The Superimposition of Circles Cut into Louis I. Kahn's Building Façades

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Abstract
The masonry arch is one of the oldest structural designs used to span openings of considerable length. Although a variety of forms of brick masonry arches have been used for aesthetic reasons throughout the history of architecture, the unique employment of simple geometric forms is conspicuous in Louis Kahn's buildings. In particular, Kahn has distinctively used overlaid circles cut into the building façade for window openings. The research elaborates on how Kahn juxtaposed circular shapes for the design of window openings in his buildings, particularly in the Indian Institute of Management (1962-74) and National Capital Complex in Bangladesh (1962-83).

Keywords: arch; circle; window openings; proportional ratio and geometry

1. Introduction
Architectural designs involve a combination of a relatively small number of geometric shapes to make the forms of buildings. In Louis Kahn's designs, geometry not only serves as a key principle for the consistent and systematic quality underlying most of his work, but also provides an order for the formal expressions that encompass both composition and construction.

The architecture of Kahn is also inspired by natural light and the characteristics of the materials that he used in building construction. The permutation of "light and no light" is dependent on the composition of façade openings where light enters. The reciprocal relationship of the light and the simple geometric shapes that are carved out in the façade wall shows the aesthetic depth of space.

Much has been written about the geometric systems and qualities of Kahn's architecture. Ayad (1997) discusses Anne Tyng's geometric influences on the works of Louis Kahn, including the tetrahedral ceiling of the Yale University Art Gallery, the cubes and pyramidal roofs of the Trenton Bath House, and the space frame of the City Tower project of Philadelphia. Kahn's experiments with space frames "owed much to the collaborative effort of Tyng," who worked with Kahn and wrote extensively about geometry and architecture (Tyng, 1969; Kahn, 1997).

Gargus (1995) and Gast (1998) analyzed Kahn's work regarding geometric systems, including a root-2 rectangle and a golden spiral, under the theoretical and methodical influences of Kahn's contemporaries, such as Hambidge, Wittkower, and Le Corbusier. Both Gargus and Gast focused their analysis mostly on the ground floor plans. Gargus explored Kahn's work regarding primary geometric figures and their dispositions, particularly in the Dominican Motherhouse in Media, Pennsylvania (1965–1969) and the Richards Medical Research Laboratories in Philadelphia (1957–1965). Gargus argues that the golden spiral acts as a controlled method toward a geometrical order in Kahn's works but is "not enough to account for the lasting potency of his work." Gast examined the simple geometric structure of the ground floor plans and the spatial composition of the components in relation to the whole using the golden section. Gast believes that the golden section was used as "a way in which design ideas can be implemented rationally," which appear to be "directly comprehensible in the rationality of geometry."

Kahn's work has often been discussed within the context of a Platonistic notion of forms and ideas. Among others, Danto (1999) compared Kahn's theory of form with the Platonistic ideas of "invisible and external" forms. Danto seems to believe that Plato and Kahn share the idea of timeless existence. Kahn's form is the fundamental in buildings, whereas Plato's form is the essential element of all things that exist.

By reviewing Kahn's theoretical writings and design works and by tracing sources that perhaps influenced Kahn's thinking, Fleming (2003) argues that tracing the direct source of Kahn's notions of form is almost impossible and that Kahn himself did "not
acknowledge Plato's influence" on him, so that it is "futile to attempt to join the dots between Kahn and Plato." Fleming concludes that Kahn's work "does not fit into that part of the tradition of architecture that claims its authority from Platonism." Nevertheless, the geometric figures used in Kahn's buildings are a means toward contemplating intelligible building forms. Thus, Kahn's buildings can be interpreted as "reflections of some of the Forms' abstract qualities."

Surprisingly, however, scant analysis has been made of Kahn's unique employment of circular geometry, despite its use as a key design in his architecture. Above all, geometric analysis of the façade in Kahn's work is extremely rare.

Although considerable complexity of the facades in Kahn's works is observed at multiple levels, the unique façade designs seem to rely on certain governing underlying geometric orders or principles. It is conjectured that this complexity arises from a multiple superimposition of various circular geometries. This article explores Kahn's conscious or subconscious uses of circular play in his building facades. This analysis is based on all of the drawings by Kahn published in a series of books, The Louis I. Kahn Archive: Personal Drawings. (Garland, 1987)

2. The Use of Circular Geometry in Kahn's Building Facades

Kahn experimented with different systems of window openings with regard to natural light, and eventually used the so-called keyhole shape window to screen the sun's glare. The design was developed after he traveled to Africa for the US Consulate in Luanda (1959-1969) (Tyng 1984). The keyhole shape window is basically composed of two parts: a large wide opening at the upper part and a vertical slit at the lower part of the façade. In its subsequent developments, the simple T-shaped keyhole window was further articulated, where various circles were superimposed on a single façade. This becomes the definitive pattern for succeeding designs. The manifestations of circles not only define the characteristics of local facades but also influence the overall design of his buildings. The sketches of various un-built and built projects show that the superimposition of circular shapes is one of his most widely employed formal expressions and design alternatives in façade designs.

Kahn's concern with different circular windows is found in a series of sketches in the Kansas City project (1966-1973). Although many sketches were made for the facades of the project, three sketches are specifically chosen to provide a glimpse of Kahn's conscious efforts to articulate circles in a building façade. These sketches were carefully drawn in a precise manner, and different arch openings were tested for the development of a single façade. The first sketch is made up of six arches, where four small arches are placed over two bigger arches in a row (Fig.1.). While the second sketch is comprised of four different arches, the third sketch is made up of six eye-shaped double convex openings. Each composition has its own characteristics in terms of how these arches are assembled and relate to each other. Certain relationships among arches may exist in terms of size and geometric position.

The series of sketches illustrate that Kahn must have considered different juxtapositions of various arches in designing the facades of buildings. This may become clearer by performing a comprehensive analysis of built works to demonstrate how several circles are specifically manifested in the design of a building façade. Although similar approaches were applied to his later project such as Performing Arts Theater (1959-73) and Theater for the Dramatic Arts (1966-73) at Fort Wayne, both the Indian Institute of Management (1962-74) and the National Capital Complex in Bangladesh (1962-83) stand out in relation to the subject of this work, as various circular geometries are articulated one upon the other in the building facades.

3. The Analysis of Two Works

The two works are especially chosen due to their various expressions of arch overlay. The entire Indian Institute of Management is constructed in brick masonry, and the subsidiary buildings of the National Capital Complex are built in the same construction except for the main Assembly Hall. Considering the demands presented by the local climate such as sheltering against the monsoon and humidity, brick was selected over other materials for both projects. A famous Kahn quote on brick conveys that each material has a unique way to be expressed and built: "I asked the brick, 'What do you like, Brick? And the brick said, I like an arch.' Manifestations of his famous brick quote can be extensively recognized in the brick masonry façade designs of both projects.

3.1 Indian Institute of Management (IIM) and Dormitory Buildings

The IIM is comprised of a main building with classrooms, a library, conference halls, and faculty offices around a main courtyard. Apart from the main building, dormitories for students are interconnected to the main building with a series of arched passages. These complex buildings are sited in diagonal orientation due to the prevailing wind.

Some of the facades are very articulated in the way that a set of repetitive circles and rectangular frames are juxtaposed, whereas some others are based on a simple composition of separately carved out circles and
squares. In some cases, circular carvings are employed not only in flat but also rounded brick walls. Arches situated over the square frame not only abandon the dullness and strictness of rectangular frames but also support a dynamic visual presentation of the local façade. There are a considerable number of arches where two ends stretch over the rectangular frame. Concrete lintel designs enable Kahn to fashion unique window openings.

![Fig.2. Cross Section Drawing Through Administration Wing, Showing Vaulted Light Well and the Northwest Façade of the Administration Unit](image)

Repetitive use of the northeast facades of the classroom blocks at the inner courtyard appears to originate from the same formal gesture. Each opening is composed of a set of three arches over rectangular frames arranged in a vertical direction so that they provide each storey with necessary lighting. The arches over the rectangular frames may be Kahn's means of emphasizing the intensity of the view.

The interplay among, arches, squares, and lintel designs of the facade that links passages between the classroom and the library block around the inner courtyard is easily recognizable from a distance (Fig.2.). It seems that the circular arches share a center point from which each arch grows. The interplay of the arches can be simply analyzed with regard to the geometric relationship of squares and circles. The underlying circle of the bottom arch circumscribes the center square. It becomes a unit circle, a modular dimension for the basis of the whole geometric construction. Each underlying circle, one after another, is very proportional (Fig.3.).

The following simple notations are used to coherently represent different analytic diagrams. Let \( O_i \) denote the center circle \( C_i \), \( O_2 \) denote the center of circle \( C_2 \), \( O_3 \) denote the center point circle \( C_3 \), and so on. \( r_u \) is the radius of the unit circle, \( r_1 \) the radius of \( C_1 \), \( r_2 \) the radius of \( C_2 \), \( r_3 \) the radius of \( C_3 \), and so on.

The facades are composed of three concentric circles that share the same center and axis. The middle circle \( C_2 \), is rooted from the inner circle \( C_2 \), which is proportional to \( r_u: r_2 = 1:1.5 \). The circle \( C_3 \) defines the location of the top arch, which is also proportional to the inner circle \( C_1 \), which is \( r_1: r_3 = 1:2.5 \). The overall ratio with regard to each length of their ratio is \( r_u: r_2: r_3 = 1:1.5:2.5 \), respectively. A relative comparison among the circles reveals that \( C_1 \) becomes a unit circle, while \( r_u \) and circle \( C_2 \) and \( C_3 \) grow out of the sum of unit circles. In addition, circles and their square openings in the façade are geometrically connected with regard to the radius of the unit circle. The inner circle is drawn around the central square, which is a passage walkway. The length of the square is equal to the chord of the top arch. The length is divided into four identical parts. Two parts become the chord of the middle arch as well as the length of the top square. They are all set symmetrically along the central vertical axis. Each chord becomes the level of the concrete lintel buttressing the two ends of the brick arch.

![Fig.3. The Construction of Façade Openings with Regard to the Underlying Circles](image)

A similar design appears in the recessed area between the student blocks of the circular parapet openings. Here again, two underlying circles are concentric in terms of their geometric position and their radii. Over the corridor wall that leads to the backyard of the school between the faculty office and the library block, two arches appear (Fig.4.). The geometric relationship of the arches is comprised of a larger arch over a smaller arch, which is located over the rectangular frame entrance. The larger arch is a semicircular opening allowing a wide range of natural light and a view to the inner courtyard. A smaller arch allows natural light to the bottom of the second floor while offering a walkway passage for the rectangular frame below.

The layout of the two arches is based on two underlying circles that meet at one point along the vertical axis. The geometry of the two circles lies on the chain of the unit circle derived from the comparison of two circles in terms of radius. The two arches are denoted as \( AB \) and \( EF \) and the outlines of the underlying circle are vertically tangent and proportional to each other. The proportional relation with regard to their radius is \( r_1:r_2 = 4:5 \). As previously mentioned, arch \( EF \) is a semicircle whose chord becomes the level of the bottom line of the window opening. For arch \( AB \), the underlying circle, \( C_1 \), circumscribes the inner square. The location of its chord is determined by the radius of the unit circle, as shown in Fig.4. The chord \( AB \) becomes the position of the concrete lintel, and the rectangle frame for the passage walkway is circumscribed in circle \( C_1 \).

Dormitory buildings are connected to the main complex by a series of arched corridors. The circular
The geometry carved out in the façade is clearly visible on the outside of the brickwork. Some of them have a relieving arch over the opening passages, others have a relieving arch over a lintel, and others have straight arches. The façade is designed with a series of relieving arches of bricks with concrete lintels within the walls that distribute the load and are visible on the outside of the brickwork.

Two arches are superimposed on each other on the dormitory walkway passage that links the school and dormitory buildings (Fig. 5.). The upper solid arch is designed with a simple arch and a lintel that is filled with bricks as if designed to carry the downward load of the wall and the floor. The arch at the lower level forms a passage in the form of a walkway.

A geometric analysis of the two arches shows that the AB line on the ground level becomes the diameter of the bottom circle \( C_1 \). The diameter of circle \( C_1 \) is equal to \( 4r_u \), whereas that of circle \( C_2 \) is \( 10r_u \). The proportional relationship between the two circles with regard to their radius is 5:3, which is \( r_1 : r_3 = 5 : 3 \). The intersection point of circle \( C_1 \) and circle \( C_3 \) becomes the convex window opening of the bottom part of the façade. In addition, the chord of the upper opening is simply drawn with regard to the basic unit circle, which is located at \( r_u \) above the center of circle \( C_1 \).

Among other openings, the southeast elevation of the student block is the most complicated element of this complex (Fig. 7.). Symmetrically composed, one large arch on the top is located above six arches over rectangular frame openings. The façade appears to be composed of three types of underlying circles and rectangular designs overlaid in a subtle manner.

Due to its spatial complexity, two underlying unit circles, denoted by \( r_u1 \) and \( r_u2 \), are used to delineate its composition. While \( r_u1 \) is used to derive the upper arches, \( r_u2 \) is used for the lower arch. First, the authors analyze the upper part of the openings. The locations of the arches and chords are determined by the radius of the unit circle, \( r_u1 \). The diameter of the underlying...
circle \( C_t \) is composed of \( 8r_{u1} \). The center points \( O_2 \) and \( O_3 \) of the following two circles are located \( 3r_{u1}/2 \) left and \( r_{u1} \) down from the center point \( O_t \). The superimposition of three circles determines the locations of the arches and chords below.

Then, the lower part is constructed based on the radius of the unit circle, \( r_{u2} \). The lower arches over the rectangular frame openings of the first and the second floor originate from overlapping circles of equal diameter, \( C_4 \), \( C_5 \), \( C_6 \) and \( C_7 \). Two circles of equal diameter, \( C_4 \) and \( C_5 \), where the circumference of each circle intersects the center point of the other, are overlapped. \( O_4 \) and \( O_5 \) are determined by an intersecting point of the ground level and \( 3r_{u1}/2 \) offset vertical line from \( O_1 \) of the upper circle. The diameter of the circles becomes \( 7r_{u2} \) and hence the distance between center points, \( O_4 \) and \( O_5 \), becomes \( 3r_{u2} \). The horizontal diameter of the circles, which intersects center points \( O_4 \) and \( O_5 \), becomes the bottom level of the ground floor. The two bottom arches are derived from two offsetting underlying circles, \( C_4 \) and \( C_5 \), located \( 2r_{u2} \) downward.

A large arch on the top and twin small arches below dominate the parapet brickwork of the southwest façade of the student block raised on a large platform (Fig. 8.). It appears that three identical circles are bilaterally juxtaposed along the central vertical axis. Their geometric positions and proportions with regard to their radii are also relevant. Two lower circles of equal diameter, where the circumference of each circle intersects the center point of the other, are overlapped. Instead of three circles linked together, their centers being vertices of an equilateral triangle, the center circle of the top arch, \( O_1 \), appears to be shifted by a unit radius \( r_{u1} \), horizontally and vertically, from its center of the bottom circle, \( O_2 \) and \( O_3 \). The chord location of the upper circle is determined with regard to the unit radius \( r_{u1} \) and the intersection point of the top and the bottom circles determines the chord position of the bottom arches.

A four-story office block that presents a repetitive set of unit facades is translated along the horizontal line (Fig. 9.). The unit design is composed of three arches respectively over rectangular frames, whereas the bottom floor opening is without an arch. The parapet arch is larger than the other two identical arches. The rectangular openings of the fourth and the third floor have the same size, but that of the second floor is relatively higher than the others. The bottom rectangular opening is also slightly smaller than that of the others.

The three arches lie on concentric circles that have their center at \( O_1 \). The underlying circles of three arches are related with regard to the proportional ratios of their radii, such as \( r_1:r_2:r_3 = 1:1.5:2 \). Thus, the radii of consecutive circles become \( 4r_{u1} \), \( 6r_{u1} \), and \( 8r_{u1} \). The top chord is composed of \( 3r_{u2}/2 \), and the width of the rectangular opening from the second to the top floor is \( 3r_{u2}/4 \). This means that when the chord of the top arc is divided by four identical parts, the two parts become the width of the rectangular opening. The vertical positions of the rectangular frames can be determined by the sum of the unit circles.

3.2 Bangladesh National Capital Building

The pursuit of such elaborate details of arches with or without concrete lintels in the IIM continuously reappear in the Dacca project, in particular in the main office building, the hostels for ministers, the hospital and the outpatient clinic. The complex of the IIM was planned in two sectors along the north-south axis: the Citadel of the Assembly and the Citadel of the Institution. While the Assembly Building is approached through the Prayer Hall to the south, the Institution...
runs through the park and the Presidential Square to the north. Facing the Assembly Building to the north is the Secretariat, with offices, library, auditoria, and a meeting hall. The hostels and dining halls are located at the edge of the triangular lake looking towards the assembly. The hospital occupies the northwest sector of the complex (Diba, 1989).

Although rough-shuttered fair-faced concrete was chosen as a structural material to provide stability for the Assembly Building, other subsidiary buildings were made of brick bearing walls with masonry arches on their façades. For Kahn, the arch is a primary selection for façade openings in these buildings. The emphasis on geometric openings appears to be related to the religious connection with Islam where form and function are connected to the utmost (Diba, 1989).

Arch openings can be thought of as an expansion of typical square openings to increase the entrance of light and air circulation. The orientation of rooms in the Hostels was a design premised on environmental aspects so that the prevailing wind can pass freely through all living spaces. The window openings of the entry hall of the Sharwardy Hospital are superlative in their hybrid use of circular wall geometries, while the entry hall is characterized by overlapping horizontal bands of different circular openings. Various circular openings in three layers are subtly permuted and aligned in order to create a different dynamism in the entry hall and perhaps to produce a unique design (Fig.10.). The predominant use of arches and circular openings entwined in three layers of walls can be regarded as stemming from careful consideration of the space and natural light, providing a spatial experience of passing through the hall.

A range of openings composed of arches, chords, and double convex series within a boundary circle is carved out of the façade of the hospital building. The design of the outermost façade of the building presumably originates from the window openings of the dormitory façade in the IIM. The arch at the top belongs to the third floor of the building whereas the double convex circumscribes the first and the second floors (Fig.11.). In addition, similar wall openings continuously reappear in the other facades of the Dacca project including a wall of the same building and a wall of the Hostels for ministers, etc. Although the size and locations are slightly different, they are generated from the same construction method.

The middle brick wall of the west façade of the hospital is comprised of two types of arches and a circular composition that are repeated longitudinally. The first is made up of $C_1$ and $C_2$ circles at both sides of the façade and the second is placed at the center of the façade, and is comprised of $C_2$ and $C_3$ circles (Fig.12.). The geometric construction for each composition is based on the same order. Although the sizes of the arches at the third floor are the same, two circular cutouts at the center are larger than the circles at both sides.

The geometric construction illustrates that circle $C_j$ in Fig.14. becomes the unit circle. Circle $C_j$ and circle $C_2$ are set along the vertical axis, as are Circle $C_1$ and circle $C_2$. The diameter of circle $C_2$ is equal to $2.5r_u$. Circles $C_1$ and $C_2$ are proportional to each other, having a ratio $C_1:C_2 = 2:5$. The center point of circle $C_1$ is located at $r_u/2$ above the center of circle $C_2$, while that of circle $C_3$ is located at $r_u/4$ above the center of circle $C_2$. The height of the chord of the two arches is equal...
to $r_u/2$ and located at $2r_u$ above the center of circle $C_2$. The proportional relation of $C_1:C_2:C_3$ becomes $1:1.25:2.5$.

When window openings of the outer façade and the middle wall of the porch are superimposed, both line up exactly. It appears that the size and location of both layers are developed in relation to each other. Both use the same underlying circles and the unit circle, and the central point is in the same location (Fig.16.).

One of the most complicated arch designs is found at an arcade inner wall of the waiting hall. It is made up of various arches that are horizontally arranged in series. They are set symmetrically along the vertical of the centerline. Looking at Kahn's original sketches, it is clear that he intentionally employed varying sizes of arch.

When the first group, arch $C_1$ and arch $C_2$, is examined, the unit circle $r_u$ is derived from the height of the upper arch (Fig.18.). The process of generating the arches is the same as that for the façade designs of the dormitory. In this case, the diameter of circle $C_1$ is $5r_u$, whereas that of circle $C_2$ is $10r_u$. The proportional relationship between the two circles is $r_1:r_2 = 1:2$. The chord of the upper arch is simply drawn at $r_u/2$ above the center of circle $C_1$. The points where $C_1$ and circle $C_2$ meet becomes the chord of the bottom arch. It also becomes the width of the rectangular opening. The height of the rectangular opening is $5r_u/2$.

It is also interesting to compare the proportional relationships among adjacent arches, since they share the same unit circle, which is $r_u$. When arches $C_1$, $C_3$, $C_5$ and $C_7$ at the second floor are compared, their proportional relationship with regard to their radii becomes $r_1:r_3:r_5:r_7 = 5:6:8:9$ in sequence. When arches $C_2$, $C_4$, $C_6$ and $C_8$ at the bottom floor are also relatively compared, their proportional relationship with regard to their radii becomes $r_2:r_4:r_6:r_8 = 5:7.5:13.5:9$. In addition, the proportional relationship with regard to the radii of $C_7$ and $C_9$ is $r_7:r_9 = 3:4$. Regardless of the meaning of their relationship, they are proportional to...
each other, and perhaps related in terms of size.

These windows are also set back from the outer façade. This creates a sort of diffusion chamber and hence there is no need for additional sun shading devices. The openings of the round walls of the Hostels for Ministers of Government is a similar case. Arches of different circles are carved out in the round wall of the Hostel building. The geometric construction is derived from the dormitory walkway of the IIM.

This analysis infers and identifies the underlying methods strategically employed by Kahn in window openings. Kahn's use of geometric shapes has been the subject of numerous examinations by Kahn scholars. However, their examination has focused on floor plans. Despite the uniqueness of circular geometries in facades in modern architecture, an in-depth analysis remains lacking. This study clearly proves that Kahn likewise devoted himself to the manifestation of simple geometry in facade designs.

Kahn's methods of designing window openings are not archetypal in any historic buildings. Kahn was deeply aware of various circular or pointed arch designs that are typically found in classical architecture. Nevertheless, he did not simply copy the historical styles but invented his own. Kahn pushed himself to develop unique arch openings for his buildings, considerably beyond the conventional wisdom. The results of this study can be further utilized in practice to develop different sequential compositions using a simple strategy.

In conclusion, the construction of window openings in Kahn's works is neither a result of mere coincidence nor a copy of the precedents; however, their level of sophistication is far beyond a simple juxtaposition. Each unique design is derived from a logical, orderly design process.

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