The Tectonic Integration of Louis I. Kahn's Exeter Library

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Abstract
Louis Kahn's architectural works embody his rational tectonic epistemological perspective by exhibiting the ways he respected the nature of construction materials and how he built his structures in accordance to how he believed that space, itself, desired to be portrayed. From the Exeter Library, which was completed in 1972, it is evident that Kahn integrates two different structural systems, bricks and reinforced concrete, into a design concept that exhibits his profound respect for the innate characteristics of the chosen construction materials and the space that they create.

The current study focuses on the concept of spatial formation, structural systems, piping distribution, and their integration into the construction of Louis I. Kahn's Exeter Library. A review of the literature is first presented, which is followed by a comparison and analysis of a number of various plans, and 3D simulation models of the project. The relationships existing between the methods that Louis Kahn employed and the nature of the materials he used during spatial formation are presented, which is followed by a description of how these techniques enabled Kahn to express his rational tectonic ideals in the integration of construction materials and piping distributions. It is shown, for example, that Kahn endeavored to integrate various types of piping distribution in relation to the demands of construction and structural forms. In this way, Kahn's work interprets different characteristics of space in various types of architecture to display a rational tectonic method that responds to the form of a space.

Keywords: Louis Kahn; tectonic; piping distribution

1. Introduction
A number of important developments following World War II, such as the invention of new types of metals and inner-structural environmental controls (e.g., air-conditioning and fluorescent lighting) led to myriad architectural innovations that continue to be felt to this very day. The increased use of air-conditioning, for example, forced builders to develop architectural spaces that could accommodate their concomitant piping distributions. In "New Buildings for 194X", a competition held by Architectural Forum on post-war architectural development trends (mid-sized city, technology and technique developments regarding the integration of advanced facilities), the Italian-American architect Pietro Belluschi triumphed over the famous architects of the time, such as Ludwig Mies van der Rohe, William Lescaze and Louis I. Kahn to take first place.1

Belluschi's victory over such renowned figures in the field was largely due to his proposed integration of aluminum, which was widely used after the war due to its relatively inexpensive production process. Belluschi developed a method that integrated aluminum windowsills with mezzanine ceilings and curtained walls to integrate air-conditioning, power piping distribution and illumination systems (Fig.1.). Moreover, he modularized metal ceilings by incorporating them into the functional distribution of compartmentalization in office building structures. Belluschi further developed this design concept in the Equitable Building (1945-48)2. From that point on, the method of using hanging metal ceilings to integrate piping distributions spread widely and rapidly throughout modern architectural circles.

In 1965, Peter Collins proposed two piping integration distribution methods in modern buildings that offered solutions for how to accommodate environment control facility development into modern architecture. The first method employed the use of hanging metal ceilings to conceal the distribution of the piping, while the second utilized the construction process to integrate the piping system within the
As opposed to the architects who accepted the first method, Louis Kahn's work has not only played a significant role in the integration of modern construction projects with air-conditioning and illumination piping distributions but also in the conceptual designing of space.\(^3\)

In his *The Architecture of the Well-Tempered Environment*, Banham (1969) credited Kahn as the key figure in leading to the development of integrating exposed piping. The integration of exposed piping distribution shed light on what modern architects presumed to be an unorthodox architectural expression because they opened a window to the development of exposing bone structure and piping distribution as a form of demonstrating its style and characteristics for high-tech architecture in the future.\(^4\) The integration of exposed piping distribution often presents different spatial characteristics in various building types. Moreover, the composition, facilities, and structural materials reflect the development of the building materials and engineering technology of the time. The aforementioned need for innovation regarding both conceptual architectural design and methods of facility integration is realized in Kahn's work via the profundity of his architectural developmental progression.

2. The Archaic Concept of Space Composition

In November of 1965, when the Philip Exeter Academy officially appointed Louis Kahn as the design architect for the slated Exeter Library, the original planning goal was depicted as: "the quality of a library, by inspiring a superior faculty and attracting superior students ..."\(^5\) Hence, when Louis Kahn contemplated the nature of the ensuing library space, he decided that the Library would not only be functional, but also resemble a temple or a church as a sacrosanct space where humankind could pay the utmost respect to books, which, of course, represented learning.\(^6\) Hence, Kahn's original designs display his desire to create a medieval, convent-like silence and sacredness manifested in the nature of the space created via a load-bearing brick structure that provided an atrium for natural lighting in a discreet location (Figs. 2 & 3). Furthermore, Kahn proposed the idea that "a man with a book goes to the light. A library begins that way."\(^7\) In other words, the nature of the very space that Kahn sought to create symbolizes the spiritual unification of humans, books and light. Kahn recognized light as a significant element of birth and, therefore, arranged the Library's spatial characteristics in a way that allowed light to illuminate the structure in a number of different ways.

To create the nature of the Library's space and respond to the campus' existing neo-Georgian brick buildings, Kahn used a brick composition to present an archaic atmosphere of space during the design process. With light and structural form determining the Library's spatial composition, lighting on solid walls of an alcove-like reading space, and a brick-arch corridor, it is evident that Kahn attempted to echo the library space of a medieval convent. In the Library's original designs, Kahn had originally planned the entire structure to be a load-bearing brick building; however, the university's limited construction budget required that he revise the design to an integrated form of reinforced concrete and brick structure systems.\(^8\) The main load-bearing structure and library space is supported by an internal reinforced concrete building, while the reading space, where visitors would commune with the written word is a brick building; this merging of the two construction methods clearly depicts Kahn's signature space utilization style that enabled 'buildings to emerge-within-buildings.'\(^9\)

3. Compound Structure Systems and Characteristics

The Exeter Library's structural system is of brick composite and reinforced concrete, with the outer brick building wrapping around the core of the inner concrete building (Fig. 4.). The brick structure is composed of a jack arch, a load-bearing brick wall, and a brick pier column, which, together, form an independent structure unit on all four façades. The structure extends 6.2 meters in length, 3.8 meters in width, with a total length of 24.8 meters on each façade (Fig. 5.). In addition to resisting dead weight, the arch style brick structure also helps absorb changes in the structure's lateral loads.

The inner reinforced concrete structure system is largely composed of eight main load-bearing walls on four sides and two pairs of oblique structural supports in the center. The entire frame structure forms
a modular 11m×11m square plane. The system is, in reality, four large reinforced concrete supports that serve the function of organizing all structural elements and loads (Fig.5.). In this way, the two system sets are integrated into one structural system with a reinforced concrete floor. The central oblique support columns cross as two beams at the top, supporting the skylight roof above. When the entire structure takes on lateral loads, the concrete-bearing walls on the corners and central walls with circular openings provide the lateral and oblique support necessary to steady the structure. Kahn also used this circular opening to create an open sight line between the lobby and the library, which portrays Kahn's aforementioned religious-like design concept that was designed to summon people forth to the knowledge found within the Library's books (Fig.6.).

When conceiving the Exeter Library's structural system, Kahn carefully pondered the ideal method of interpreting the materials' inner nature that would still allow them to display their expression onto the form's outer features. He described this accordingly: "A form emerges from the structural elements inherent in the form." The outer brick building structure of the Library undeniably embodies this design concept. The sizes of columns on the façade decrease with altitude, demonstrating the features of a solid foundation and a slim upper portion, while clearly labeling the differences in dynamic load-bearing with different altitudes via the outer form (Fig.7.). When describing the structural features of a load-bearing brick building structure of this type, Kahn said, "The brick was always talking to me, saying you're missing an opportunity … The weight of the brick makes it dance like a fairy above and groan below."

The Library area's structural form also adopts the characteristics of the unique reinforced concrete structure. The density of beam distribution is increased to support the load-bearing of the library area with four beam-supporting columns in between. In order to form a large span spatial form in the public space below, two deep beams with triangle openings are used to replace the standing columns as structural supports (Fig.8.). During the Library's construction period, Kahn continued to interpret the different natures of the spaces existing between visitors to the Library and its books through the employment of different materials and structural forms. As noted, Kahn believed in the importance of respecting the spirit of individual existence in every structural element and displaying the existing will of each item through its material structural form. Kahn reinforced this notion in his statement that a great building "must begin with the unmeasurable, must go through measurable means when it is being designed and in the end must be unmeasurable."

4. Structural form, Material and Detail

When contemplating the nature of the Library's structural materials, Kahn proposed a design concept that required an objective comprehension of the materials' nature. He believed that the natural and the artificial co-exist spiritually and materially, with the
natural emanating from the will of God and having been formed in conjunction with the existing laws of nature. On the contrary, Kahn viewed the artificial as being the expression of human will that is formed according to mankind's rules. Hence, the human will is subjective as well as objective, and the difference between architecture and artistic creation lies in the fact that artists must not re-present reality, but rather allow it to express itself directly. The creative result thereof is the artist's response to the nature of the substance, itself, which expresses humankind's subjective will. However, architects cannot express subjective consciousness directly as the basis of creation, but must further realize the objective spirit of the existence of the substance, explore its nature, and express it as the artificial with an objective consciousness.\textsuperscript{13}

In this way, Kahn maintained that the architect's role in the creation process is to realize the nature of the material through the material, itself, and allow it to reflect onto one's architectural design rather than expressing the material according to subjective perception. In accordance with this theory, Kahn invented the method of "conversing with the material" as a way of exploring the characteristics of the materials, themselves. Pursuant to this philosophy, Kahn was even known to have spoken with his building materials by asking: "what do you want, brick? And brick says to you, 'I like an arch.'"\textsuperscript{14} Kahn devoted much thought to contemplating how to unite the materials' inner nature with the structure that they would ultimately construct. He expressed this as follows:

"You don't bandy it around as though to say, 'Well, we have a lot of material around. We can do it one way. We can do it another way.' It's not true. You can only do it if you honor the brick and glorify the brick instead of just shortchanging it or giving it an inferior job to do, where it loses its character. When you use it as infill material, for instance - which I have done, you have done - the brick feels like a servant."\textsuperscript{15}

Louis Kahn focused on applying the nature of material of the load-bearing brick and resistant reinforced concrete appropriately to the correct location within the structure when integrating the two materials of brick and reinforced concrete in the Exeter Library. Behind the Library's brick jack arch opening on the façade is a reinforced concrete beam, sharing part of the perpendicular loads on the brick arch with the floor boards, so that the size of brick building openings on the corners may remain the same per elevation spacing intervals. Kahn commented on this, saying: "Sometimes you ask concrete to help the brick, and brick is very happy."\textsuperscript{16} (Figs.9. & 10.). Accordingly, Kahn sought to use the physical property of the nature of material by applying it to the location within the structure that would most befit the dynamic characteristics of its inner form.

5. The Integration of Structure and A/C Piping

Based on the spatial construction concept of servant and the served space, Kahn responded to the issue of integrating piping distribution by proposing that various servant spaces must be independent in terms of space and structural form. He described this accordingly: "The nature of space is further characterized by the minor spaces that serve it. Storage rooms, service rooms, and cubicles must not be partitioned areas of a single-space structure, they must be given their own structure."

Guided by this spatial manipulation concept, Kahn used spaces to transmit and integrate piping distribution that were equipped with independent spatial balance and structural forms; in other words, servant space was no longer partitioned away from other areas of the structure. The Exeter Library's servant spaces are all placed within the four corners of the plane; in the original design, spaces transmitting the piping are shaped with an independent square brick facility unit (Fig.11.), transmitting A/C piping upward from the machine room down below. However, due to budget limitations and the geological characteristics of the base, Kahn was forced to integrate the original square brick facility with a perpendicular circulation (Fig.12.) in order to reduce the number of basement A/C machine room distributions from four machine rooms down to three (Figs.13. & 14.).
In addition to contemplating the ideal methods for the integration of the piping distribution within the structure in terms of spatial scale, Kahn also proposed the idea of "hollow stone" for the structural form. He accomplished this by responding to the nature of the material, as opposed to using a hanging ceiling that would hide the piping distribution. Kahn described his thoughts regarding the relationship between the features of the materials and the piping accordingly: "...ceiling tile concealing hangers, conduits, pipes, and ducts deform the image of how a space is made or served and therefore presents no reflection of order and meaningful form...Building elements of solids and voids are inherent in steel and concrete. These voids are in tune with the service needs of spaces. This characteristic combined with space needs suggest new forms...The intrusion of mechanical space needs can push forward and obscure form in structure ...Long ago they built with solid stones. Today we must build with hollow stones."^{18}

Kahn also maintained that a space's characteristics are determined by the very characteristics of the structure that creates it, and that different spatial manifestations must be displayed with different forms of structures. By discovering the various meaningful structural possibilities in architecture, Kahn attempted to integrate servant space, piping distribution and the most efficient structural forms with one another. This, in turn, allowed for various interpretations of the form and nature of space when integrating piping distributions within different spatial types.

Furthermore, Kahn used the integration of the piping distribution with the nature of the brick and concrete structural element to express the aforementioned "hollow stone" concept. By creating voids and interweaving the structural element or independent facility spaces constructed by voids he exemplified his tectonic belief that enabled the scale of the "hollow stone" space to adopt multiple spatial flexibilities. He expressed this in the following statement:

"In Gothic times, architects built in solid stones. Now we can build with hollow stones. The spaces defined by the members of a structure are as important as the members. These spaces range in scale from the voids of an insulation panel, voids for air, lighting and heat to circulate, to spaces big enough to walk through or live in."^{19}

The ultimate integration of the structure and piping distribution of the Exeter Library combined the two building materials of brick and reinforced concrete. Congruent to Kahn's tectonic ideals, the characteristic of a space originates from the nature of the structure that creates it. Therefore, the structural order of the materials, themselves, had to be mutually integrated into the Exeter Library's structure, as did the A/C piping that snakes throughout it. In this way, Kahn carefully arranged the three material elements of brick, reinforced concrete, and aluminum A/C pipes in a way that enabled them to "communicate" amongst themselves. By completely exposing the aluminum A/C pipes and integrating them beneath the floorboard where the brick building meets the reinforced concrete building systems, the visual and tactile experience of the material texture highlight the construction logic of these three materials. Moreover, it demonstrates the lucidity of the form of service that the A/C piping provides between people (in the reading area) and the books (in the library area)^{20} (Figs.15.-17.).

1. Concrete building; 2. See Fig.17.; 3. Brick building
Fig.15. A/C Piping Distribution Cross-section Perspective

1. Aluminum panel; 2. Brick pier; 3. RC floor slab; 4. RC load-bearing wall; 5. Piping distribution; 6. Brick wall
Fig.16. Integration of Exposed A/C Piping

Fig.17. Brick, RC and A/C Piping Integration Cross-section

The entire A/C piping distribution forms a circulation route on every floor. It begins in the machine room in the basement and transmits upward via the vertical piping transmission unit in the four corners, and
horizontally via the aluminum A/C piping distributed between the brick and reinforced concrete structure. Save the A/C piping in the special book storage and the study room spaces on the top floor that connect directly to the vertical transmission unit through the reinforced concrete wall, the entire horizontal A/C piping enters the brick wall from the outside of the vertical transmission unit (Fig.18.).

Furthermore, the construction of piping transmission units reflect Kahn's flexibility in integrating the characteristics of the construction materials and the piping distribution. The inner reinforced concrete wall bears the main structure's load, while the outer brick wall utilizes the brick-laying feature's structural convenience to prepare for possible future changes in piping distribution, thus making it possible to adjust flexibly to future opening (Figs.19. & 20.). As opposed to simply utilizing brick when constructing the façade and displaying its structural element by means of a load-bearing nature, Kahn used the structural variations existing in the nature of the material to respond to flexible mechanical adjustments in integration when faced with the issue of integrating piping distribution within the structure.

6. The Principle of Structural Rationality and Authenticity Integration

Kahn inherited the tradition of structural rationalism from the *Ecole des Beaux-Arts*.* In addition to respecting the material's nature and structural rationality, he further emphasized that the relationship of the tectonic logic between structural elements must be displayed during the shaping of spaces and sensual experiences. In other words, Kahn's architectural works not only embody his epistemological beliefs regarding how space desires to be protrayed, but also the very way in which the completed structure should respect the space that it creates. In this vein, Vincent Scully stated, "Kahn would never design anything the shape of which didn't derive from its structural character … You feel the materials thrumming with tension...". On the other hand, Kahn's interpretation of tectonic logic is also evident in how he displayed the materials used to form the work's integral whole. According to Kahn, the way in which materials are put together, arranged or separated cannot be concealed. This would violate his belief of the materials' intrinsic natural decoration that emanates from their very nature and that, thereby, serves as the most authentic mark that elucidates the construction process.

In the integrated design of structure and the A/C piping distribution of the Exeter Library, the brick not only demonstrates its functional use in forming the jack arch and pier column mechanical characteristics, but also serves as a testimony to the convenient constructional and brick-laying features that are also used in the integration of the A/C piping in response to future continued integration. The aluminum A/C piping distributed beneath the floorboards that are connected by brick and reinforced concrete further accentuate Kahn's tectonic ideal of integrating structures' materials to please both the visual and tactile senses. Furthermore, in addition to acting as the structural support for a vertical piping transmission unit, the circular template joints and imprints left on the surface of the reinforced concrete illustrate how the templates were constructed, as well as the order of construction for the pouring of the reinforced concrete. The mechanical characteristics of bricks, A/C piping distribution and even the traces of the reinforced concrete construction all serve together to present lucid illustrations of Kahn's design concept of "how space is constructed and served." Moreover, they also offer testimony to Kahn's belief in a tectonic grammar that, formed by the nature of the materials used to create the structure, itself, creates a unique type of spatial
atmosphere much like the way that truth is revealed through poetry.

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Notes
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