

RESEARCH ARTICLE

Analysis and constructing the formation of volumetric light space in the works of Louis I. Kahn



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Abstract This article takes a look at Louis I. Kahn's volumetric light space as a clue to the unique process and construction of his volumetric light space. Specifically, the article analyzes Kahn's early travels and teaching process, as well as the influence of his paintings and quotes on the formation of volumetric light spaces. Through a chronological analysis of Kahn's built and unbuilt works in his 50-year architectural career, the article identifies representative examples of volumetric light spaces and summarizes the three core elements of volumetric light spaces: volumetric frames, apertures, and light conditioning structures. After that, the graphic analysis of the volumetric light space of key cases (Exeter Library and Kimbell Art Museum) is used to reveal the design connection between spatial layout, interface organization and structural relationship. By emphasizing the formation of Kahn's particular light space, the article attempts to integrate Kahn's philosophical perspectives, interpret this unique personal label, and demonstrate the design rules and logic of the formation of this space.

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1. Introduction

As one of the most influential architects of the 20th century, Louis I. Kahn produced an extensive body of work between 1924 and 1974, distinguished by his masterful use of natural light and a uniquely defined spatial identity. In Kahn's architectural practice, light was not merely a core element in shaping atmosphere and enhancing meaning; it functioned as an integrated design strategy, deeply interwoven with structure, materiality, and function. Building on this foundation, architects and scholars across the globe have examined Kahn's luminous spaces from diverse perspectives, including his philosophical outlook, structural systems, and spatial organization. However, existing scholarship tends to emphasize the symbolic significance of natural light or the aesthetic effects of light and shadow, often overlooking a comprehensive analysis of the systematic development of volumetric light spaces throughout Kahn's career.

Accordingly, the central question this article seeks to address is: How did Louis I. Kahn conceptualize and construct the notion of volumetric light spaces over the course of his career? To answer this question, the study first offers a systematic definition of volumetric light spaces and examines the evolution of this concept through an in-depth analysis of Kahn's representative works. Drawing from these case studies, the article further articulates a design strategy characterized by the interrelation of three core components—volumetric frame, lighting aperture, and light-modulating structure. Each element reinforces and enhances the others, revealing Kahn's nuanced integration of form, light, and structure in the creation of his luminous spatial compositions.

This study not only deepens the understanding of Kahn's design logic regarding light spaces but also enriches the current research by articulating his core ideas in shaping light spaces, addressing gaps in defining this design concept and its intrinsic mechanisms. Moreover, it provides contemporary architects with new ideas and technical support for creating natural light environments, adapting designs to their environments, and shaping spatial intentions. Additionally, it offers fresh perspectives for the academic community to extend Kahn research or explore interdisciplinary fields between optics and architectural design.

2. Literature review

2.1. Definition of “volumetric light-space” in architectural design

The term “volumetric lighting” originated in computer-generated graphic arts and was initially applied to computer-generated images in three-dimensional (3D) games and films (Kniss et al., 2003). Essentially, “volumetric lighting” refers to a lighting technique that enhances, amplifies, or simulates the sense of volume in a given three-dimensional space by providing a specific perspective, direction, and effect (Nowrouzezahrai et al., 2011; Lam, 1992). As early as in his own philosophical reflections, architect Louis Kahn integrated light with mass,

likening architectural structures to “containers of light” (Büttiker, 2019; Steane, 2011), in *The Architecture of Light*, pointed out that natural light can serve as a design tool. Through the guidance of architectural openings, reflective surfaces, and refractive elements, it can create an integration of light and material within a space.

Jin et al. (2022) further advanced this concept from the perspective of artificial lighting design. In his analysis of Alvar Aalto's luminaire designs, he proposed that the propagation of light can be shaped through design into a form of “volume,” which is not merely a physical phenomenon but is also closely linked to the expressive qualities of light in space. This theory provides insight into the transition from artificial light to the study of “volumetric light space” in natural lighting. Although Tanizaki, J. I. and Tanizaki, J (2001) did not explicitly use the term “volumetric light space” in his seminal work *In Praise of Shadows*, his descriptions of the soft diffusion of light and shadow in traditional Japanese architecture implicitly suggest how light, when controlled, can create a sense of volume and atmosphere. Within the context of modern architecture, Neumann et al. (2010) explored the “ontological presence” of light in architecture by examining the collaboration between Louis Kahn and lighting designer Richard Kelly”. Similarly, Lobell and Kahn (2008) argued that Kahn regarded light as the “source of existence,” endowing it with a material-like quality through architectural structure—an idea that aligns closely with the core principles of “volumetric light space.”

2.2. Research on Kahn's “light space” design philosophy and construction techniques

Louis Kahn is widely recognized in twentieth-century architectural discourse for his philosophical reflections and methodical approach to the use of light. As noted by Kahn (1991), Kahn did not treat light as an ancillary element but rather as a constitutive material—equally essential as architectural form itself. Light played a pivotal role in both the spatial organization and the emotional resonance of his architecture. In his philosophical interpretation of Kahn's use of light, Lobell and Kahn (2008) introduced the Daoist concept of “wu wei” (non-action) from Chinese philosophy, proposing that Kahn's conception of “light as matter” reflects the yin-yang dialectic of complementary opposites. Adopting a phenomenological lens, Pallasmaa (2024) explores the philosophical depth of Kahn's treatment of light, emphasizing its profound implications for human perception. Curtis (2012) highlights how Kahn's “light-space” design, through the metaphor of silence and light, makes architecture's invisible order tangibly expressive. Furthermore, in *Rome and the Legacy of Louis I. Kahn*, Barizza and Falsetti (2018) traces Kahn's philosophical roots, arguing that his meditations on light were deeply influenced by ancient Roman architecture.

In examining the construction of luminous environments in Kahn's architecture, Büttiker (2019), in *Louis I. Kahn: Light and Space*, analyzed how Kahn employed architectural elements to guide and modulate light, thereby creating spatial experiences characterized by a pronounced volumetric presence. Kacel and Lau (2018), through their

study of Kahn's collaborations with lighting designer Richard Kelly, highlighted Kahn's consistent use of meticulously designed light-modulating structures to craft interior lighting conditions that reinforced spatial differentiation and evoked a sense of ritual. Drawing upon Kahn's philosophical reflections on natural light and his material choices, Lu (2017) and Hu (2018) explored the symbolic meanings and material foundations underpinning his concept of light-space. Yi and Li (2017), focusing on the dome and lighting system of the Kimbell Art Museum, emphasized the building's innovative treatment of transparency and diffuse illumination. Ronner et al. (1987), in a comprehensive review of Kahn's oeuvre, argued that his later works increasingly abstracted architectural form into vessels for light, reflecting a growing emphasis on spatial essence over structural complexity. Kacel and Lau (2018) further emphasized Kahn's distinctive preference for integrating natural light into interior environments, underscoring the synergy between lighting design and architectural construction in his collaborative works.

2.3. Limitations of existing research

- (1) Lack of definition and design strategy summary for "volumetric light space"

Although existing research literature on Louis Kahn's architectural works frequently discusses "light space" or "natural lighting," most studies approach these topics from aesthetic or symbolic perspectives. There is a lack of definition and design strategy summary regarding how light manifests a recognizable three-dimensional "volumetric quality" in architecture. Researchers often analyze specific case studies but fail to extract universally applicable light-space models (Brownlee et al., 1991). Similarly, while some researchers have explored the interaction between light and space in Kahn's work, they have not developed a structured volumetric light model. Their studies tend to focus on phenomenological descriptions rather than systematic summarization (Büttiker and Kahn, 1994; Plummer, 2016; Neumann et al., 2010; Steane, 2011).

- (2) Disconnection between conceptual origins and design practice

Kahn's concept of light space was deeply influenced by his travel sketches and philosophical reflections. However, existing research often separates his conceptual origins from his architectural practice. While scholars have conducted in-depth analyses of Kahn's philosophical foundations, they have not effectively linked these ideas to the construction methods in his specific works (Lobell and Kahn, 2008; Curtis, 2012). Some researchers have explored the spatial effects of light from a perceptual perspective but have not traced these effects back to their design origins (Pallasmaa, 2024). This disconnection results in an incomplete understanding of the formation process of Kahn's light space.

- (3) Insufficient exploration of construction logic and element interaction

Although previous studies have discussed daylighting structures (Yi and Li, 2017), they have not systematically explained how Kahn utilized three key elements—"volumetric frame," "lighting aperture," and "light modulating structure"—to achieve layering and control of light in space. With advancements in computer simulation and rendering technologies, research on the numerical and simulation-based evaluation of light environments in Kahn's architectural works has been gradually increasing (Nasrollahi and Shokry, 2020; Abdollahzadeh et al., 2020; Ahmady et al., 2023). However, there is still a lack of systematic research focusing on the concept of "volumetric light space." Most technical studies concentrate on energy efficiency and comfort assessments, without deeply analyzing Kahn's distinctive "mass meets light" design philosophy.

2.4. Innovations of this study

This study is the first to systematically identify the compositional elements of Kahn's volumetric light space and to propose an operational model for its architectural articulation. It begins with a chronological analysis of the evolution of Kahn's light-space concepts, drawing on his paintings, sketches, and written reflections. Subsequently, representative case studies of volumetric light spaces are selected, with their developmental trajectories examined through simplified sectional and plan diagrams. These diagrams are cross-referenced with Kahn's major works to reveal the conceptual and design logics underlying his approach to volumetric light. Finally, two key projects are analyzed using the proposed framework of volumetric frame—lighting aperture—light modulating structure, elucidating how Kahn introduced and integrated natural light into architectural volumes from the external environment. By doing so, this study offers a comprehensive strategy for both future architectural practice and academic research on the integration of light and space.

3. Research design and methods

3.1. Research objectives

This study aims to deconstruct the formation logic of volumetric light space in Louis I. Kahn's architectural works and extract its applicable design principles. The specific objectives include:

- Establish the conceptual definition of volumetric light space, tracing Kahn's intellectual progression from the intuitive perception of light to its rational architectural construction.
- Conducting a longitudinal comparison of light-space design across Kahn's different project phases, identifying the evolutionary trajectory of volumetric light space.
- Analyzing key case studies to examine the detailed design strategies of Kahn's volumetric light space, extracting actionable design principles.

3.2. Methods

This study integrates multiple research methods, including textual interpretation, evolutionary synthesis, and case analysis. Textual interpretation and evolutionary synthesis provide philosophical-historical and stage-characteristic background support for case studies, respectively. Meanwhile, case analysis utilizes diagrammatic techniques to examine the practical application of Kahn's volumetric light space.

These three methods complement each other, forming a comprehensive research framework that unifies historical and technical perspectives as well as macro and micro-level analyses. The specific methodological framework is illustrated in Fig. 1.

3.2.1. Textual interpretation

The study collects and organizes paintings and sketches, including Kahn's manuscripts, sketchbooks, and watercolor works from his early travels, teaching, and conceptual design phases. These materials often hint at the architect's initial reflections on the relationship between light and volume. Secondly, the study collects quotations and interviews, focusing on Kahn's discussions about the relationship between light, space, and structure in lectures, speeches, and student interactions (Kahn, 1991), as well as his reflections on the use of natural light upon project completion. By comparing high-frequency concepts and key visual/verbal imagery, the study identifies potential patterns and philosophical principles in Kahn's integration of light and space, providing theoretical support for subsequent evolutionary synthesis and case validation.

3.2.2. Evolutionary synthesis

Given that Kahn's reflections on light and space evolved progressively over his 50-year career—from vague concepts to mature applications—this study adopts an “evolutionary synthesis” approach to systematically analyze his works across different periods (Sun, 2023; López-Sanvicente, 2023; Rubio and Rubio, 2024).

- Early exploration stage (1924–1954): Focuses on Kahn's academic projects and early works, examining his initial attempts at light-space integration.
- Formative stage (1954–1967): Investigates his continuous experimentation with “volumetric light” in religious and public buildings.
- Mature stage (1967–1974): Highlights recognized masterpieces of Kahn's light-space design, such as the Kimbell Art Museum, discussing the integration of light guidance and structural fusion.

The periodization criteria are based on Kahn's architectural timeline and the widely accepted classifications by key scholars, organizing his works according to chronological milestones and significant projects (Ronner et al., 1987; Büttiker, 2019). After a comprehensive review, we further extract works with distinct volumetric light characteristics and analyze them in conjunction with textual and pictorial materials. This process aims to identify key milestones in the maturation of volumetric light spaces.

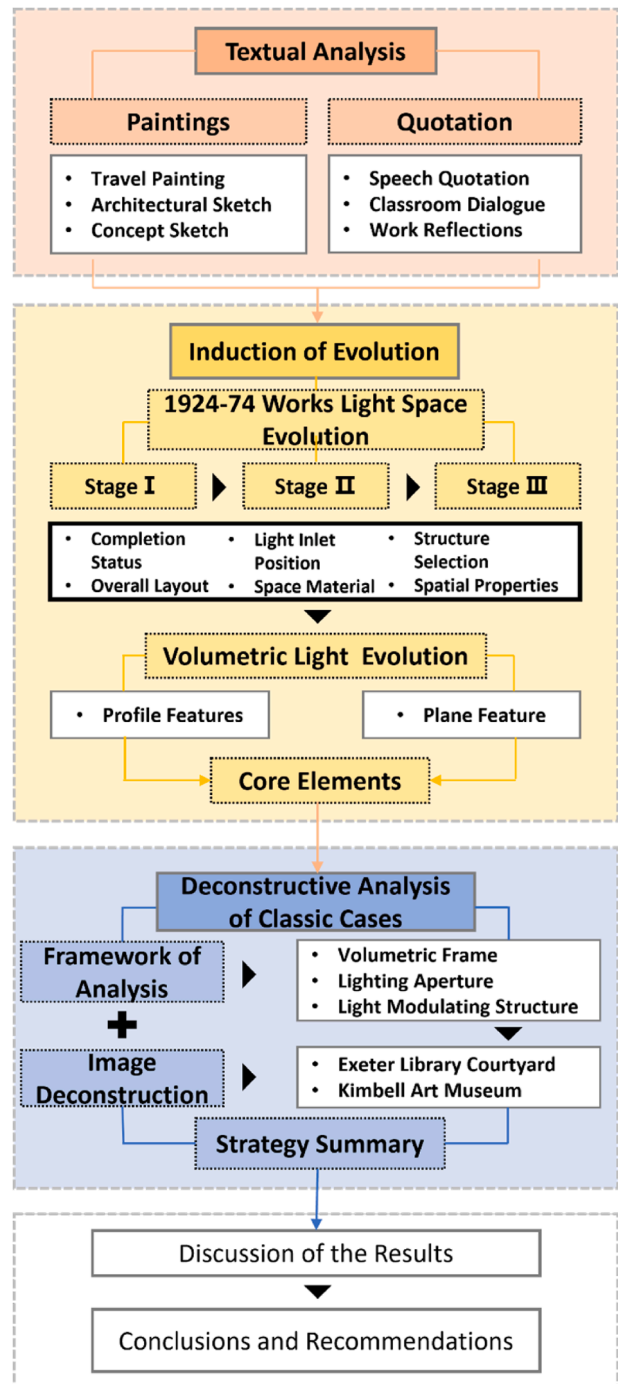


Fig. 1 Research framework.

Ultimately, we distill the relevant features of light-space treatment and synthesize the three core elements of volumetric light space.

3.2.3. Case study: diagrammatic analysis

This study employs diagrammatic analysis to conduct an in-depth examination of key cases. Diagrammatic analysis can visually represent complex design concepts and structural relationships, transforming abstract ideas into comprehensible visual formats that facilitate the understanding and communication of design logic. By utilizing plan

drawings, sectional diagrams, and detail illustrations, the study clearly expresses the relationships among various compositional elements and their evolutionary processes. This approach helps to reveal the overall design framework and its progressive development. Moreover, diagrammatic analysis highlights similarities and differences across different cases, enabling cross-case comparisons that help verify the universality and limitations of design strategies (Büttiker, 2019; Zhang, 2022; Ching, 2023).

The study selects Exeter Library and Kimbell Art Museum as in-depth case studies. Both buildings, completed in 1972, are widely regarded as the most representative examples of Kahn's mature-phase natural lighting design. Based on original architectural drawings, the study distills key spatial diagrams that highlight geometric order, light entry points, and light-modulating components to clearly express Kahn's design intent. Following the three core elements of volumetric light space identified earlier, the study conducts a diagrammatic logic analysis and deconstruction of the light-mass relationship.

4. Analysis and results

4.1. Textual analysis

The study traces the origins and evolution of Kahn's "volumetric light" concept by analyzing his paintings, sketches, and public lecture texts. By examining Kahn's early travel sketches, mid-career lecture notes, and scholarly interpretations of his artworks, we can explore how he developed a distinctive sense of volume through the interplay of light and structure.

4.1.1. Clues to volumetric light

Although interpretations of Kahn's works often focus on his architectural forms, some researchers have pointed out that analyzing his texts and drawings can also provide deeper insights into his spatial logic (Espelta, 2003; Wiseman, 2007; Serrano and Desvaux, 2016). RG Rubio focuses on three of Kahn's paintings from his travels in Italy, interpreting his thoughts on Mediterranean architecture (Rubio and Orusco, 2020). Costa assert that Kahn's paintings from his travels have a profound influence on his architectural works (Barros Costa et al., 2020).

Kahn's travels and drawings in Italy, Egypt, and Greece from December 1950 to February 1951 are regarded as pivotal to the formation of his design concepts. In numerous sketches, Kahn used bright blocks of color to eliminate the

background of buildings, outlining the edges of silhouettes with contrasting shadows (Zhang, 2020). As shown in Fig. 2, Kahn uses a square frame as the overall visual boundary and outlines the building with a light background color. The warm colors emitted by the building are more vibrant than the solid colors of the background. Additionally, the shadows create a distinct boundary for the buildings, providing the outlines with a rich variety and a sense of solidity. This visual treatment suggests that light is not merely a measure of brightness and darkness but appears to possess a perceptible or even compositional volumetric quality.

For Kahn, light and shadow were interdependent. In his paintings, he depicted light as a substance capable of penetrating walls and floors to reach the depths of a space, making contours appear especially distinct. This subtly echoes his later architectural philosophy of "holding light within structure."

The most significant sense of light materialisation that we find presented in Kahn's paintings was in September 1959, Kahn's third trip to Europe. As shown in Fig. 3, in his sketches of the Chapel of Notre Dame du Haut, Kahn emphasizes the spatial state created by natural light, which is channeled through the window openings from the east wall to the entire interior. Kahn used white to depict light and black to represent shadow in his black-and-white sketch. The light gradually enters the room through the corner window, penetrating the interior space along the wall and floor. A sentiment echoed by Le Corbusier, the architect of the Chapel of Notre Dame du Haut, who stated that "light is the key" when describing the building's design (Yang et al., 2021).

In addition to expressing light indirectly through architecture in his travel sketches, Kahn also experimented with directly depicting light as a tangible entity using white paper and black ink in his later career. As shown in Fig. 4, two of Kahn's rare 1972 artworks integrate both image and text. In these pieces, he uses a continuous flow of words to form a frame on a boundless white surface, thereby creating a defined boundary for light within the plane (Desvaux and Áilvaro, 2017).

This, in turn, establishes a closed boundary for light within the plane. The text on the left emphasizes the relationship between matter and light, with light permeating the entire interface—irregular yet omnipresent: spending to the emergence of materia, the prevailing luminous, groups to ignore or wild chance of flaming prevalence. The image on the right, on the other hand, suggests the interdependence of light and shadow. The fleeting

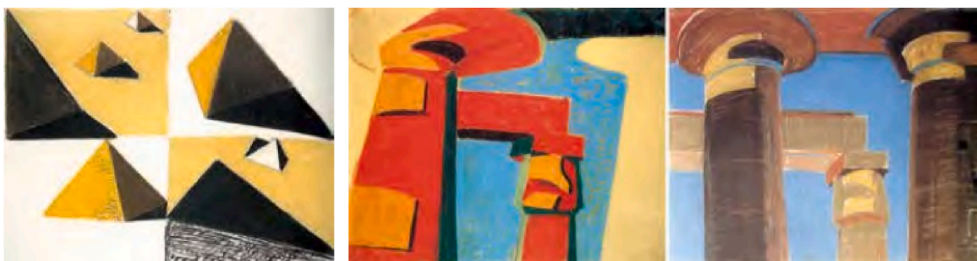


Fig. 2 Louis I. Kahn's European sketches. Photo Source: Hochstim et al. (1991).



Fig. 3 Comparison of interior spatial sketch and actual view—Chapel of Notre Dame du Haut. Photo Source: [Hochstim et al. \(1991\)](#) (left); Jean-Pierre Dalbéra (right), licensed under CC BY 2.0.

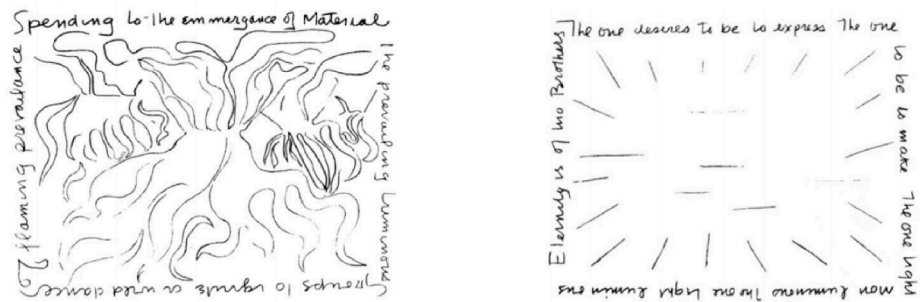


Fig. 4 Light emitted by matter (left); eternally existing bright light (right). Photo Source: [Desvaux and Áilvaro \(2017\)](#).

black lines represent shadow, while the shadows seeming to be brighter, as if the light is entrapped and infused within them: the one deserves to be to express, the one to be to make, the one light more luminous, the one light luminous; Eternity is of two brothers.

In these two manuscripts, Kahn depicts the fullness of light and the contrasting interplay between light and shadow, framing both states of illumination as though they were contained within a picture frame. Even as a flat expression, Kahn wants to convey a diffuse quality that fills the entire space, suggesting that this is the only way to capture the attention of all viewers. This suggests that Kahn had already developed a clear artistic expression of light's "containability," laying the foundation for his later proposition that "Light is the measurable."

A comprehensive analysis of his sketches and drawings reveals that beneath Kahn's brushstrokes and words lay the early seeds of his concept of light as a tangible entity for organizing architectural space. At the same time, many scholars have regarded Kahn's artistic and literary expressions as key elements that bridge his architectural philosophy and practical design methods ([Rubio and Orusco, 2020](#); [Barros Costa et al., 2020](#)).

4.1.2. Philosophical underpinnings

Kahn frequently emphasized personally significant keywords such as "order," "form," "being," and "light" in his writings ([Kahn, 1991](#)). "Light is the measurable" as defined by Kahn, who describes it as being intertwined with matter. In his 1973 lecture at Pratt Institute in New York, he stated, "Light is, in fact, the source of all that exists. I tell myself that while the world remains in a state of chaos, without

any shape or direction, this chaos is filled with a desire for expression—a wonderful amalgamation of joy, this desire serves as its shell, making it visible." ([Lobell and Kahn, 2008](#)).

In addition to describing the physical properties of light, Kahn is particularly focused on the presence of shadows: "Light, the giver of the actual thing, casts its shadow, and the shadow belongs to the light" ([Lobell and Kahn, 2008](#)). This fully highlights the interdependent nature of light and shadow. Kahn believed that the shadows created by light define light itself, serving as a symbolic expression of its presence.

Kahn further regarded light and matter as two inseparable aspects of the same entity, introducing the counterintuitive concept that "Matter is the light that exists" ([Lobell and Kahn, 2008](#)). In his philosophy, light was no longer merely an environmental factor but, together with material and structure, became the fundamental substance of architectural creation.

What Kahn accomplished was not merely the introduction of natural light into architecture but rather the interweaving of light and shadow, material and form, allowing light to become the dominant force in shaping spatial experience. From a philosophical perspective, his advocacy for "the measurability of light" was not a matter of simple rational calculation. Instead, he treated the measurement of light with the same importance as the order of form, endowing light with a sense of materiality and sacredness. This aligns with his deep contemplation of the concept of "presence."

Our examination of Kahn's past texts and images reveals that he had already begun attempting to connect light with

quantifiable concepts such as matter, form, and presence, gradually clarifying the spatial manifestation of light. Within the architectural context, the concept of “volumetric light space” also became increasingly distinct: The phenomenological articulation of light as a tangible, spatial entity with distinct massing characteristics and material presence.

4.2. Evolutionary synthesis of Kahn’s light-space

In our analysis of Kahn’s works, we have included statistical information on unbuilt projects alongside completed ones. To differentiate between them, we use the following notation: 0-xxxx for unbuilt projects; 1-xxxx for built projects.

4.2.1. Overview of Kahn’s 1924–1974 design career

(1) 1924–1954: early exploration stage

As shown in [Table 1](#), an analysis of Kahn’s works from 1924 to 1954 indicates that his early light-space designs lacked complex light-modulating structures. Nonetheless, Kahn consistently explored shading strategies, evolving from simple roof eaves to cantilevered wooden louvers and perforated aluminum panels. He employed elements like glass bricks and curtains to regulate sunlight based on spatial function, and used sliding wooden panels in four projects for active light control. Most light spaces from this period were rectangular, except the cylindrical stairwell in the Yale Art Gallery, which also introduced Kahn’s first defined light-modulating structure—a triangular beam diffusing upper-level light downward.

(2) Lighting aperture

As shown in [Table 2](#), from 1954 to 1960, Kahn’s light-space compositions became more refined, often adopting centrally or axially symmetrical volumes. He introduced light gaps between roofs and walls to enable controlled daylighting and diffuse reflection, improving interior light quality. The iconic “T”-shaped window first appeared in the Tribune Review Publishing Company Building, balancing large solid wall surfaces with generous upper-level glazing for effective daylight penetration ([Büttiker and Kahn, 1994](#)).

The most notable advancement during this period was the refinement of light-modulating elements. In the unbuilt U.S. Consulate in Luanda, Kahn introduced the double-wall structure and transformed the “T”-shaped window into a “parasol”-shaped aperture to filter direct sunlight. This design was later re-applied in the Salk Institute’s conference center. In terms of light-entry strategies, Kahn made a breakthrough by exclusively using high clerestory windows to illuminate a windowless room, fully meeting functional lighting needs. This approach was further developed in Erdman Hall Auditorium, where minimized openings subtly shaped the lighting atmosphere. At the Philadelphia Arts Center, Kahn introduced vertical light shafts—precursors to the “light tower”—which became a recurring feature in his later work.

As shown in [Table 3](#), Kahn’s projects during this period—including religious, cultural, and academic buildings—are renowned for their refined interior light and atmospheric depth. In the unbuilt Mikveh Israel Synagogue, Kahn first introduced a suspended curved ceiling and the “light tower” concept. These elements were later realized in the National Assembly Building in Dhaka, where the mosque featured the first built “light tower” and suspended ceiling, bringing daylight and ventilation into the enclosed prayer hall to enhance spiritual ambience. The Exeter Library atrium developed the ring-shaped clerestory windows from the Yale Art Gallery and refined the light-guiding system of the Dhaka Mosque. The Kimbell Art Museum marked the culmination of Kahn’s daylighting strategies, synthesizing earlier elements such as perforated aluminum panels, roof openings from the Trenton Bath House, and concealed skylights from the First Unitarian Church into a coherent, sophisticated lighting system.

4.2.2. Evolving analysis of “volumetric light”

We find that the evolution of Louis I. Kahn’s architectural creation can be distinctly interpreted through the interaction between volumetric/mass and natural light. In the early stage (1924–1954), Kahn’s works were largely function-driven, relying on simple window openings for daylighting. At this point, volumetric form and light remained independent elements in his designs.

As he moved into the mid-stage (1954–1960), projects such as the Yale University Art Gallery and the Trenton Bath House demonstrated his growing exploration of spatial modules and window opening strategies. During this phase, the relationship between form and light became increasingly clear—space was endowed with a sense of order, while light predominantly entered from the upper part of the space, marking the early conceptualization of “Volumetric Light.”

The mature stage (1960–1974) was the period when Kahn brought “Volumetric Light” to its fullest expression. Clearly defined geometric volumes (Volumetric/Mass), carefully designed lighting aperture, and light-modulating structures worked together to shape space. Natural light was no longer merely a decorative or functional supplement but became a structurally bounded and “materialized” spatial element in its own right.

This article further refines the selection of representative works that best embody “Volumetric Light Space” characteristics. By aligning these projects with key moments in Kahn’s sketches and statements, a visualized evolutionary timeline of “Volumetric Light” is constructed. As shown in [Fig. 5](#), we examine Kahn’s work after his 1951 European trip, accompanied by a concise diagrammatic representation of volumetric light space in both section and plan. In his design for the stairwell of the Yale University Museum of Art, created between 1951 and 1953, Kahn introduced natural light for the first time, achieving a complete volumetric state through the use of an upright cylinder. In his design for the Trenton Bathroom, which spanned four years from 1954 to 1959, Kahn’s approach to natural light became even more diverse. He employed a combination of a “cone” roof and a central skylight to gently diffuse light into the interior space while directing it

Table 1 Statistics of architectural light space elements in the early exploration stage 1924–1954. Source: Büttiker (2019), Ronner et al. (1987).

Name	Time	City	Spatial element		Lighting element		Dimming element	
			Volume	Function	Location	Method	Component	Function
0-Shopping center	1924	None	Asymmetrical form	Shopping	Single-sided wall	Floor-to-ceiling window	None	None
1-Jersey homesteads	1935–1937	New Jersey, USA	Asymmetrical form	Living room	Single-sided wall	Floor-to-ceiling window	Cornice	Blocking light
0-Ahavath Israel synagogue	1935–1937	Pennsylvania, USA	Asymmetrical form	Lecture room	Single-sided wall	Square window	Curtains + glass tiles	Filtering light
0-Prepabricated house studies	1937–1938	None	Asymmetrical form	Living room	Single-sided wall	Floor-to-ceiling window	Cornice	Blocking light
1-Jesse oser house	1940–1942	Pennsylvania, USA	Asymmetrical form	Living room	Corner wall	Floor-to-ceiling window	Curtains	Filtering light
0-L. Broydo house	1941–1942	None	Asymmetrical form	Living room	Single-sided wall	Ribbon window	Cantilevered timber brise-soleil	Blocking + filtering light
1-Carver court housing	1941–1942	Pennsylvania, USA	Asymmetrical form	Bedroom	Single-sided wall	High square window	Cornice + curtains	Blocking + filtering light
0- Hotel for 194X	1942	None	Asymmetrical form	Hotel	Single-sided wall	Ribbon window	Cantilevered corrugated aluminum panel	Blocking + filtering light
0-International ladies garment workers union health center	1943–1945	None	Asymmetrical form	Lobby	Single-sided wall	Floor-to-ceiling bay window	None	None
0-Parasol houses	1944	None	Asymmetrical form	Cafeteria	Articulated wall	Floor-to-ceiling window	Cantilevered brise-soleil	Blocking + filtering light
0-Philadelphia psychiatric hospital	1944–1946	None	Asymmetrical form	Sickroom	Single-sided wall	Slanted high window	None	None
1-B.A. Bernard house	1945	Pennsylvania, USA	Asymmetrical form	Bedroom	Single-sided wall	Ribbon window	Cornice	Blocking + filtering light
0-Solar house	1945–1947	None	Asymmetrical form	Living room	Single-sided wall	Ribbon window	Cornice + cantilevered timber brise-soleil + sliding wooden panel	Blocking + filtering light
1-Roche house	1947–1949	Pennsylvania, USA	Asymmetrical form	Living room	Articulated wall	Floor-to-ceiling window	Cornice + skylights	Blocking + filtering light
1-Weiss house	1947–1950	Pennsylvania, USA	Asymmetrical form	Living room	Single-sided wall	Divided-light floor-to-ceiling window	Cornice + cantilevered timber brise-soleil + sliding wooden panel	Blocking + filtering + Screening light
1-Bernard S. Pincus Building, Philadelphia	1948–1954	Pennsylvania, USA	Asymmetrical form	Function room	Single-sided wall	Divided-light floor-to-ceiling window	Cornice + sliding wooden panel	Blocking + screening light

Psychiatric hospital 1-Radbill Building, Philadelphia	1948–1954	Pennsylvania, USA	Asymmetrical form	Sickroom	Single-sided wall	Ribbon window	Cornice + suspended hollow wooden skeleton	Blocking + filtering light
Psychiatric hospital 1-Yale university art gallery	1951–1953	Connecticut, USA	Centrally symmetric cylinder	Stairwell	Continuous wall	Circular high window	Glass brick + triangular concrete plates as “light blades”	Filtering + diffusing light
0-Fruchter house	1951–1954	None	Asymmetrical form	Living room	Single-sided wall	Divided-light floor- to-ceiling window	Sliding wooden panels	Screening light

along the interior walls. Architect Ann Ting, who collaborated closely with Kahn in the documentary film *My Architect: A Son's Journey*, credits Kahn with discovering his own identity in the design of the building. Kahn has said, “After the Trenton Baths were completed, I no longer needed to be inspired by any other architect” (Ronner et al., 1987). On his third trip after this, Kahn travelled to France and visited the churches of Albi, the medieval château of Carcassonne, and Corbusier’s La Chapelle de Ronchamp. During this journey, he gradually began to emphasize the physical state of light’s existence. In the First Unitarian Church and the Eleanor Donnelly Erdman Hall, both constructed between 1959 and 1969, the centrally symmetrical space of both adopts a decentralized layout with lateral light inlets. Columnar volumetric light located at the corners, utilizing right-angled walls to enclose the volumetric silhouette.

In 1972, Kahn sketched two representations of light on white paper (Fig. 4). Corresponding to this temporal anchor, he also completed two of his most iconic works—the Exeter Library and the Kimbell Art Museum. The light-space atmosphere of these two buildings perfectly corresponds to Kahn’s two depictions of light: light contrasted by shadow, appearing radiant and striking; light filling the space, omnipresent and diffuse. In Kahn’s post-1972 works, he continued to use square barrels in the design of the atrium space at the Yale Center for British Art. However, this time he chose to open the windows directly into the roof. With a sophisticated dimming structure that diffuses light before it enters the space, each skylight is designed as a large concrete cross with four rounded glass roofs. This design creates a dynamic interplay of light and shadow as if it were the Exeter Library all over again. In the octagonal silo of the Dhaka Convention Hall in Bangladesh, Kahn’s hyperbolic parabolic suspended ceiling maximizes the concentration of natural light around the edges toward the center. This design enhances the brightness of the upper space, resulting in a clear image of evenly diffused light.

4.2.3. The constructive logic of volumetric light space

By considering the temporal sequence of volumetric light generation, we can define volumetric contour in two key ways: first, it requires the interface of objective entities to create an enclosure, and second, it necessitates precise control over the angle and intensity of incoming light to ensure that the light and matter within the space undergo a transformative “existence property.” As the final step in shaping volumetric light, Kahn’s architectural designs incorporate unique dimming components, which can be categorized into structural dimming and independent dimming based on their functionality. Structural dimming utilizes the building’s structure itself to modulate light, while independent dimming employs separate components to optimize the quality of natural light entering the building. In Kahn’s approach to volumetric light space shaping, the volumetric frame serves as the foundation for existence; the light entry aperture acts as the prerequisite for illumination; and the dimming structure ensures the stable realization of light within the space.

As evident from the previous discussion, around 1972 marked the critical moment when Kahn fully realized the three key elements of “Volumetric Framework—Lighting

Table 2 Statistics of architectural light space elements in the 1954–1960 formative stage phase. Source: Büttiker (2019), Ronner et al. (1987).

Name	Time	City	Spatial element		Lighting element		Dimming element	
			Volume	Function	Location	Method	Component	Function
1-American federation of labor medical services Building	1954–1957	Pennsylvania, USA	Asymmetrical form	Function room	Continuous wall	Glass facade	Skeleton beams + curtain	Blocking + filtering light
1-Ewing township Jewish community center bath house	1954–1959	New Jersey, USA	Central symmetry cube	Changing room	Roof centre + roof-wall skylight	Skylight + high side window	Roof + wall	Diffusing light
0-Morris house	1955–1958	New York, USA	Asymmetrical form	Living room	Single-sided wall	Vertical floor-to-ceiling window	Vertical divider	Blocking light
0-Washington university library	1956	Missouri, USA	Asymmetrical form	Library	Articulated wall	Glass facade	Cantilevered metal brise-soleil	Blocking + filtering light
1-Clever house	1957–1962	New Jersey, USA	Central symmetry cube	Living room	Continuous high-side wall	Protruding triangular window	Triangular-shaped cornice	Blocking + diffusing light
1-Pennsylvania University laboratory	1957–1965	Pennsylvania, USA	Central symmetry cube	Studios	Articulated wall	Ribbon window	Blue glass	Filtering light
1-Tribune review publishing company building	1958–1962	Pennsylvania, USA	Asymmetrical form	Studios	Single-sided wall	T-shaped window	None	None
0-Fleisher house	1959	Pennsylvania, USA	Central symmetry cube	Living room	Single-sided wall	Umbrella-shaped window	None	None
1-Esherick house	1959–1961	Pennsylvania, USA	Asymmetrical form	Living room	Single-sided wall	Floor-to-ceiling window/T-shaped window	Curtain + sliding wooden panel	Diffusing + screening light
0-U.S. Consulate and residence	1959–1962	Luanda, Angola	Asymmetrical form	Studios	Single-sided wall	Floor-to-ceiling window	Perforated double-layer wall	Blocking + filtering light
1-Salk institute for biological studies-laboratory	1959–1965	California, USA	Asymmetrical form	Laboratory	Single-sided wall	Floor-to-ceiling window	Cantilever beams + sliding wooden panel	Diffusing + screening light
0-Salk institute for biological studies-conference centre	1959–1965	California, USA	Centrally symmetric cylinder + cube	Chapel	Continuous wall	Floor-to-ceiling window	Perforated double-layer wall	Blocking + filtering light
1-First unitarian church and school	1959–1969	New York, USA	Central symmetry cube	Chapel	Continuous high-side wall	Ribbon window	Roof + wall	Diffusing light
1-Erdman Hall	1960–1965	Pennsylvania, USA	Central symmetry cube	Chapel	Four-cornerd tower	Floor-to-ceiling window	Roof + wall	Diffusing light
0-Philadelphia college of art	1960–1966	Pennsylvania, USA	Asymmetrical form	Courtyard	Roof	Circular window	None	None
1-Fisher house	1960–1967	Pennsylvania, USA	Asymmetrical form	Living room	Articulated wall	Floor-to-ceiling window	Sliding wooden panel	Filtering light

Table 3 Statistics of architectural light space elements in the maturation and refinement stage 1960–1972. Source: Büttiker (2019), Ronner et al. (1987).

Name	Time	City	Spatial element		Lighting element		Dimming element	
			Volume	Function	Location	Method	Component	Function
0-Mikveh Israel synagogue	1961–1972	Pennsylvania, USA	Centrally symmetric cylinder	Chapel	Continuous wall	Vertical light tower	Suspended roof + wall	Diffusing + filtering light
1-Indian institute of management	1962–1974	Ahmedabad, India	Axially symmetric cuboid	Library	Single-sided wall	Large circular window	Overhanging eave + double-layer wall	Blocking + filtering light
1-Ayub central hospital	1962–1974	Dhaka, Bangladesh	Asymmetrical form	Portico	Continuous wall	Large circular window	Roof + double-layer wall	Diffusing + filtering light
1-National assembly complex mosque	1962–1983	Dhaka, Bangladesh	Centrally symmetric cylinder + square column	Chapel	Articulated wall	Light column + grid window	Cross beam + cylindrical wall	Diffusing light
1-Phillips exeter academy library	1965–1972	New Hampshire, USA	Centrally symmetric cylinder	Atrium	Continuous wall	High-side window	Cross beam + cylindrical wall	Diffusing + contrasting light
1-Olivetti-underwood factory	1966–1970	Pennsylvania, USA	Centrally symmetric cube	Living room	Single-sided wall	Umbrella-shaped window	None	None
1-Kimbell art museum	1966–1972	Texas, USA	Axially symmetric arch	Public space/ Exhibition hall	Arch crown	Linear window	Curved glass + vaulted structure + aluminum light modulator	Filtering + diffusing light
1- Temple beth-el synagogue	1966–1972	New York, USA	Centrally symmetric square column	Chapel	High-side continuous wall	Square window	Wall	Diffusing light
0-Hurva synagogue	1967–1974	Jerusalem, Israel	Centrally symmetric cube	Chapel	Wall light slit + roof-wall skylight	Linear window	Wall	Diffusing light
1-Wolfson center for mechanical and transportation engineering	1968–1974	Tel aviv, Israel	Axially symmetric arch	Mechanical room	Wall light slit + roof-wall skylight + arch crown	Linear window	Curved glass + vaulted structure + aluminum light modulator	Filtering + diffusing light
1-Yale center for british art	1969–1974	Connecticut, USA	Centrally symmetric cube	Atrium	Roof	Skylight	Metal louver + sunshade + curved plexiglass + V-shaped cross beam	Blocking + filtering + diffusing light
1-Family planning center and maternal health center	1970–1975	Kathmandu, Nepal	Axially symmetric rectangular prism	Office	Recessed wall	Grid window	Projecting eave	Blocking light
1-Common Library,GTU	1971–1974	California, USA	Axially symmetric cube	Library	Single-sided wall	Recessed window	Continuous planting	Filtering light
1-National parliament building	1972–1983	Dhaka, Bangladesh	Centrally symmetric cylinder	Parliament hall	Continuous wall	Clerestory window	Hyperbolic paraboloid roof	Diffusing light

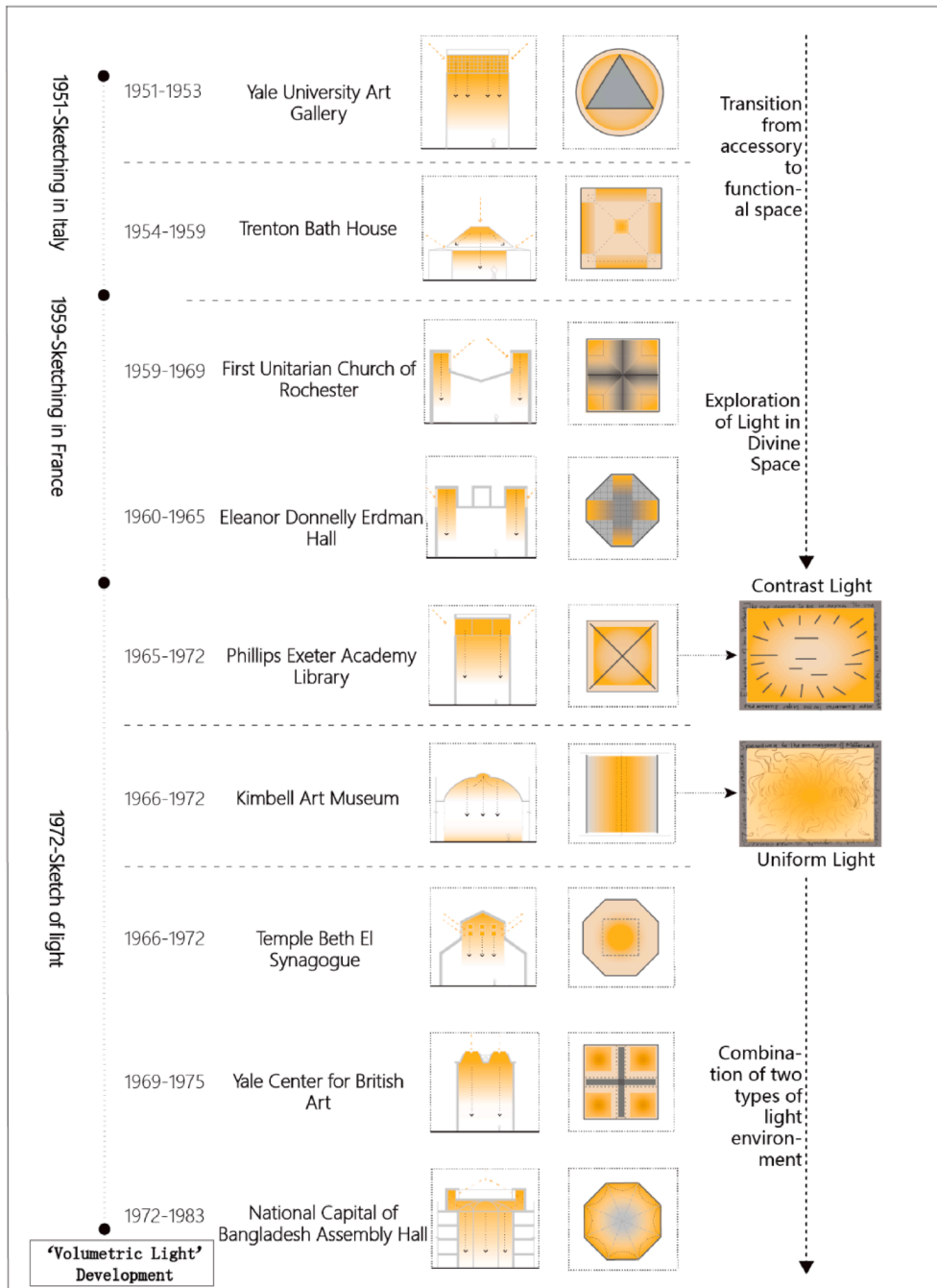


Fig. 5 1951–1974 Louis I. Kahn volumetric light space retracement

Aperture–Light Modulating Structure”. Therefore, we apply the established operational logic to conduct an in-depth analysis of two representative works from the mature phase of Volumetric Light (Fig. 6).

4.3. Case study: diagrammatic analysis

4.3.1. Exeter Library

(1) Volumetric frame

In the Phillips Exeter Library, the central atrium plays a key role in generating the Volumetric Light Space. As shown in Fig. 7, the atrium is positioned at the geometric center of both the plan and section, establishing itself as a “light generator” in the form of a cylindrical volume. Enclosed by tall vertical walls, this volume is divided into three segments along its height, ensuring that the gradation of light from bottom to top aligns seamlessly with the functional needs of the space.

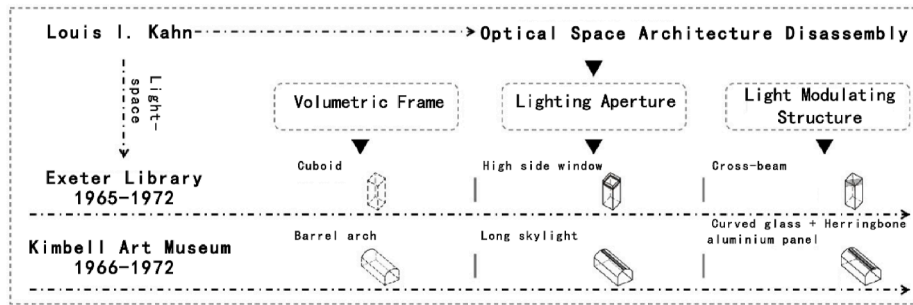


Fig. 6 Volumetric light construction method.

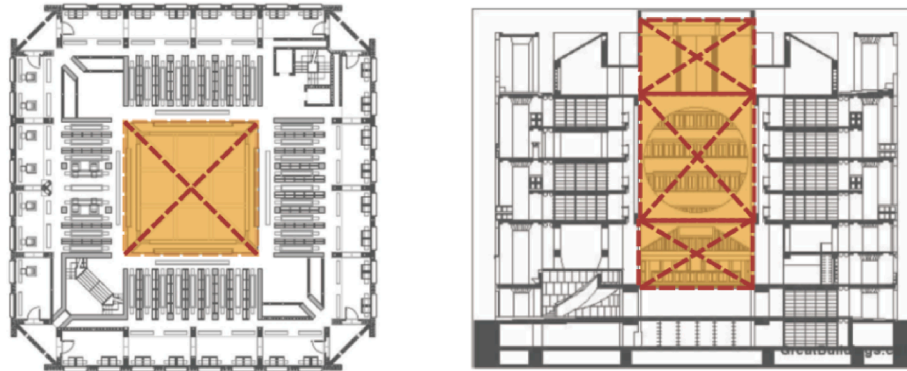


Fig. 7 Exeter light space plan location and profile location map.

As shown in Table 4, the atrium is defined by six enclosing surfaces, forming a “vertical volume” (A-1). Its square cross-section (A-2) ensures central symmetry, while in the vertical dimension, the cylindrical space is divided into three sections (A-3) based on the controlled daylighting strategy. Kahn masterfully integrates functional zoning with structural logic in this design: The upper section merges with the massive roof-supporting beams (A-4). The middle section houses bookshelves and reading areas, enclosed by perforated circular openings on all four walls, reinforcing the atrium’s spatial enclosure (A-5). The lower section is supported by flattened columns, visually echoing the cross beams above (A-6).

(2) Lighting aperture

The lighting aperture determine both the entry method and intensity of daylight, directly influencing the brightness distribution and layering within the atrium (Table 5). From top to bottom, the light intensity gradually decreases, creating a progressive layering of volumetric light (B-1). To ensure sufficient and continuous natural lighting in the uppermost section, Kahn designed a ring-shaped linear window at the junction between the massive roof and the four enclosing walls (B-2, B-4). This approach not only introduces direct daylight but also preserves the five-sided enclosure, reinforcing the strong volumetric

Table 4 Volumetric frame analysis of the Exeter Libraries.

Volume Frames — Cube	Nature of framework		Framework operation	Split frame structure	Crossbeam ribs	Vertical and horizontal walls	Sheet plate columns
	Enclosure	Centrality	Trisection		A-4	A-5	A-6
A-1				A-4			

Table 5 Analysis of lighting aperture at the Exeter Library.

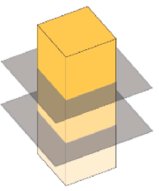
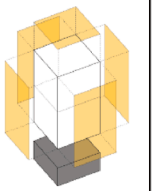
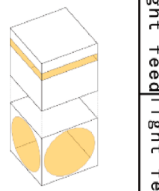
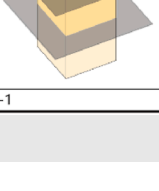
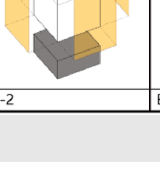
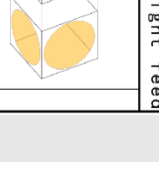
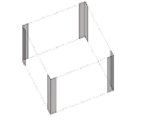
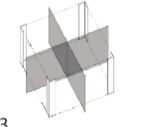

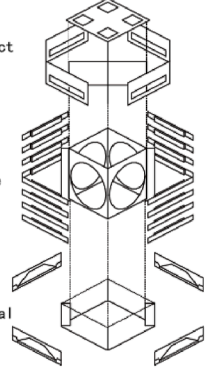

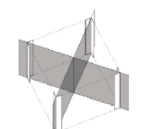
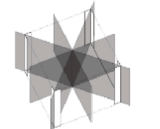
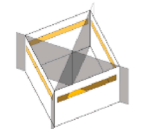
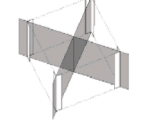
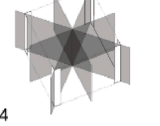
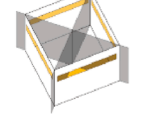
Light Entrance – Three Sections	Domain characterization		Light feed operation	Location characteristics	Cavity characteristics	Spatial feature
	Diminishing light	Light surface enclosure	Classification of light feed			
B-1				Core	Embedding	Surround
				B-4-1	B-4-2	B-4-3
B-5				Core	Qualify	Surround
				B-5-1	B-5-2	B-5-3

Table 6 Analysis of light modulating structure at Exeter Library. Source: Gunnar Klack, licensed under CC BY 2.0.

Dimming Structure – Crossbeam	Structural characteristic	Spatial characteristics	Characterization of the light domain	Top direct light	Middle diffuse light	Bottom artificial light
	Strut	Centre	Surround			
C-1						
C-2						
C-3						

presence of the cylindrical atrium. In the middle section, Kahn incorporated large circular openings on the walls, paired with wooden surfaces to facilitate diffuse reflection and secondary light filtering (B-3, B-5). This results in a gradual softening of light transitions while aligning with the functional needs of the bookshelf and reading areas. The lower section functions as both the termination point for the vertical volume of light and the first spatial encounter with daylight for visitors entering from below. The solid enclosure and smaller light openings at this level create a more subdued lighting environment, enhancing the contrast and dramatic impact of the brighter vertical light volume above.

(3) Light modulating structure

The upper cylindrical volume relies on direct light entry, making the lighting effect highly unpredictable. This results in strong light-shadow contrasts on the cylindrical walls, ultimately weakening the uniformity of volumetric light and reducing the spatial centrality of the light environment. To address this, Kahn introduced a distinct light-modulating structure—the cross beams (Table 6). These beams serve a dual function: they conceal lateral light-induced shadows while; evenly reflecting light onto the cylindrical walls, ensuring a more balanced and diffused lighting effect.

Additionally, the “black lines” at the base create a sharp visual contrast against the stable ambient lighting of the surrounding space, further emphasizing the dramatic spatial hierarchy of light. Structurally, since the cylindrical volume is supported by four columns (C-1), the cross beams in the upper section (C-2) ensure the structural connection between the massive roof and the supporting columns, while also reinforcing the geometric center of the volumetric space.

4.3.2. Kimbell Art Museum

(1) Volumetric frame

From the outset, the Kimbell Art Museum was designed with the core concept of creating a seamless luminous environment, where natural top lighting and the concrete vaults would function as an integrated whole (Hawkes, 2019). When reflecting on his creative inspiration, Louis I. Kahn once stated: “My mind is filled with the greatness of Rome. The vault has left a deep impression on me. Even though I could not use it, it was always there. The vault seemed to be the best. I realized that light must enter from the highest point, where it is at its finest” (Kahn and Johnson, 1975). The crack at the keystone serves as a critical passage for light to enter the interior, allowing light to fill the vaulted space. Through carefully controlled

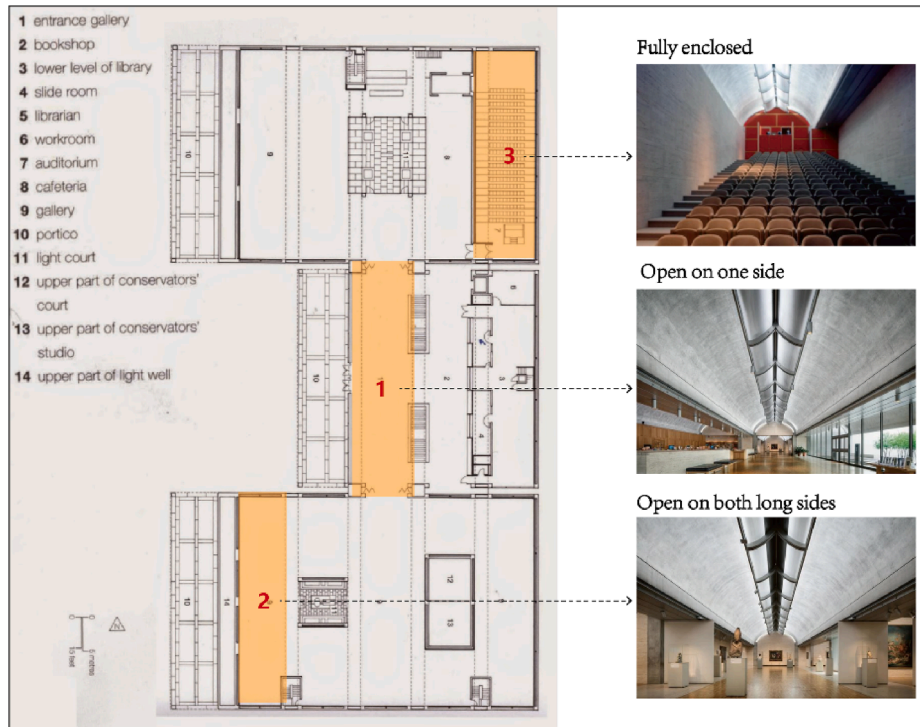


Fig. 8 Three forms of cycloidal vaulted space at the Kimbell Art Museum. Photo Source: Peter J. Sieger, licensed under CC BY 2.0.

Table 7 Analysis of volumetric frame of the Kimbell Art Museum.

Volume Cylinder Arch	Short-side enclosure	Long side unilateral enclosure	Long side both enclosure	Rectangular section		Barrel arch section	
				Core	Right angle	Dome	Spherical
	D-1	D-2	D-3	D-4	D-5	D-6	D-7

openings, Kahn accentuates the “omnipresence” of light, making it a defining element of the architectural experience.

The core volumetric framework of the Kimbell Art Museum adopts a cycloidal vaulted ceiling, with the vaults categorized into three enclosure types based on different functional needs: fully open on both long sides, open on one side, or fully enclosed (Fig. 8). This flexible division not only accommodates the diverse spatial requirements of exhibition and public areas but also creates varied light organization layers in both plan and section, enriching the museum’s luminous environment.

In Table 7, the three enclosure types of the vaulted framework correspond to the creation of distinct volumetric light spaces (D-1, D-2, D-3), each shaping a unique spatial lighting condition and atmospheric effect. In the longitudinal section, the central symmetry of the composition (D-4, D-7) is preserved, ensuring that visitors immediately perceive how light is stably enclosed within the

vault upon entering the museum. As the vaulted ceiling curves downward on both sides, it further enhances the visual focus along the longitudinal axis, reinforcing the spatial directionality and depth of the light. Additionally, while ensuring that the long sides remain open, the cycloidal vault cleverly transforms the upper rectangular section’s two right-angle boundaries into lowered double-curved surfaces. This modification enhances the sense of volumetric enclosure, creating a more uniform and immersive spatial experience (D-5, D-6).

(2) Lighting aperture

As shown in Table 8, Since the vaulted volumetric framework is divided into two main sections in the section, the primary luminous surfaces can be understood as “vault + floor”. The vault introduces direct light through linear skylights. The floor, made of warm-toned, highly reflective oak panels, expands the light reflection surface

Table 8 Analysis of lighting aperture of the Kimbell Art Museum.

Light Entrance — Arch Center	Diminishing light	Light surface enclosure	Feed position	Hole Position	Central axis	Light feed characteristics	Continuous light feed
					E-3-1 		E-3-3
	E-1	E-2	E-3		E-3-2 		E-3-4

and softens the light’s color tone (E–1, E–2, E–3). This dual-surface approach ensures balanced light diffusion and enhances the museum’s luminous atmosphere.

Kahn positioned the skylight at the keystone and covered it with curved glass. This design not only expands the daylighting surface but also utilizes refraction and scattering to concentrate light along the central axis. This linear skylight not only emphasizes the longitudinal axis but also visually extends the depth of the vault, enhancing the observer’s perception of volumetric light. Unlike the vertically organized volume of the Exeter Library, the Kimbell Art Museum emphasizes a balanced integration of both horizontal and longitudinal light distribution, allowing light to naturally diffuse throughout the galleries and other functional areas.

(3) Light modulating structure

In this project, Kahn explicitly introduced the concept of the “light modulator” for the first time (Büttiker, 2019). Unlike the cross beams in the Exeter Library atrium, which served both light modulation and structural support functions, the “light modulator” in the Kimbell Art Museum was designed solely for light control, independent of structural requirements (Table 9). The curved glass cover placed over the skylight exterior first refracts the incoming direct light

and redirects it toward the central axis (F-1). At the same time, the curved glass echoes the form of the vaulted ceiling, preserving the cohesion of the arch while further enhancing the concentration and flow of light along the longitudinal axis.

The light passing through the curved skylight cover undergoes secondary modulation on the V-shaped aluminum reflector positioned beneath the vault. The reflector, positioned directly beneath the vault, features a symmetrical reverse-arc shape that both shields the skylight opening and further reinforces the central axis (F-2). The perforated aluminum panel was designed with a 50% porosity to allow for partial light transmission and reflection (Büttiker, 2019). By adjusting the ratio between the fully reflective surface and the semi-reflective perforated areas, Kahn was able to create distinct lighting effects for the exhibition spaces and public areas (F-3; F-4) (Neumann et al., 2010).

During the design process of the Kimbell Art Museum, Kahn received assistance from many collaborators. Frank Sherwood, the museum’s associate architect, suggested making the reflector panels in the exhibition halls partially solid and partially perforated to provide better light control. Meanwhile, in public spaces such as the auditorium and bookstore, where light stability was less critical, he proposed retaining fully perforated reflectors (Speck,

Table 9 Analysis of light modulating structure of the Kimbell Art Museum. Photo Source: Peter J. Sieger, licensed under CC BY 2.0.

Light Modulating Structure — Light Shield, Reflector	Arc Lighting Cover				Human Reflector — Dimming Classification	Exhibition spaces		
	Spotlight	Core	Arch	Deflection		Winter solstice	Summer solstice	Actual view of showroom
		F-1-1 	F-1-2 	F-1-3 		F-3-1 	F-3-2 	
	F-1	F-1-1	F-1-2	F-1-3		F-3-1	F-3-2	
Light Modulating Structure — Light Shield, Reflector	Human Reflector				Human Reflector — Dimming Classification	Public space		
	Diffuse light	Core	Reflex	Filtration		Winter solstice	Summer solstice	Actual view of foyer
		F-2-1 	F-2-2 	F-2-3 		F-4-1 	F-4-2 	
	F-2	F-2-1	F-2-2	F-2-3		F-4-1	F-4-2	

2015). The V-shaped reflector panel directs light as far as possible toward the distant sections of the vault. By leveraging the concrete material and cycloidal shape of the vault, the reflection angles are maximized, ensuring that light spreads evenly across the entire ceiling.

After the completion of the Kimbell Art Museum, Kahn stated that it was his favorite work (Brownlee et al., 1991). By deconstructing the volumetric light space of the Kimbell Art Museum, one can progressively perceive Kahn's rigorous approach to directing light into the interior and the ingenious coordination between various daylighting structures. As Kahn once said: "Structural design is essentially the design of light. Vaults, domes, arches, and columns are all structural forms that respond to the various qualities of light. The subtle changes of natural light throughout the seasons and times of day create different spatial atmospheres, as if light itself enters the space and shapes it." (Kahn, 2005).

4.4. Volumetric light space construction

Based on the above research analysis and a comparative review of existing literature, this article systematically summarizes, for the first time, three key design strategies of Louis I. Kahn's "volumetric light space":

(1) Volumetric frame

Kahn regarded natural light as a malleable and containable "spatial material." Therefore, the primary task of architectural design is to establish a clear spatial container or boundary for light. This container is typically integrated into the building's overall structural system, establishing visual and structural stability through clear geometric order (such as axial or central symmetry). This ensures that light is confined within a well-defined and perceptible spatial boundary. Additionally, material selection (such as the combination of exposed concrete and natural wood) influences light reflection and absorption properties, further enhancing the sense of volumetric light and imparting a warm, tactile quality to the space.

(2) Lighting aperture

The shaping of light space requires precisely designed light openings positioned at high points of the building envelope or roof. These openings not only control the path, intensity, and angle of natural light but also, through their placement and scale, emphasize the intrinsic geometric logic of the volumetric framework. For example, continuous ring-shaped clerestory windows or keystone skylights not only effectively introduce natural light but also clearly reveal the axial order or hierarchical relationships within the architectural space.

(3) Light modulating structure

To achieve the final texture and layered distribution of light space, Kahn employed carefully designed light-modulating components to implement a secondary control over the incoming natural light. These components serve a dual function: regulating light intensity, direction, and diffuse reflection, creating a richer and more defined volumetric layering of light in the vertical dimension; reinforcing and accentuating the overall architectural spatial logic and geometric composition, further integrating light as a fundamental design element.

These three strategies are interdependent and mutually reinforcing. The volumetric framework establishes the fundamental spatial boundary for the presence and expression of light. The light openings control the initial path and intensity of incoming light while emphasizing the geometric characteristics of the framework. The light-modulating components provide precise adjustments and secondary light distribution, ensuring a clear layering of light space and a cohesive visual effect.

5. Discussion of the results

5.1. Material and form: their effect on volumetric light

Although this study focuses on the three core elements of volumetric light, Kahn's choice of materials and the evolution of aperture forms also played a critical role in shaping luminous spatial atmospheres.

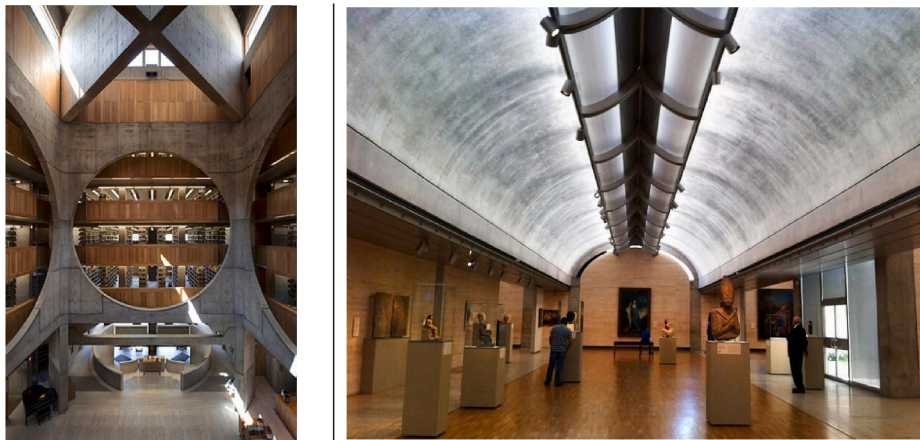


Fig. 9 Phillips Exeter Academy Library. Source: Wikimedia Commons; Kimbell Art Museum. Photo Source: Gunnar Klack and Peter J. Sieger, licensed under CC BY 2.0.

As shown in Fig. 9, In the Exeter Library, the atrium’s enclosing surfaces consist of exposed concrete and warm-toned wood paneling. The neutral gray concrete (reflectance $\sim 0.4\text{--}0.5$) scatters incoming light from above and the sides, while the wood (reflectance $\sim 0.3\text{--}0.4$) softens the interior tone, enhancing warmth and depth. Together, they create a balanced and perceptible volume of light. Similarly, the Kimbell Art Museum features exposed concrete vaults that gently diffuse natural light along their curves, avoiding glare while promoting uniform brightness. Oak floors and exhibit areas (reflectance $\sim 0.3\text{--}0.4$) contribute to a warm, luminous ambiance. Kahn also introduced perforated aluminum reflectors beneath the skylights (reflectance $\sim 0.6\text{--}0.8$), enabling layered diffusion between metal and concrete surfaces. Their neutral tone avoids color distortion and helps maintain stable wall illumination in the range of 20–30 lux (Causer, 2024).

Beyond material effects, Kahn’s aperture strategies evolved from scattered forms to systematic and modular compositions. In his early works (1924–1954), window placement was largely functional, with irregular or floor-to-ceiling glazing responding to specific uses. By the mid-1950s, distinctive geometric forms such as T-shaped and parasol-shaped openings began to appear in projects like the Tribune Review Building and the U.S. Consulate in Angola, often arranged in grid-like patterns. In his mature period (1960–1972), apertures became increasingly modular and repetitive—as seen in the circular clerestories of the Exeter Library and the continuous skylights at the Kimbell Art Museum—demonstrating refined control over size, spacing, and spatial coherence.

From a contemporary perspective, Kahn’s approach foreshadowed parametric logic in architectural design: a system of repetitive units with systematic variation and geometric interdependence. Today’s digital tools, including BIM and AI-driven optimization, enable architects to simulate and evolve Kahn’s strategies, dynamically adjusting aperture form, density, and orientation to achieve optimal daylighting, energy performance, and spatial quality (Hosseini et al., 2024; Queiroz et al., 2024). In this sense,

Kahn’s material and formal strategies offer a valuable prototype for sustainable light-space design in the digital era.

5.2. The role of sun position and building orientation

Louis I. Kahn shaped Volumetric Light Space through the three key elements. However, the adaptation of the building to solar orientation is also an essential factor, especially considering different geographic locations and climatic conditions. The building’s orientation and the sun’s altitude astudyngle play a crucial role in the utilization and control of natural light. Based on information gathered from public archives and literature (Ronner et al., 1987; Büttiker, 2019), this has created a geographic distribution map of Kahn’s completed projects within the United States (see Fig. 10).

Kahn’s projects are distributed across the East Coast (New Jersey, Pennsylvania, Connecticut), the South (Texas), and the West Coast (San Francisco, California). These locations exhibit significant variations in sunlight duration, solar altitude angle, and outdoor temperature and humidity conditions.

In the Exeter Library (43°N, New Hampshire), the low winter sun and extended summer daylight led Kahn to place clerestory windows at the roof’s geometric center. This continuous ring of overhead glazing ensured adequate illumination of reading areas year-round—capturing oblique winter light and filtering intense summer light through cross beams to reduce glare and thermal gain. In contrast, the Kimbell Art Museum in Fort Worth, Texas (32.5°N) faces intense solar exposure and prolonged summer heat. Here, Kahn used vaulted ceilings with precisely oriented skylights and perforated reflector panels to mitigate midday glare while maintaining soft, indirect lighting during morning and afternoon hours. The system balances natural light intake with thermal comfort and energy efficiency. In both cases, Kahn’s control of light is not solely internal but intimately tied to macro-scale environmental alignment—latitude, solar path, building orientation, and

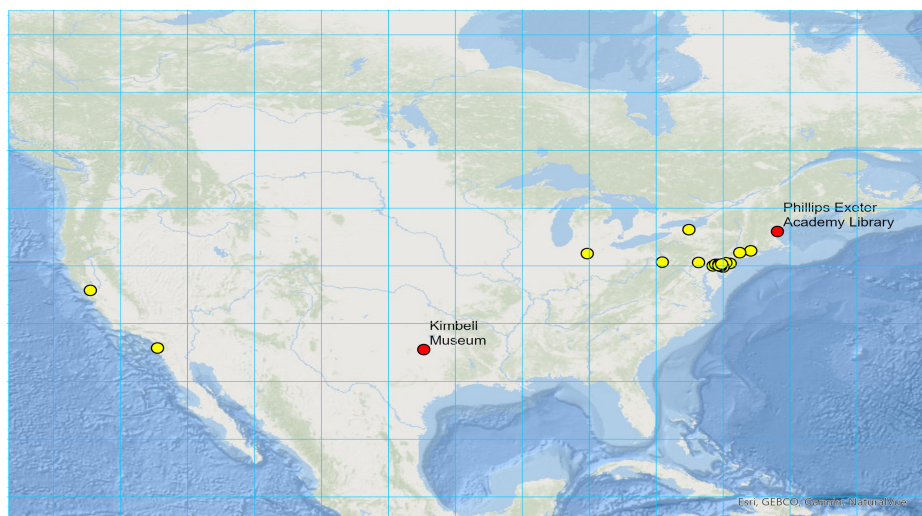


Fig. 10 General layout of the Kahn Project in the United States. Map Source: ArcGIS Pro.

massing. These external parameters form the foundation upon which the volumetric light-space operates, ensuring that modulating structures and internal strategies function effectively. In Kahn's work, solar position and architectural orientation are not auxiliary conditions but fundamental design variables embedded within his spatial logic.

5.3. Contemporary relevance of Kahn's volumetric light space

Kahn is widely recognized as a key figure in the history of American modernist architecture. His work embodies both rationalism—emphasizing order and structure—and regional exploration, with a deep focus on light and material qualities. As a result, he established a distinct architectural style within the American built landscape, one that seamlessly integrates classical geometric principles with contemporary technology (Brownlee et al., 1991). Kahn's emphasis on light and space not only aligns with European modernism's focus on function and form but also served as a catalyst for the spatial poetics of the postmodern era (Frampton, 2020). In France, Italy, and other regions, many researchers regard Kahn's work as a "bridge between classical order and contemporary technology," further enriching European discourse on the relationship between light and space (Curtis, 2012). In Asia, the light-space design in the works of Japanese architect Tadao Ando is often compared to Kahn's, highlighting how Kahn's pursuit of light and sacredness inspired Asian architects to explore concrete, light, and spatial spirituality within their own cultural contexts (Meneses Díaz, 2023).

In the field of international architectural academia and education, Kahn's "mass meets light" design philosophy has had a significant and lasting influence. Scholars argue that Kahn's spatial philosophy contributed to the diversification of modernist architecture, broadening its formal and experiential dimensions (Frampton, 2020). Many research topics on natural light, structural order, and spatial atmosphere can draw valuable insights from Kahn's architectural prototypes (Leatherbarrow, 2009). Contemporary scholars continue to integrate Kahn's principles with sustainable strategies, exploring how the concept of "shaping space with light" can be applied across different climates and cultural contexts.

5.4. Toward sustainability and digital evolution

Although Kahn's works were conceived in the mid-20th century, his precise use of natural light, spatial organization, and material sensitivity aligns closely with contemporary sustainable design principles, including energy efficiency, environmental comfort, and responsible material use (Heidari et al., 2024; Holdsworth, 2024). In projects such as the Exeter Library and the Kimbell Art Museum, Kahn strategically positioned openings and integrated reflective and shading elements to reduce dependence on artificial lighting, thereby improving daylight performance and overall energy efficiency.

Today, advances in computational design and digital fabrication enable further evolution of Kahn's light-space strategies. Parametric modeling tools (Grasshopper, Dynamo) and performance simulation platforms (Honeybee, Ladybug) allow designers to optimize natural lighting, opening dimensions, and energy use from early design stages (Sharbafian et al., 2024; Sadeghipour Roudsari et al., 2013). Meanwhile, smart materials—such as dynamic shading systems, PHPA hydrogel glass, and light-responsive composites—offer adaptive responses to climatic and functional demands, continuing Kahn's legacy of material innovation (Chen et al., 2024; Hu and Yu, 2019).

Moreover, the integration of AI and machine learning is transforming the concept of "Volumetric Light Space" from a static form into a responsive light ecosystem. These systems can dynamically adjust lighting strategies based on climate data, spatial geometry, and occupant behavior, supported by simulation tools that model annual shading, visual comfort, and human well-being (Nazari and Matusiak, 2024; Reinhart and Wienold, 2011; Inanici and Hashemloo, 2017). Combined with robotic construction and 3D printing, Kahn's vision of structured light can be realized with greater precision and adaptability (De Wolf et al., 2024; Madrid et al., 2024).

In this context, Kahn's approach—grounded in geometry, light, and material—is not only historically significant but remains a powerful model for sustainable and digitally augmented architectural practice.

6. Conclusions and recommendations

This article, through a systematic tracing, chronological analysis, and case-based diagrammatic examination of Louis I. Kahn's "Volumetric Light Space", reveals how Kahn, over the course of his half-century career, gradually transformed natural light from an abstract symbolic element into a practical and operable design tool. "Volumetric Light Space" in Louis I. Kahn's architectural practice is not merely an incidental visual outcome but a consistent design logic that extends from his philosophical reflections and painterly explorations to his structural and spatial compositions. This article not only provides an operational model for academia in interpreting Kahn's light-space concepts but also offers insights for contemporary architecture in the use of natural light, energy efficiency, and the creation of spatial solemnity and ritualistic experience.

However, given that light-modulating structures and perforated materials require high-precision data support, this article ultimately adopts a chronological analysis and diagrammatic comparison approach, instead of relying on overly complex and potentially disputable environmental renderings. This represents a rational choice made to balance academic rigor and feasibility in the research process. For works like the Kimbell Art Museum, where perforated panels, curved vaults, and multi-layered light-modulating devices are integral, achieving high-precision contemporary simulation standards would require extensive original material properties and geometric detail data. At this stage, such comprehensive data is not fully available within the

collected literature and architectural drawings used in this article.

If more detailed geometric and material data become available in the future, or if professional-grade physical simulation tools such as Radiance or VELUX are utilized, further numerical analysis could be conducted to explore the energy efficiency and glare control of such lighting environments, thereby expanding the depth of research (Hajji et al., 2024; Durak and Çifci, 2023). If behavioral studies or ergonomic perspectives are incorporated, research could further investigate users' subjective experiences in Volumetric Light Spaces, such as reading comfort and spatial atmosphere perception, through targeted surveys and analysis (Shawash, 2023). This would enable a deeper exploration of the human-centered significance in Kahn's light-space design, while also providing stronger evidence for integrating sustainability and human well-being in contemporary architecture.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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