evolved beyond its traditional technical role to become an active architectural element that shapes spatial perception, artifact conservation, and visitor experience. However, research on daylighting, artificial lighting, human perception, and museum conservation remains largely fragmented, limiting the development of integrated design strategies. This study develops a theoretical framework that conceptualizes lighting as a spatial mediator linking architecture, human perception, conservation requirements, and visitor experience within museum interior architecture. The framework is constructed through a critical synthesis of interdisciplinary literature spanning architecture, environmental psychology, lighting design, museum studies, and heritage conservation. It integrates daylighting strategies, perceptual theories, adaptive lighting technologies, and conservation principles into a unified conceptual model that explains how lighting simultaneously influences spatial atmosphere, visitor behavior, and artifact preservation. The study positions lighting as an adaptive design system and proposes design guidelines that balance experiential quality, sustainability, and preventive conservation. The framework offers a theoretical foundation and practical guidance for architects, museum professionals, and lighting designers seeking to create more integrated, engaging, and conservation-sensitive museum environments.

**Keywords:** interior lighting; museum interior; museum architecture; daylighting; environmental perception; visitor experience; heritage conservation; spatial mediation

## 1. Introduction

### 1.1. Museum Architecture and the Evolution of Lighting

Lighting has long been an essential component of museum architecture because it shapes the perception of collections and the character of exhibition spaces. Early museums relied primarily on natural daylight or conventional artificial lighting to provide adequate visibility. As awareness of light-induced deterioration increased, attention shifted toward conservation-oriented lighting standards that prioritized artifact preservation [1,2]. Advances in lighting technology, daylight simulation, and environmental psychology have since expanded the role of lighting beyond illumination, recognizing its influence on spatial perception, emotional response, visitor movement, and architectural atmosphere [3,4]. Consequently, museum lighting has evolved into an interdisciplinary field that integrates building design, environmental performance, conservation science, environmental psychology, and lighting engineering to balance artifact preservation with meaningful visitor experiences. Within this context, lighting is understood not merely as a building service but



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as an integral component of architectural design that shapes both building performance and visitor experience.

### *1.2. From Technical Illumination to Spatial Mediation*

The traditional perception of museum lighting as a technical building service has gradually evolved toward an architectural perspective in which lighting actively shapes spatial experience. Rather than serving only as a source of illumination, lighting organizes visual hierarchy, emphasizes architectural elements, guides circulation, and reinforces exhibition narratives [5]. Both daylight and artificial lighting influence the interpretation of collections by directing visual attention and modifying visitors' psychological responses to space. Intelligent lighting technologies and adaptive daylight management further demonstrate that lighting can continuously redefine relationships among architecture, exhibits, and users without physical intervention. Within this context, lighting may be understood as a spatial mediator that integrates environmental performance with human experience. In this study, spatial mediator refers to lighting's capacity to connect architectural space, environmental conditions, human perception, visitor behavior, and conservation requirements through dynamic interactions.

### *1.3. Research Gap and Aim*

Despite substantial advances in museum lighting research, existing studies remain fragmented across architecture, conservation science, environmental psychology, and visitor studies. Architectural research has primarily focused on daylight optimization and environmental performance, conservation research on minimizing photochemical deterioration, environmental psychology on perceptual and emotional responses, and museum studies on visitor behavior and satisfaction. As these perspectives are typically investigated independently, integrated design strategies that simultaneously address spatial quality, human perception, conservation requirements, and visitor engagement remain underdeveloped [6–8]. Consequently, the architectural role of lighting as an integrative design strategy in museum buildings remains insufficiently theorized, particularly regarding its capacity to connect building performance, spatial experience, and heritage conservation within a unified framework.

This study aims to develop a theoretical framework that conceptualizes lighting as a spatial mediator in museum interior architecture by integrating daylighting strategies, human perception, conservation requirements, and visitor experience within a unified architectural model. Through a critical synthesis of interdisciplinary literature, the study examines the relationships among these domains and proposes a conceptual framework to support future museum design and research. Accordingly, this paper is presented as a theoretical conceptual framework paper rather than a narrative or systematic review.

### *1.4. Research Questions*

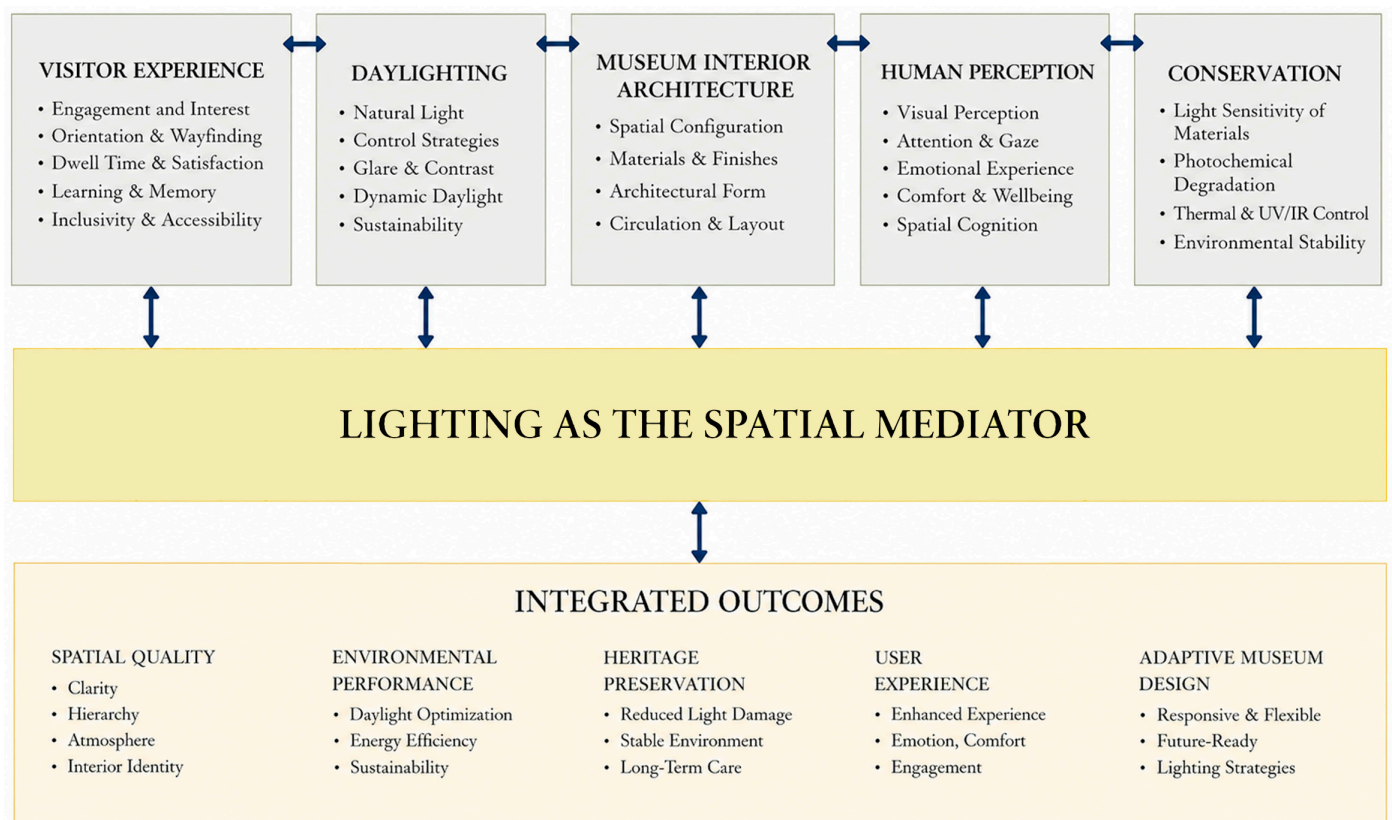
This study addresses the following research questions:

- How can lighting be conceptualized as a spatial mediator within museum interior architecture?
- How do daylighting and artificial lighting mediate the relationships among architectural configuration, human perception, visitor behavior, and conservation requirements in museum environments?
- How can the proposed theoretical framework inform adaptive lighting strategies and future museum interior architecture?

These questions collectively examine the generative mechanisms through which lighting functions as a spatial mediator, providing the conceptual basis for the theoretical framework developed in this study.

### 1.5. Novelty and Contribution

This study proposes a unified architectural framework that positions lighting as the central environmental mediator connecting building performance, museum interior architecture, human perception, artifact conservation, and visitor experience. Unlike previous studies that examine these domains separately, the proposed framework integrates interior lighting strategies with perceptual theory, conservation principles, and visitor-centered design within a single conceptual model. By bridging disciplinary boundaries, the study contributes to the theoretical development of museum interior architecture and provides architects, museum professionals, and lighting designers with a holistic foundation for creating adaptive, sustainable, conservation-sensitive, and human-centered museum environments. Beyond museum studies, the framework contributes to interior research by reconceptualizing lighting as an environmental design variable that simultaneously influences spatial organization, environmental performance, human experience, and conservation within building design. As illustrated in Figure 1, the framework also establishes a platform for future empirical investigations into intelligent lighting systems, adaptive daylight management, and evidence-based museum design.



**Figure 1.** Conceptual position of lighting as the spatial mediator integrating museum interior architecture, human perception, conservation, and visitor experience. The figure illustrates the interdisciplinary scope of the proposed framework and shows how lighting connects architectural, environmental, perceptual, and conservation dimensions within museum buildings. (Figure created by the authors.).

## 2. Methodology

### 2.1. Research Design

This study adopts a qualitative theoretical review methodology to develop an integrated conceptual framework for museum lighting within the context of museum interior architecture. Rather than conducting empirical research, this study develops a theoretical framework through a critical synthesis of interdisciplinary literature. The objective of this literature synthesis is not to provide a comprehensive review of all published studies but to develop a coherent theoretical framework that integrates knowledge from architecture, environmental psychology, lighting design, museum studies, and conservation science. This interpretive approach is appropriate for addressing the identified theoretical fragmentation within museum lighting research and for developing a unified framework that integrates previously disconnected research domains [9].

### 2.2. Literature Scope and Selection

The review draws upon the literature from architecture, interior architecture, lighting design, environmental psychology, museum studies, heritage conservation, building science, and intelligent environmental systems. Priority was given to peer-reviewed journal articles, academic books, and publications that examine museum daylighting, artificial lighting, visitor perception, conservation requirements, adaptive lighting technologies, and environmental performance. Earlier seminal publications were retained where they established fundamental theoretical concepts, while recent literature was incorporated to reflect current developments in smart lighting systems, computational simulation, and adaptive environmental control.

The literature was identified through searches of Scopus, Web of Science, ScienceDirect, and Google Scholar. The review primarily considered publications from 2000 to 2025, while retaining selected seminal studies that established the theoretical foundations of museum lighting, environmental psychology, and heritage conservation. The search included keyword combinations such as “museum lighting,” “museum interior architecture,” “daylighting,” “artificial lighting,” “human perception,” “visitor experience,” “heritage conservation,” “adaptive lighting,” “intelligent lighting,” and “spatial mediation.”

Studies unrelated to museum environments, or those focusing exclusively on engineering performance without considering architectural, conservation, or human dimensions, were excluded from the conceptual synthesis. This selection strategy ensured that the review remained focused on the interdisciplinary relationships necessary to develop the proposed framework.

### 2.3. Analytical Approach

The selected literature was examined using a thematic analysis. Recurring concepts, relationships, and design principles were identified and organized into five interconnected thematic domains: theoretical foundations of lighting as spatial mediation, daylighting strategies, human perception, conservation requirements, and visitor experience. Each theme was critically examined to identify common findings, conceptual relationships, and remaining research gaps across the different disciplines.

Rather than presenting these themes as independent bodies of knowledge, the analysis focused on identifying their points of intersection and the mechanisms through which lighting simultaneously influences architectural performance, perceptual experience, conservation practice, and environmental quality.

#### 2.4. Framework Development

The conceptual framework was developed by integrating the thematic findings from the literature review. Relationships that consistently appeared across the reviewed studies were synthesized into a unified architectural model in which lighting serves as the central spatial mediator linking environmental conditions, architectural configuration, collection sensitivity, and visitor characteristics to three interconnected outcome categories: human, conservation, and spatial. The resulting framework provides a theoretical structure that explains how daylighting and artificial lighting operate collectively as architectural, environmental, and perceptual systems within museum interior architecture, while also establishing a foundation for future empirical validation and evidence-based museum lighting research [10].

The proposed framework represents the authors' conceptual synthesis of the reviewed literature rather than a direct representation of any individual study. The reviewed evidence establishes the theoretical foundations for understanding the relationships among lighting, architecture, human perception, conservation, and visitor experience. Through thematic interpretation, recurring concepts and interactions identified across the five analytical domains were integrated into a unified conceptual model. The resulting framework distinguishes between existing evidence presented throughout the review and the authors' contribution, which lies in organizing these interdisciplinary findings into a coherent model that positions lighting as the central spatial mediator within museum interior architecture.

### 3. Lighting as a Spatial Mediator: Theoretical Foundations

Understanding lighting as a spatial mediator requires moving beyond its traditional interpretation as a technical building service toward a multidisciplinary perspective in which interior architectural phenomenology, environmental psychology, human perception theory, museum spatial experience, and environmental communication collectively explain how lighting mediates the relationship among architecture, collections, and human experience. Contemporary research demonstrates that these complementary perspectives do not operate independently but together explain how lighting influences spatial atmosphere, visual perception, visitor behavior, and conservation performance within museum interior architecture [11,12].

#### 3.1. Interior Architectural Phenomenology

Phenomenological theory considers interior space as an environment experienced through sensory perception. Within this perspective, lighting reveals materiality, texture, scale, and spatial hierarchy while shaping atmosphere and architectural meaning. In museum interiors, variations in light intensity, direction, and color temperature continuously transform spatial experience and strengthen the relationship between architecture and exhibited artifacts [13].

#### 3.2. Environmental Psychology

Environmental psychology explains how physical environments influence cognition, emotion, comfort, and behavior. Lighting represents one of the most influential environmental variables because it affects orientation, visual comfort, attention, and emotional engagement [14]. Appropriate lighting conditions encourage longer viewing durations and improve visitor satisfaction, whereas excessive glare or poor illumination may reduce spatial quality and cognitive performance [15,16].

### 3.3. Human Perception Theory

Human perception involves the active interpretation of visual information through attention, memory, and previous experience [13]. Lighting influences these processes by controlling brightness, contrast, color appearance, and visual hierarchy. In museum environments, illuminated objects naturally attract attention and guide visual exploration, while correlated color temperature and spectral composition contribute to emotional response and environmental preference [17].

### 3.4. Museum Spatial Experience

The museum experience extends beyond artifact observation to encompass the interplay among architecture, circulation, lighting, and interpretation. Daylight strengthens spatial continuity and environmental awareness, whereas artificial lighting emphasizes focal exhibits and reinforces exhibition narratives. The resulting experience emerges from the integration of architectural form and luminous environment rather than from isolated design components [18,19].

### 3.5. Lighting as Environmental Communication and Spatial Mediation

Lighting functions as a nonverbal environmental communication system that organizes spatial hierarchy, directs visitor attention, and shapes the interpretation of museum interiors [5]. Through variations in brightness, contrast, color temperature, and luminous composition, lighting distinguishes circulation areas from exhibition spaces, reinforces curatorial narratives, and supports orientation without relying on physical barriers or verbal instruction [19]. Dynamic lighting technologies further extend this communicative role by adapting illumination according to exhibition content, conservation requirements, and visitor activity [20].

From a broader theoretical perspective, lighting serves as a spatial mediator that connects architecture, collections, and human experience [16]. Rather than functioning solely as a technical building service, lighting regulates environmental performance, supports preventive conservation, enhances perception, and enriches visitor engagement [15,20]. This synthesis establishes the theoretical perspectives presented in the previous subsections and establishes the conceptual foundation for the framework developed in the following sections.

No single theoretical perspective sufficiently explains the multidimensional role of lighting within museum interior architecture. Table 1 synthesizes the complementary contributions and limitations of the principal theoretical perspectives discussed above, demonstrating how their integration provides the conceptual foundation for the proposed Spatial Mediator framework.

**Table 1.** Theoretical foundations informing the proposed spatial mediation framework.

| Theoretical Approach                 | Primary Focus                               | Contribution to Museum Lighting                                                                            | Main Limitation                                                         |
|--------------------------------------|---------------------------------------------|------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Interior architectural phenomenology | Lived spatial experience and atmosphere     | Explains how light reveals architectural form, materiality, and spatial meaning through sensory experience | Limited consideration of conservation requirements and visitor behavior |
| Environmental psychology             | Human behavior and the environment response | Explains the influence of lighting on emotion, comfort, stress, attention, and behavioral outcomes         | Limited integration of architecture as an active environmental variable |

Table 1. Cont.

| Theoretical Approach                              | Primary Focus                                                             | Contribution to Museum Lighting                                                                                                                                                                        | Main Limitation                                                                                 |
|---------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Human perception theory                           | Visual cognition and information processing                               | Explains visual attention, contrast perception, wayfinding, and cognitive interpretation of illuminated environments                                                                                   | Limited integration with broader spatial and environmental systems                              |
| Museum spatial experience                         | Visitor interaction with exhibitions and space                            | Examines how lighting supports navigation, engagement, learning, and overall visitor satisfaction                                                                                                      | Limited integration of lighting performance and conservation requirements                       |
| Light as environmental communication              | Nonverbal communication through luminous environments                     | Demonstrates how lighting directs attention, establishes hierarchy, and reinforces exhibition narratives                                                                                               | Limited integration with environmental psychology and heritage conservation                     |
| Conventional museum lighting frameworks           | Illumination standards and artifact preservation                          | Provides technical guidance for daylight control, artificial lighting, and preventive conservation                                                                                                     | Fragmented treatment of interior architecture, perception, conservation, and visitor experience |
| Proposed spatial mediation framework (this study) | Integration of architecture, lighting, conservation, and human experience | Positions lighting as the central spatial mediator linking architectural configuration, environmental conditions, collection sensitivity, and visitor experience within a unified conceptual framework | Requires empirical validation across diverse museum typologies and cultural contexts            |

4. Daylighting in Museum Interior Architecture

Daylighting is a fundamental component of museum interior architecture, contributing to visual illumination, spatial atmosphere, architectural identity, environmental sustainability, and visitor well-being. At the same time, uncontrolled daylight exposure poses significant conservation challenges because of the photochemical deterioration of sensitive collections [18,19]. Contemporary museum design therefore balances daylight utilization with artifact protection through architectural design, advanced glazing technologies, and adaptive environmental control systems [20,21]. Recent advances in daylight simulation, parametric optimization, and climate-responsive building envelopes have transformed daylighting from a passive architectural feature into an actively managed design strategy that supports spatial quality, visitor perception, and collection preservation [22–25].

4.1. Historical Evolution

Natural daylight was the primary source of illumination in early museums, where roof lanterns, skylights, courtyards, and large windows provided sufficient light before the widespread adoption of electric lighting [19,26]. Top lighting became particularly common because it produced relatively uniform illumination while minimizing shadows on exhibited objects. During the twentieth century, growing awareness of light-induced deterioration encouraged museums to reduce daylight penetration in favor of artificial lighting systems that offered greater environmental control [27,28]. Advances in glazing technologies, solar control systems, and environmental monitoring have since renewed interest in daylight integration, allowing contemporary museums to reconnect visitors with

natural light while maintaining strict conservation standards through intelligent daylight management [20,21].

#### 4.2. Museum Daylighting Strategies

Museum interiors employ multiple daylighting strategies to balance visual quality and conservation requirements. Skylights and roof systems provide diffuse top lighting that distributes illumination uniformly while limiting direct solar penetration [21]. Clerestory windows introduce indirect daylight through elevated openings, improving visual comfort and spatial perception while preserving exhibition walls [22,26]. Side lighting strengthens visual connections with the external environment but requires careful integration of shading devices, high-performance glazing, and facade design to control glare and solar gain [20,23]. Diffused daylight systems that use translucent materials, reflective ceilings, and light wells further stabilize the luminance distribution and provide appropriate conditions for sensitive collections [26].

#### 4.3. Computational Simulation and Parametric Optimization

Computational daylight simulation is an essential design tool for evaluating illuminance, daylight autonomy, annual sunlight exposure, glare probability, and luminance distribution during the early design process [20,21]. These methods enable architects to identify conservation risks, assess environmental performance, and optimize architectural geometry before construction.

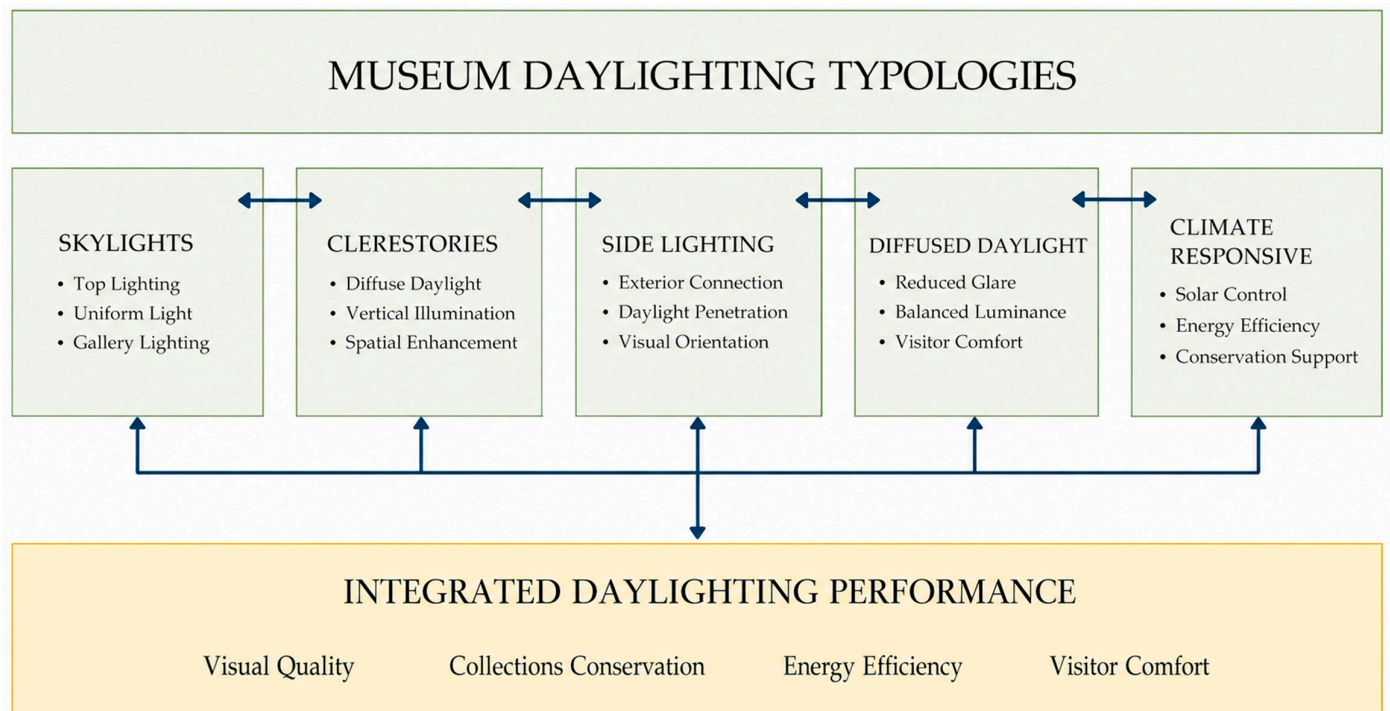
Parametric optimization further improves this process by optimizing skylight design, facade geometry, glazing, shading systems, and interior reflectance to maximize daylight quality while minimizing energy consumption and photochemical deterioration [21,24]. Multi-objective optimization increasingly integrates daylight performance with thermal comfort, visual comfort, and building energy efficiency, supporting evidence-based museum interior architecture through advanced digital design technologies [24,27].

#### 4.4. Climate-Responsive Daylighting

Effective museum daylighting must respond to geographical location, solar geometry, and local climatic conditions [26]. Museums in hot and arid climates often require extensive solar protection through shading systems, reflective roofs, double-skin facades, and high-performance glazing to reduce heat gain while maintaining adequate daylight availability [20]. In temperate regions, daylight harvesting strategies may instead prioritize increased natural illumination to reduce energy demand while maintaining appropriate conservation conditions.

Climate-responsive museum interior architecture, therefore, integrates local environmental characteristics with conservation requirements and visitor comfort to create adaptive daylighting solutions that improve sustainability without compromising collection preservation [27,28].

As illustrated in Figure 2, contemporary museum daylighting combines skylights, clerestories, side lighting, diffused daylight systems, computational optimization, and climate-responsive envelope strategies to balance spatial quality, visitor experience, environmental performance, and conservation requirements within an integrated interior architectural approach.



**Figure 2.** Museum daylighting typologies. The figure summarizes the principal architectural daylighting strategies, including skylights, clerestories, side lighting, and diffused daylight systems, and illustrates their role in balancing daylight availability, visitor experience, and artifact conservation. (Figure created by the authors.).

## 5. Human Perception and Museum Lighting

Human perception determines how visitors experience museum interiors through vision, cognition, and spatial interpretation. Lighting shapes this interaction by influencing visual clarity, attention, emotional interpretation, spatial orientation, and behavioral response [29]. Contemporary research demonstrates that museum lighting should be understood not merely as a technical system for object visibility but as an active environmental component that shapes the overall museum experience [30].

Within museum interiors, the interaction between daylight and artificial lighting creates dynamic perceptual environments that continuously influence the interpretation of architectural space and exhibited collections [31]. Variations in luminance distribution, color temperature, spectral composition, and spatial contrast modify visual adaptation and psychological atmosphere, establishing lighting as a mediator between the physical environment and human experience [32]. The discussion in this section focuses on the perceptual and cognitive mechanisms through which lighting influences human responses, whereas Section 7 examines how these mechanisms manifest as visitor experience and spatial behavior within museum environments.

### 5.1. Visual Perception

Visual perception represents the first stage of visitor interaction with museum interiors. The human visual system interprets luminance, contrast, color, texture, and depth cues to construct spatial understanding and recognize objects in view. Appropriate lighting enhances visual comfort, material appreciation, and object recognition while reducing fatigue during prolonged visits [11,33]. Balanced luminance ratios and moderate correlated color temperatures improve visual satisfaction, whereas controlled variations in illumination establish visual hierarchy without compromising comfort [34].

### 5.2. Attention and Gaze

Lighting strongly influences visual attention by directing gaze toward selected architectural features and exhibited artifacts. Human eye movements naturally respond to luminance contrast, brightness gradients, and illuminated focal points, allowing designers to guide visitor exploration through environmental cues rather than physical barriers or signage [9,34]. Accent lighting and carefully controlled contrast improve visual navigation and reinforce exhibition sequencing by sustaining attention on significant objects [35].

### 5.3. Emotional Response

Lighting contributes substantially to emotional interpretation by regulating atmosphere, visual warmth, intimacy, and environmental comfort [36]. Warm lighting generally supports contemplation and emotional immersion, whereas cooler lighting enhances alertness and visual clarity. Dynamic lighting scenarios that modify intensity and color temperature can further strengthen exhibition narratives by adapting environmental atmosphere to curatorial objectives and visitor expectations [37,38].

### 5.4. Spatial Cognition and Wayfinding

Spatial cognition and navigation depend on the visitor's ability to interpret environmental cues and construct mental representations of museum layouts. Lighting contributes to this process by establishing visual hierarchy, emphasizing circulation routes, and reinforcing orientation through illuminated landmarks and transitions [39]. Daylight entering through skylights or clerestories often serves as a natural reference point, while artificial lighting supports intuitive movement by differentiating circulation spaces from exhibition zones and emphasizing architectural sequences [34,37].

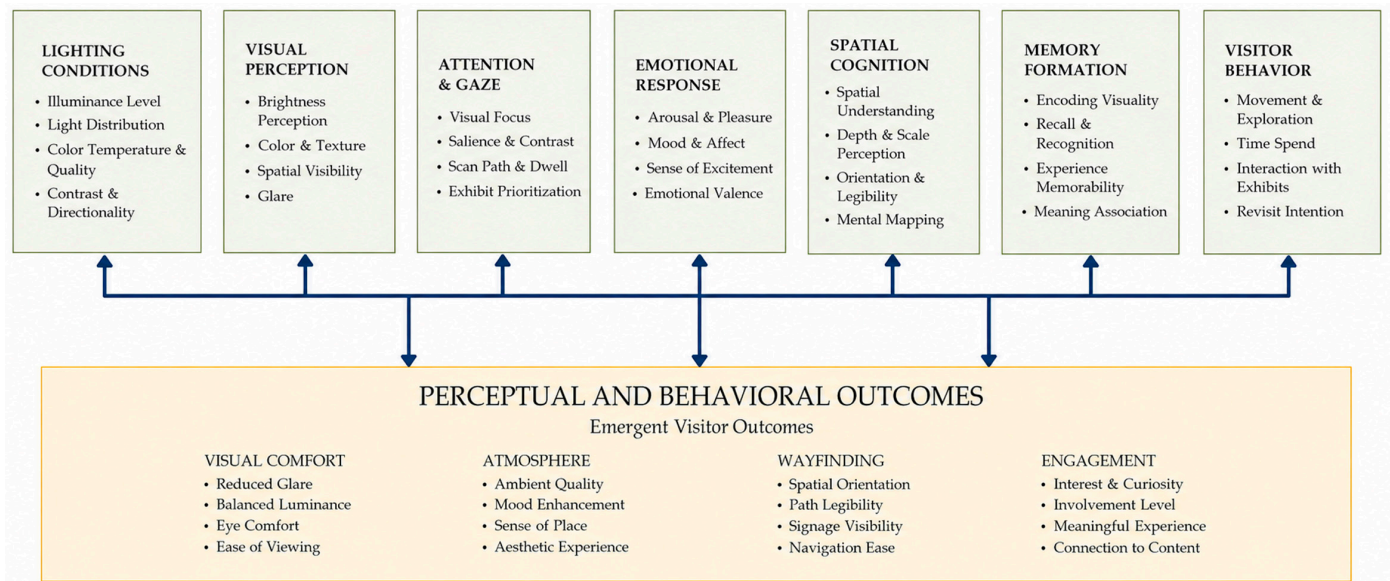
### 5.5. Atmosphere and Memory Formation

The museum atmosphere emerges from the interaction among architecture, materiality, and the luminous environment. Diffuse daylight creates calm and contemplative interiors, whereas focused artificial lighting produces dramatic emphasis and strengthens exhibition narratives [38,40]. These environments contribute to episodic memory formation by increasing visual saliency and emotional engagement. Dynamic lighting sequences and carefully illuminated focal points strengthen long-term cognitive associations between space and exhibited collections, thereby enhancing educational effectiveness and visitor recall [41–43].

### 5.6. Behavioral Response

Lighting influences visitor behavior by affecting movement patterns, attention, dwell time, social interaction, and perceived environmental quality [10]. Comfortable, luminous environments encourage prolonged observation and greater engagement with exhibitions, whereas glare or inadequate illumination may reduce visitor satisfaction and accelerate circulation through galleries. Intelligent lighting systems that respond to occupancy and environmental conditions provide new opportunities to optimize visitor behavior while maintaining conservation requirements [44].

As illustrated in Figure 3, lighting influences visitor perception through interconnected visual, cognitive, emotional, and behavioral processes that collectively shape the museum experience.



**Figure 3.** Relationship between lighting and visitor perception. The figure illustrates how lighting characteristics influence visual perception, cognition, emotional response, spatial orientation, memory formation, and visitor behavior within museum environments. (Figure created by the authors.).

## 6. Conservation Constraints and Lighting

Museum lighting supports visitor experience while preserving cultural heritage. Although appropriate illumination enhances visibility, spatial atmosphere, and interpretive engagement, excessive light exposure accelerates irreversible photochemical and thermal deterioration of sensitive collections. Consequently, lighting design requires a careful balance between accessibility and preservation through collaboration among architects, conservators, lighting designers, and museum professionals [19,20].

Advances in LED technology, computational environmental modeling, and intelligent control systems have improved the integration of conservation requirements with visitor-centered design. Contemporary museums employ adaptive lighting systems that respond to daylight availability, occupancy patterns, exhibition schedules, and conservation thresholds, supporting preventive conservation while reinforcing lighting's role as a spatial mediator within museum interior architecture [45].

### 6.1. Light-Sensitive Materials

Museum collections exhibit considerable variation in their susceptibility to light-induced deterioration. Organic materials generally exhibit greater sensitivity than inorganic materials due to their chemical composition and molecular instability under prolonged radiation exposure. Paper manuscripts, textiles, natural dyes, watercolor paintings, photographs, leather, feathers, botanical specimens, and archival documents require particularly strict environmental control, whereas stone sculpture, ceramics, metals, and glass are comparatively resistant to visible light exposure, although prolonged ultraviolet radiation may still contribute to gradual deterioration [19]. Photochemical damage is cumulative and irreversible because radiation permanently alters molecular structures through oxidation, pigment degradation, and fiber deterioration. The resulting fading, discoloration, embrittlement, and structural weakening cannot be reversed through conservation treatment, making preventive lighting design the most effective strategy for long-term preservation [25].

Contemporary museum practice increasingly classifies artifacts by sensitivity categories rather than by material type alone, allowing exhibition lighting to respond to cumulative exposure limits and display duration. This risk-based approach provides

greater flexibility in lighting design while ensuring long-term conservation objectives remain protected and reflects the growing integration of conservation science within museum interior architecture [18].

### 6.2. UV and Infrared Damage

Ultraviolet and infrared radiation represent two of the principal environmental hazards associated with museum lighting. Although ultraviolet radiation comprises only a small portion of the solar spectrum, it possesses sufficient energy to initiate photochemical degradation in numerous organic materials. Cellulose fibers, pigments, textile dyes, varnishes, and photographic emulsions are particularly susceptible to ultraviolet-induced deterioration, resulting in irreversible discoloration and structural weakening [19].

Infrared radiation poses a distinct conservation challenge by causing localized heating in illuminated objects. Thermal accumulation may accelerate chemical reactions, promote moisture migration, induce dimensional instability, and create differential expansion between heterogeneous materials. Composite artifacts with multiple material layers are particularly vulnerable to cracking, delamination, and deformation during prolonged infrared exposure [25].

Modern museum lighting systems, therefore, incorporate ultraviolet filters, infrared suppression technologies, low-emission glazing, spectrally optimized LED luminaires, and automated daylight control systems to minimize harmful radiation while preserving visual quality. Laminated glazing, selective coatings, and adaptive shading devices similarly reduce damaging wavelengths without sacrificing the perceptual benefits associated with natural illumination [20,24].

### 6.3. Exposure Limits

International conservation guidelines recommend maximum illuminance levels based on material sensitivity and expected exhibition duration, rather than on aesthetic considerations alone. Highly sensitive materials such as manuscripts, textiles, watercolor paintings, and photographs generally require illumination of no more than 50 lux during display. Moderately sensitive collections, including oil paintings, wood objects, leather artifacts, and natural history specimens, typically permit illuminance levels between 150 and 200 lux, whereas durable materials such as stone sculpture, ceramics, and metal artifacts may tolerate levels approaching 300 lux under controlled environmental conditions [44,46].

These recommendations represent compromises between visual accessibility and preservation rather than absolute physical thresholds. Exhibition duration, cumulative exposure, spectral distribution, viewing distance, and annual lux-hour dosage all influence acceptable lighting conditions. Consequently, museum conservation increasingly emphasizes integrated exposure management instead of relying solely on instantaneous illuminance measurements [44]. Architectural lighting strategies, including daylight zoning, selective shading, indirect illumination, beam control, and adaptive dimming technologies, help museums maintain appropriate exposure while preserving visual quality. This transition from fixed lighting standards toward dynamic exposure management represents a significant development in contemporary museum lighting practice [24].

### 6.4. Cumulative Exposure

Conservation science recognizes that artifact deterioration depends primarily upon accumulated light dosage rather than instantaneous illuminance. The reciprocity principle suggests that comparable cumulative exposure may produce similar deterioration, whether illumination occurs over short periods at high intensity or longer periods at lower intensity. For this reason, museums increasingly evaluate annual lux-hours rather than lux values alone when assessing conservation risk [44,47]. The concept of cumulative exposure

has transformed exhibition management by encouraging rotational display strategies, controlled exhibition durations, dark storage periods, and adaptive lighting schedules that distribute radiation over time. Sensitive collections may remain on display for only limited periods before entering extended storage, while digital monitoring systems continuously record exposure histories to support long-term conservation planning [19].

Recent advances in environmental sensing, digital twins, and intelligent building management systems enable real-time calculation of cumulative exposure by integrating daylight availability, artificial lighting operation, occupancy patterns, and exhibition schedules. These technologies support predictive conservation management by automatically adjusting lighting intensity based on predefined exposure budgets, thereby extending collection longevity while maintaining an appropriate visitor experience and environmental quality [24].

#### 6.5. Smart LED Systems

Modern LED technology enables museum illumination with unprecedented control over luminous intensity, spectral composition, color rendering, and energy consumption. Compared with conventional lighting technologies, light-emitting diode (LED) systems offer higher energy efficiency, longer operational life, negligible ultraviolet and infrared emissions, and excellent optical control, making them particularly suitable for museum applications where visitor experience and artifact preservation must be balanced simultaneously [5,19].

Modern smart LED systems integrate occupancy sensors, daylight harvesting, wireless communication, and centralized environmental management platforms that automatically adjust lighting according to visitor movement, daylight availability, exhibition schedules, and conservation thresholds. These adaptive technologies reduce unnecessary exposure while maintaining appropriate visual conditions throughout museum interiors. The integration of Internet of Things technologies and artificial intelligence further enables predictive lighting management, optimizing environmental performance while supporting preventive conservation and sustainable museum operations [6,18].

#### 6.6. Spectral Tuning

Beyond illuminance levels alone, spectral composition has become an essential consideration in museum lighting design because different wavelengths interact with pigments, dyes, textiles, and photographic materials in distinct ways. Shorter wavelengths, particularly within the blue and ultraviolet regions, generally present greater potential for photochemical deterioration than longer wavelengths, highlighting the importance of spectral management for sensitive collections [25,45].

Programmable LED technology enables precise spectral tuning by regulating individual wavelength bands while maintaining acceptable color rendering and visitor comfort. Such control allows museums to optimize lighting conditions according to collection sensitivity while preserving aesthetic appreciation and exhibition quality. Recent studies further indicate that adaptive spectral composition may improve visual perception and emotional engagement while reducing conservation risks, reinforcing the integration of conservation science with human-centered lighting design [46,48].

#### 6.7. Dynamic Conservation Control

Contemporary conservation philosophy increasingly favors adaptive environmental control over fixed lighting settings. Intelligent systems continuously regulate illuminance based on daylight availability, occupancy patterns, exhibition schedules, and conservation thresholds, thereby minimizing unnecessary radiation exposure and improving environmental efficiency [18]. Environmental sensors, daylight monitoring, occupancy detection,

lux meters, spectral sensors, and centralized management systems allow continuous adjustment of illuminance and spectral output throughout exhibition spaces. During periods of low occupancy, lighting intensity may be reduced or automatically switched off, while daylight-responsive dimming systems compensate for variations in natural illumination to maintain stable visual conditions [24].

Artificial intelligence, machine learning algorithms, and digital twins further extend these capabilities by predicting visitor movement and optimizing lighting schedules before environmental changes occur. Such predictive environmental management represents a significant transition from reactive conservation toward intelligent preventive preservation supported by computational technologies [49].

#### 6.8. Adaptive Heritage Museums

Adaptive heritage museums increasingly integrate intelligent lighting technologies with conservation science and architectural preservation strategies to create resilient exhibition environments that respond to changing environmental and operational conditions. Rather than relying on static lighting settings, adaptive systems continuously balance artifact preservation, visitor comfort, energy efficiency, and architectural authenticity through responsive environmental management [45].

Historic buildings adapted as museums present unique challenges because lighting interventions must respect existing architectural fabric while satisfying modern exhibition requirements. Advanced daylight management systems, smart glazing technologies, automated shading devices, spectrally optimized LEDs, and wireless sensor networks enable effective environmental control with minimal physical intervention, preserving both historic architecture and displayed collections [25,50].

Future adaptive museums are expected to integrate artificial intelligence, digital twins, Internet of Things technologies, and predictive environmental analytics to continuously optimize lighting based on conservation risk assessments and visitor behavior. These technologies position lighting as a spatial mediator that supports sustainable heritage management and enhances visitor experience.

The recommended lighting levels and adaptive conservation strategies for different categories of museum collections are summarized in Table 2.

**Table 2.** Recommended Illuminance Levels and Adaptive Lighting Strategies for Museum Collections.

| Collection Category              | Representative Materials                                                   | Recommended Illuminance (lux) | Recommended Lighting Strategy                                                            |
|----------------------------------|----------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------------|
| Highly sensitive collections     | Manuscripts, textiles, photographs, watercolor paintings, and natural dyes | 50                            | Strict exposure control, limited exhibition duration, and cumulative lux-hour monitoring |
| Moderately sensitive collections | Oil paintings, wood artifacts, leather objects, ethnographic collections   | 150 to 200                    | Controlled display duration, adaptive dimming, spectral management                       |
| Low-sensitivity collections      | Furniture, archaeological objects, and natural history specimens           | 200 to 300                    | Moderate environmental monitoring and daylight control                                   |
| Durable collections              | Stone sculpture, ceramics, glass, metals                                   | 100 to 300                    | Thermal control, glare management, routine environmental monitoring                      |

Table 2. *Cont.*

| Collection Category             | Representative Materials                                           | Recommended Illuminance (lux)            | Recommended Lighting Strategy                                                                                                  |
|---------------------------------|--------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Interactive digital exhibitions | Digital displays, multimedia installations, immersive environments | 100–300 (adaptive)                       | Adaptive lighting based on screen luminance, visitor interaction, and ambient lighting conditions                              |
| Temporary mixed exhibitions     | Mixed collections with varying sensitivities                       | Adaptive according to object sensitivity | Adaptive lighting control, spectral tuning, occupancy sensing, and dynamic exposure management based on collection sensitivity |

The recommended illuminance values reflect commonly adopted museum conservation guidelines and should be interpreted alongside cumulative annual exposure, exhibition duration, spectral composition, material sensitivity, and institutional conservation policies. Contemporary museum practice increasingly combines illuminance limits with cumulative lux-hour monitoring and intelligent adaptive lighting control to balance collection preservation with visitor experience [44,46].

## 7. Visitor Experience and Spatial Behavior

Museum visits are influenced by exhibited collections and the environmental conditions that frame visual perception and spatial experience. Among these conditions, lighting plays a central role by influencing navigation, exhibit interpretation, emotional response, and interaction with architectural space. Beyond illumination, lighting organizes visual hierarchy, supports orientation, reinforces exhibition narratives, and creates memorable atmospheric conditions. Contemporary museum design, therefore, recognizes lighting as a fundamental component of visitor-centered interior architecture that balances educational objectives with experiential quality [48,51].

### 7.1. Spatial Navigation

Lighting contributes significantly to spatial navigation by improving visual legibility and reinforcing circulation patterns throughout museum interiors. Variations in brightness, contrast, and focal illumination naturally attract attention and guide movement toward exhibition areas, circulation routes, and architectural landmarks. Illuminated focal points establish intuitive wayfinding cues that reduce visitor confusion and improve orientation, particularly within complex gallery layouts [33,52]. Daylight entering through atria, skylights, and clerestories further strengthens spatial understanding by providing visual reference points and reinforcing relationships between interior and exterior environments. Combined with carefully positioned artificial lighting, these strategies establish coherent visual sequences that encourage exploration while maintaining spatial continuity [20,47].

### 7.2. Dwell Time and Visitor Satisfaction

Lighting conditions directly influence visitor engagement and overall satisfaction. Comfortable visual environments characterized by balanced illumination, appropriate contrast, and high color rendering quality encourage prolonged observation and deeper interaction with exhibited artifacts, whereas excessive glare or insufficient illumination may reduce viewing duration and diminish experiential quality [32,35].

Research indicates that visitor engagement increases when lighting provides balanced luminance distribution, controlled luminance contrast, and high color rendering, allowing visual details to be perceived without discomfort. Excessive luminance contrast, glare, or

uneven illumination increases visual fatigue and may shorten viewing duration, whereas moderate contrast combined with appropriate spectral quality supports sustained attention, deeper cognitive processing, and greater emotional engagement with exhibited artifacts. Although specific lighting parameters vary by collection type, exhibition design, and museum context, the literature consistently demonstrates that lighting influences visitor behavior through the sequential relationship among visual input, cognitive interpretation, emotional response, and behavioral outcomes [51].

### *7.3. Museum Identity and Emotional Engagement*

Lighting contributes to museum identity by defining spatial character and reinforcing curatorial narratives. Distinctive luminous environments establish memorable impressions that differentiate museums from other cultural institutions while strengthening architectural identity and visitor recognition [52].

Lighting also shapes emotional responses by modifying perceived warmth, intimacy, drama, and visual atmosphere. Variations in brightness, correlated color temperature, and luminance contrast influence psychological states ranging from curiosity and excitement to contemplation and tranquility. Moderate illumination, combined with balanced color temperatures, generally promotes emotional immersion, while dynamic lighting scenarios reinforce exhibition narratives and enrich the visitor experience [53].

### *7.4. Social Interaction*

Lighting influences patterns of social behavior by shaping how visitors gather, communicate, and collectively experience exhibitions. Comfortable ambient lighting encourages conversation and shared observation, whereas localized accent lighting promotes individual contemplation by directing attention toward specific artifacts. The spatial distribution of illumination therefore supports both social interaction and personal reflection, in line with the exhibition's objectives [54].

Public gathering spaces and interactive exhibitions typically employ brighter, more uniform illumination to facilitate communication, whereas quieter gallery spaces benefit from focused, subdued lighting that encourages individual engagement with exhibited objects [35].

### *7.5. Cultural Adaptation*

Visitor responses to lighting are influenced by cultural background, regional preferences, and previous environmental experiences. Preferences for brightness, color temperature, and daylight availability vary across cultural groups, suggesting that universal lighting solutions may not meet the needs of increasingly diverse museum audiences [55]. Adaptive lighting systems capable of modifying intensity and spectral composition offer opportunities to accommodate these differences while maintaining conservation requirements and architectural coherence. Such flexibility supports more inclusive and culturally responsive museum environments [20].

### *7.6. Inclusive Museum Lighting*

Inclusive lighting design seeks to provide equitable visual conditions for visitors of diverse ages, physical abilities, and perceptual characteristics. Appropriate luminance distribution, glare control, color contrast, and visual clarity improve accessibility for elderly visitors and individuals with visual impairments while enhancing environmental comfort for all users [47,50].

Recent advances in intelligent lighting systems enable museums to combine adaptive illumination, occupancy sensing, and daylight-responsive controls to create environments that respond to changing visitor needs throughout the day. By integrating accessibility principles with architectural design and conservation objectives, inclusive lighting con-

tributes to museum environments that are simultaneously welcoming, educational, and culturally meaningful. These human-centered approaches reinforce lighting's role as a spatial mediator that connects architecture, collections, and diverse visitor populations through adaptive environmental design [56].

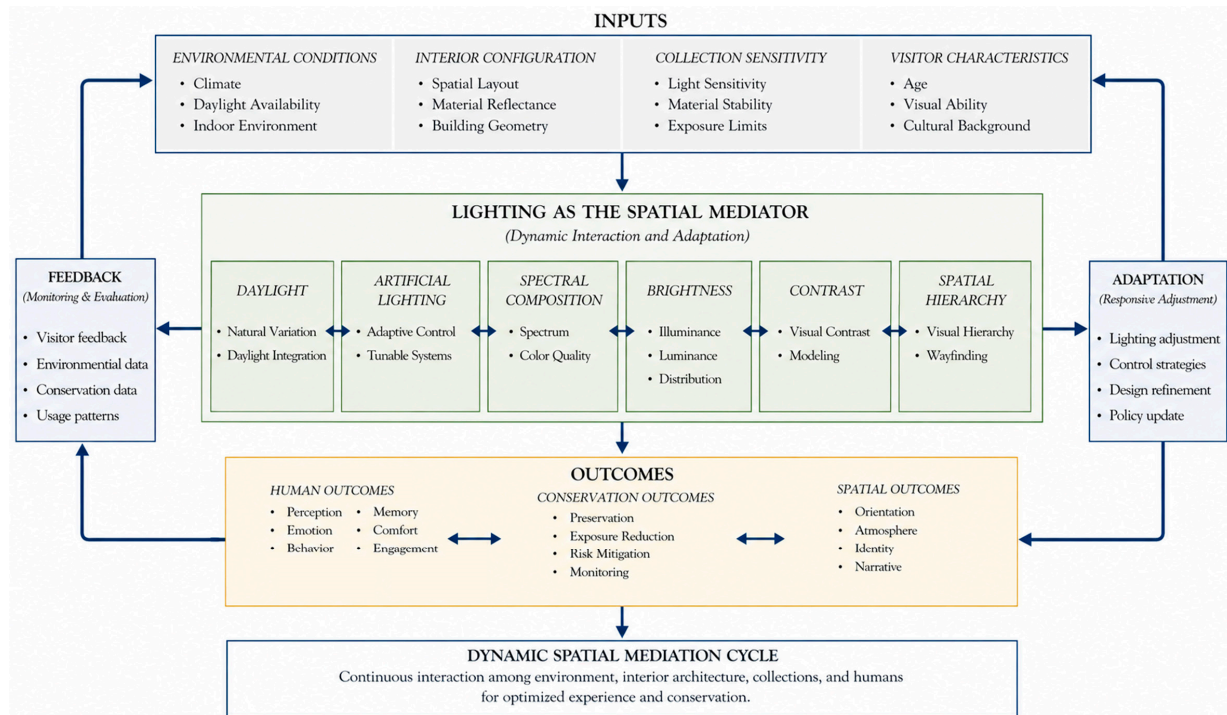
Before presenting the integrated framework, it is important to position the proposed model within the existing body of museum lighting research. Previous studies have generated valuable knowledge on individual aspects of museum lighting, including daylighting performance, conservation requirements, visitor perception, and environmental psychology. However, these perspectives have generally been developed independently and therefore provide only partial representations of the complex relationships that shape museum interior environments. Table 3 compares the principal perspectives identified in the literature with the proposed framework and highlights the additional contribution of integrating architectural, environmental, perceptual, conservation, and experiential dimensions within a single conceptual model.

**Table 3.** Comparison of Existing Perspectives and the Proposed Spatial Mediation Framework for Museum Interior Architecture.

| Existing Perspective       | Primary Focus                                      | Main Limitation                                              | Contribution of the Proposed Framework                                                                                                                                                      |
|----------------------------|----------------------------------------------------|--------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Museum lighting studies    | Illumination quality and exhibit visibility        | Fragmented consideration of perception and conservation      | Integrates lighting with architectural configuration, human perception, conservation, and visitor experience                                                                                |
| Daylighting research       | Daylight performance and environmental efficiency  | Emphasis on environmental performance                        | Integrates daylighting with artificial lighting, spatial experience, and conservation requirements                                                                                          |
| Conservation guidelines    | Protection of light-sensitive collections          | Priority is given to preservation over visitor experience    | Balances conservation requirements with human-centered design                                                                                                                               |
| Environmental psychology   | Perception, cognition, and emotional response      | Limited architectural integration                            | Connects psychological responses with architectural lighting strategies                                                                                                                     |
| Visitor experience studies | Navigation, engagement, satisfaction, and behavior | Weak integration with environmental control and conservation | Integrates visitor experience within a comprehensive environmental framework                                                                                                                |
| <b>Proposed framework</b>  | <b>Integrated museum interior architecture</b>     | <b>Requires future empirical validation</b>                  | <b>Integrates previously independent research domains by positioning lighting as the central spatial mediator linking architecture, environmental conditions, collections, and visitors</b> |

As illustrated in Figure 4, the proposed Spatial Mediation Cycle demonstrates the adaptive feedback relationships among environmental conditions, lighting variables, visitor responses, conservation requirements, and spatial outcomes, showing how these continuously influence subsequent lighting decisions within museum interior architecture.

To further demonstrate the practical relevance of the proposed framework, Figure 5 presents a hypothetical application within a daylight-sensitive museum gallery. The illustration shows how environmental conditions, architectural configuration, collection sensitivity, and visitor characteristics collectively inform lighting decisions to achieve balanced human, conservation, and spatial outcomes. The scenario is intended solely to illustrate the conceptual application of the framework and does not represent an empirical case study or validated design.



**Figure 4.** Integrated theoretical framework for lighting as a spatial mediator in museum interior architecture. The figure presents the proposed Spatial Mediation Cycle, illustrating the relationships among environmental inputs, lighting variables, human outcomes, conservation performance, and spatial experience. (Figure created by the authors.).

#### Illustrative Application of the Theoretical Framework in a Daylight-Sensitive Exhibition Gallery (Hypothetical Scenario)

This illustration demonstrates how the proposed framework can guide lighting decisions in a museum context. It does not present empirical findings but shows a potential application scenario.

| CONTEXT<br>Environmental & Spatial Conditions                                                                                                                                                                                                                                                       | FRAMEWORK INPUTS<br>Key Considerations                                                                                                                                                                                                                                                                                                                                                                                                                               | LIGHTING DECISIONS<br>Framework-Based Responses                                                                                                                                                                                                                                                                                                                                                                                                                                       | EXPECTED OUTCOMES<br>Theoretical Implications                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>Hot-arid climate</li> <li>East-west building orientation</li> <li>High daylight availability with potential glare</li> <li>Temporary exhibition gallery</li> <li>Daylight-sensitive mixed-media artworks on loan</li> <li>General public visitors</li> </ul> | <p><b>Daylighting Strategy</b><br/>Top lighting with diffused north light; light shelves to improve uniformity</p> <p><b>Zoning</b><br/>High sensitivity artworks near façade; moderate and low sensitivity zones toward the interior</p> <p><b>Lighting Approach</b><br/>Minimize daylight exposure; use adaptive artificial light</p> <p><b>Control Strategy</b><br/>Dynamic adjustment based on daylight availability, occupancy, and conservation thresholds</p> | <p><b>Daylight Management</b><br/>Filtered north light, external shading, and high-performance glazing</p> <p><b>Artificial Lighting</b><br/>Adjustable track spotlights with narrow beam for accent; uniform ambient lighting for general areas</p> <p><b>Controls</b><br/>Daylight sensors, occupancy sensors, and dimming for real-time adaptation</p> <p><b>Conservation Measures</b><br/>Maintain illuminance and UV/IR within safe limits; reduce cumulative light exposure</p> | <p><b>Perceptual &amp; Experiential Outcomes</b><br/>Balanced brightness, enhanced artwork emphasis, spatial comfort</p> <p><b>Behavioral Outcomes</b><br/>Clear circulation, longer dwell time, increased engagement</p> <p><b>Conservation Outcomes</b><br/>Controlled light levels and spectrum protect sensitive materials</p> <p><b>Environmental &amp; Operational Outcomes</b><br/>Reduced energy use through daylight utilization and adaptive controls</p> | <p>These outcomes are interdependent and respond continuously to changing environmental and occupancy conditions.</p> |

| APPLICATION SCENARIO<br>Daylight-Sensitive Exhibition Gallery                                                                                                                                                                                                                                                                                                                                                                          |                             |                                        |                                                    | LIGHTING STRATEGY IN ACTION                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | FEEDBACK & ADAPTIVE LOOP                                                                                                                                                                                                                                                                                                                                                                                        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|----------------------------------------|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>A temporary exhibition gallery with mixed-media artworks that include light-sensitive materials (e.g., drawings, textiles, photographs) and moderately sensitive paintings. The gallery has a large clerestory on the north with high daylight availability and the potential for glare on the east and west. The design challenge is to provide visual comfort and highlight artworks while protecting them from light damage.</p> |                             |                                        |                                                    | <p><b>Daylight Management</b></p> <ul style="list-style-type: none"> <li>North clerestory with diffusing glazing</li> <li>Light shelves redirect daylight to the ceiling</li> <li>External louvers reduce east-west glare</li> </ul> <p><b>Artificial Lighting</b></p> <ul style="list-style-type: none"> <li>Track spotlights with 10°–20° beam for accents</li> <li>Adjustable CCT (2700–4000K) for ambience</li> <li>Uniform ambient lighting for general circulation</li> </ul> <p><b>Controls &amp; Adaptation</b></p> <ul style="list-style-type: none"> <li>Daylight-linked dimming</li> <li>Occupancy-based adjustment</li> <li>Scene setting for different exhibition activities</li> </ul> <p><b>Conservation Control</b></p> <ul style="list-style-type: none"> <li>Illuminance within recommended limits</li> <li>UV/IR filtered or eliminated</li> <li>Regular monitoring and preventive maintenance</li> </ul> | <p><b>Monitor</b><br/>(Daylight levels, illuminance, occupancy, light dose)</p> <p><b>Evaluate</b><br/>(Performance for visitors, collections, energy)</p> <p><b>Continuous adaptation to achieve balanced human, conservation, and environmental performance.</b></p> <p><b>Analyze</b><br/>(Compare with thresholds &amp; objectives)</p> <p><b>Adjust</b><br/>(Lighting levels, scenes, shading devices)</p> |
| Zone                                                                                                                                                                                                                                                                                                                                                                                                                                   | Location in Gallery         | Collection Sensitivity                 | Lighting Priority                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Zone A                                                                                                                                                                                                                                                                                                                                                                                                                                 | Along façade (north & east) | High (drawings, textiles, photographs) | Protection first (low illuminance, strict control) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Zone B                                                                                                                                                                                                                                                                                                                                                                                                                                 | Central display area        | Moderate (paintings)                   | Balanced (visual quality + conservation)           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Zone C                                                                                                                                                                                                                                                                                                                                                                                                                                 | Toward the interior         | Low (sculptures, digital displays)     | Experience first (higher flexibility)              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                 |

Note: This scenario is illustrative and based on the proposed theoretical framework. It does not represent an empirical case study or measured outcomes.

**Figure 5.** Application of the proposed framework to museum interior architecture. The figure demonstrates how the theoretical framework informs adaptive lighting strategies that integrate daylighting, artificial lighting, conservation requirements, and visitor-centered design to support sustainable museum environments. (Figure created by the authors.).

## 8. Results: Integrated Theoretical Framework for Museum Interior Architecture

The proposed framework is founded on the principle that every lighting decision shapes architectural perception, emotional response, spatial orientation, conservation performance, visual comfort, and museum identity. Rather than functioning as a static technical system, museum lighting responds to daylight availability, occupancy patterns, exhibition requirements, climatic conditions, and collection sensitivity, thereby generating interconnected perceptual, behavioral, spatial, and conservation outcomes [51,52].

The proposed Spatial Mediation Cycle explains how environmental inputs shape lighting decisions that, in turn, influence visitor perception, conservation performance, and spatial experience. Visitor responses, including movement, visual attention, and exhibition interaction, subsequently inform later lighting decisions through intelligent control systems. Unlike conventional linear lighting models, this cyclic process presents museum interiors as adaptive environments characterized by continuous interaction among architecture, collections, lighting, and visitors [53].

The framework comprises four categories of environmental inputs. Environmental conditions, including climate, daylight availability, weather, and seasonal variation, influence lighting performance [57]. Architectural configuration, including spatial geometry, skylight systems, facade openings, exhibition layout, and circulation patterns, shapes daylight distribution and spatial hierarchy [20,56]. Collection sensitivity defines conservation requirements through material composition, pigment stability, cumulative exposure limits, and exhibition duration [44,46]. Visitor characteristics, including visual ability, accessibility needs, cultural background, and previous museum experience, influence environmental perception and lighting requirements [12,50].

These inputs are mediated through six lighting variables. Daylight and artificial lighting provide complementary sources of illumination, while spectral composition influences visual perception and material deterioration [58]. Contrast establishes visual hierarchy and supports navigation, brightness regulates visual comfort and emotional response, and spatial hierarchy organizes architectural sequences and visitor movement through coordinated luminous composition [13].

The interaction of these variables produces three interconnected outcome categories. Human outcomes include perception, emotion, behavior, memory, comfort, and engagement [48]. Conservation outcomes include artifact preservation, reduced cumulative light exposure, and intelligent environmental monitoring [45]. Spatial outcomes include orientation, narrative sequencing, atmosphere, and institutional identity that collectively define the architectural character of museum interiors [59].

The proposed framework integrates previously fragmented research domains into a unified conceptual model that positions lighting as the central spatial mediator linking architectural configuration, conservation requirements, and human experience. It provides a theoretical foundation for museum interior architecture that balances sustainability, heritage preservation, and visitor-centered design, and establishes the conceptual basis for the practical design guidelines presented in the following section [45,47].

## 9. Discussion and Design Implications

### 9.1. Discussion

The proposed framework positions lighting as an active spatial mediator that integrates architectural configuration, visitor perception, environmental performance, and conservation requirements within a unified conceptual model. Unlike previous studies that have examined daylighting, conservation, visitor perception, and intelligent lighting technologies as separate domains, the proposed framework synthesizes these perspectives

into a coherent theoretical model for museum interior architecture. This synthesis extends current museum lighting research by linking architectural design, environmental psychology, conservation science, and intelligent environmental control within a single theoretical perspective [53].

From a practical standpoint, the framework provides a conceptual foundation for interdisciplinary collaboration among architects, interior designers, lighting consultants, conservators, and museum professionals. Rather than treating lighting as a technical service, the framework supports a human-centered approach in which lighting functions as an environmental system that simultaneously contributes to visitor experience, sustainability, and preventive conservation.

Future museum design should adopt adaptive lighting strategies that simultaneously enhance visitor experience, support artifact preservation, and improve environmental sustainability through intelligent building technologies [58]. Building upon the proposed theoretical framework, the following design guidelines translate its conceptual principles into practical recommendations for museum interior architecture.

The proposed framework also provides direct answers to the research questions established at the beginning of this study. First, it conceptualizes lighting as a spatial mediator that connects architectural configuration, environmental conditions, conservation requirements, and visitor experience within the museum interior. Second, it demonstrates that daylighting and artificial lighting influence perception, spatial experience, and visitor behavior through their effects on visual hierarchy, environmental quality, and adaptive environmental control. Third, it shows that conservation requirements can be integrated with visitor-centered lighting strategies through intelligent environmental management, spectral control, cumulative exposure monitoring, and adaptive lighting systems. Finally, the study presents an integrated theoretical framework that unifies the architectural, perceptual, conservation, and experiential dimensions into a coherent model to support future museum lighting design and research.

### 9.2. Integrated Lighting Strategies

Museum lighting should combine daylight and artificial illumination through coordinated design supported by daylight simulation and environmental modeling [60]. Intelligent zoning, occupancy sensing, and adaptive control systems support responsive environmental management [47]. High-performance LED luminaires with programmable spectral output, daylight harvesting technologies, and centralized environmental management platforms can optimize visual comfort while minimizing cumulative light exposure and operational energy consumption [49,59]. Heritage museums should prioritize minimally invasive interventions and reversible technologies [61,62], whereas contemporary museums should integrate intelligent facades, digital environmental modeling, and predictive lighting management from the earliest design stages [63]. The principal recommendations for integrating daylighting, artificial lighting, conservation, and intelligent environmental control are summarized in Table 4.

**Table 4.** Design recommendations for interior architects and museum designers.

| Design Aspect        | Recommended Strategy                                                                                                                                                                                                              | Primary Benefit                                                                     |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Daylight integration | Integrate diffuse daylight through skylights, clerestories, light wells, and filtered glazing as part of a spatial mediation strategy that balances visitor perception, conservation requirements, and environmental performance. | Improves visual quality, reduces energy demand, and strengthens spatial experience. |

Table 4. *Cont.*

| Design Aspect                              | Recommended Strategy                                                                                                                                                                                                                                      | Primary Benefit                                                                                                                                              |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Artificial lighting</b>                 | Employ high-CRI LED luminaires with programmable intensity and spectral composition to reinforce spatial hierarchy, enhance visual perception, and protect sensitive collections.                                                                         | Enhances visual perception while supporting artifact conservation.                                                                                           |
| <b>Lighting zoning</b>                     | Organize lighting zones according to collection sensitivity, visitor activities, and spatial functions to support adaptive spatial mediation rather than uniform illumination.                                                                            | Improves environmental control, operational flexibility, and exhibition quality.                                                                             |
| <b>Smart controls</b>                      | Integrate occupancy sensing, daylight harvesting, programmable dimming, and centralized environmental management to continuously balance visitor experience, conservation requirements, and energy efficiency.                                            | Reduces energy consumption and minimizes unnecessary light exposure.                                                                                         |
| <b>Adaptive systems</b>                    | Utilize real-time environmental monitoring and adaptive lighting control that respond continuously to visitor behavior, daylight availability, and conservation thresholds through continuous feedback.                                                   | Optimizes lighting performance while balancing visitor experience and preservation needs.                                                                    |
| <b>Heritage museums</b>                    | Apply reversible, minimally invasive lighting interventions that preserve historic fabric while integrating adaptive environmental controls compatible with heritage conservation.                                                                        | Preserves historic architectural fabric while improving exhibition performance.                                                                              |
| <b>Contemporary museums</b>                | Integrate daylight simulation, parametric design, intelligent facades, and digital environmental modeling from the earliest design stages to optimize the interaction among architecture, lighting, and visitor experience.                               | Supports holistic optimization of sustainability, perception, and conservation objectives.                                                                   |
| <b>Future AI-assisted lighting systems</b> | Employ artificial intelligence, digital twins, predictive analytics, and machine learning to support adaptive spatial mediation that continuously optimizes lighting according to environmental conditions, visitor behavior, and collection sensitivity. | Enables intelligent adaptive environmental control, improved visitor experience, enhanced artifact preservation, and reduced operational energy consumption. |

### 9.3. Study Limitations

The proposed framework is conceptual and synthesizes evidence from interdisciplinary literature rather than being empirically validated in a specific museum context. Consequently, the relationships among lighting variables, visitor behavior, conservation performance, and environmental outcomes should be interpreted as a theoretical model that requires future validation through post-occupancy evaluation, environmental monitoring, behavioral observation, and experimental studies across different museum typologies and climatic regions. Furthermore, the framework does not account for differences in museum governance, operational constraints, budget availability, or rapidly evolving lighting technologies, which may influence its implementation in practice. In addition, the framework is intended as a conceptual foundation rather than a prescriptive design methodology and should therefore be adapted to the specific functional, climatic, cultural, and operational requirements of individual museum projects.

### 9.4. Future Research Directions

Future museum interior architecture will increasingly integrate artificial intelligence, digital twins, real-time environmental sensing, immersive technologies, and biometric evaluation to create adaptive museum environments that continuously optimize lighting in response to visitor behavior, environmental conditions, and conservation requirements [64].

Machine learning algorithms, occupancy analytics, virtual reality simulation, and cross-cultural lighting research will support evidence-based environmental management while strengthening accessibility, emotional engagement, and long-term preservation of cultural heritage. These developments position lighting as an intelligent architectural system that has the potential to enhance sustainability, operational efficiency, visitor experience, and collection protection. However, their practical implementation requires careful consideration of economic feasibility, technical complexity, maintenance requirements, data privacy, and compliance with conservation standards. Future empirical research should validate and refine the proposed framework through comparative case studies, post-occupancy evaluations, environmental measurements, behavioral observations, and interdisciplinary investigations across different museum typologies, climatic regions, and cultural contexts.

## 10. Conclusions

This study reconceptualizes museum lighting as a spatial mediator that actively links architectural configuration, environmental conditions, human perception, artifact conservation, and visitor experience. Through a critical synthesis of interdisciplinary literature, it proposes a unified theoretical framework that integrates previously fragmented perspectives from architecture, lighting design, environmental psychology, museum studies, and conservation science.

The proposed framework positions lighting as an adaptive interior architectural system rather than a technical building service, demonstrating how daylighting, artificial lighting, and intelligent environmental control can simultaneously support spatial quality, visitor engagement, and preventive conservation. By integrating these dimensions within a single conceptual model, the study contributes to the theoretical development of museum interior architecture and provides a foundation for more holistic and human-centered design approaches.

As a theoretical contribution, the proposed framework should be regarded as a conceptual foundation rather than an empirically validated model. Future research should evaluate and refine the framework through comparative case studies, post-occupancy evaluations, environmental monitoring, and behavioral investigations across diverse museum typologies and cultural contexts.

Overall, the study advances current understanding of museum lighting by positioning it as an active architectural system that connects building performance, conservation, and human experience. This perspective provides a foundation for future research and supports the development of adaptive, sustainable, and conservation-sensitive museum environments.

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