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*Timely Timelessness:
Traditional Proportions and Modern
Practice in Kahn's Kimbell Museum*

The twentieth century witnessed declining interest in architectural proportioning systems, which were virtually eclipsed by technical, social and fiscal agendas. Louis Kahn is a seminal architect, whose most acclaimed building, the Kimbell Art Museum (1966-72), represents a compelling case-study in the use of proportions by twentieth-century architects. In spite of a raft of peculiarly modern restrictions (both technological and programmatic), Kahn appears – despite his espoused ambivalence concerning proportion – to have intentionally produced a building with an array of approximate geometrical as well as precise harmonic proportions.

This two-part paper presents the findings of a multifaceted research project that examined the Kimbell's proportions from numerous standpoints. Part 1 presents a textural analysis of Kahn's statements regarding proportion, as well as the findings of an archival study of correspondence between the architect and his client and consultants. Part 2 presents a *prima facie* geometrical analysis of the construction drawings for the project. The division into parts reflects an apparent discrepancy between Kahn's buildings and what he had to say about them.

PART 1

Introduction

If the proportions of buildings are symbolic, then in the case of much twentieth-century architecture, mathematics symbolises the cultural authority of nothing more than everyday instrumentalism, the overwhelming imperative to produce buildings on time and on budget for profit-orientated clients. Architects often make a virtue of standard-sized products – such as sheets of form-ply – thus producing symbols of industrial production. Design decisions often fall to others on the design team. Structural engineers, for example, may determine a space's width according to the maximum span of a commonly available steel section. A services engineer can reduce the overall height of an office block simply by specifying slimmer ductwork for its ceilings. When contemporary architects bring out their calculators, it is not usually to find the golden mean, but to calculate permissible floor space ratios, or fire egress limits, or the number of toilets required on a floor. The proportions of buildings are often subservient to, and symbolic of, a plethora of apparently mundane concerns.

But is this true of all modern buildings? Perhaps among a rarefied minority of great works of architecture there are cases in which the noble tradition of inscribing meaningful proportions has been kept alive by architects dedicated to the art, rather than the business, of architecture. With this question in mind, the present paper examines the most revered building of the celebrated modern master, Louis I. Kahn, whose name is often invoked as a synonym for devotion to the art of architecture. If any twentieth-century architect ever resisted the everyday obstacles that fetter most architects' symbolic geometrising, it was Kahn. The paper will focus on the Kimbell Art

Museum in Fort Worth, Texas (1966-72), and approach the topic from a number of angles. Firstly, Kahn's public statements concerning proportion will be considered. Secondly, geometrical analyses of the plans and sections of the Kimbell are presented, showing where precise and approximate proportions actually exist. Analytical mathematical and geometrical findings are then reconciled with the archival records for this project in an attempt to determine the extent to which existing proportions reflect deliberate architectural intentions.

The paper highlights a complex interplay of forces and draws few general conclusions. For Kahn, the incorporation of harmonic proportions (that is, proportions based on musical ratios) is a stated aim, but it is not an overriding concern. Part of his genius could rest in his ability to frame correspondence with his client and specialist consultants in terms that would make music-based proportions a likely outcome of their dialogue. In particular, Kahn couched queries and suggestions regarding dimensions in terms of whole feet dimensions. When dealing with major dimensions, he errs away from prime numbers, preferring numbers with factors that could be shared with related dimensions. In this way, he is able to appease others' instrumentalist and fiscal agendas while leaving himself greater scope for establishing music-based ratios. The apparent use of geometric proportions in the plan suggests another step in Kahn's design process, in which the plan was massaged until it complied with classic geometric grids. The identification of these grids, which appear to underpin the plan, is the most fascinating aspect of this inquiry, as the archival and oral histories provide no trace of such a step in the Kimbell's design or documentation phases.

The complex and tentative nature of these findings reflects the disparate backgrounds of this paper's authors. Mark Reynolds is a geometer whose publications in this field are specifically concerned with finding geometrical relationships. Steven Fleming is an architectural historian who has published texts challenging geometrical analyses, showing their inconsistency with archival records. The present work is the result of a genuinely dialectical collaboration, involving a meeting in Mexico, exchanged plans, and over 300 emails by two scholars who have relentlessly scrutinised one another's positions, culminating in a joint publication effort. The hope now is that readers of the *Nexus Network Journal* will engage in this debate, leading, ultimately, to a better picture of how great Modern architects incorporate geometry into their work.

Kahn's stated views regarding proportion

A sense of Kahn's attitude towards proportion must be sifted from seemingly conflicting public statements. Regular *NNJ* readers may be frustrated by the present authors' decision to approach the topic of the Kimbell's proportions from what may seem to be quite a distance, by first looking at his broader theoretical concerns and at what can be thought of as Kahn's central theoretical statement, his article titled "Form and Design." It will hopefully become apparent how such an obtuse strategy will, in the end, provide a clearer picture of the building's proportions – or lack thereof.

According to Tim Vreeland from Kahn's office, "Form and Design" embodies Kahn's thinking better than any previous text [Vreeland 1961], and Kahn would not produce such a painstakingly considered text at any later time. David De Long claims that those inquiring about Kahn's theory would be routinely sent a copy of this article [De Long 1991, 71]. In it, Kahn argues that particular buildings of the same type share an archetypal essence, or "form," which is transcendent. He speaks of architects having mystical revelations of ideal "forms", then translating these into terrestrial buildings through a process he refers to as "design". According to Kahn's favourite illustration of his thesis,

... in the differentiation of a spoon from spoon, spoon characterizes a form having two inseparable parts, the handle and the bowl. A spoon implies a specific design made of silver or wood, big or little, shallow or deep. Form is “what.” Design is “how” [Kahn 1961b, 145-154].

Kahn’s terms “form” and “design” openly acknowledge the tension between the timeless aspects of architecture and the circumstantial processes that frame the design and construction of particular buildings.

Although it is undated, Kahn’s earliest documentation of this thesis is most likely a hand-written draft within his personal notebook [Kahn 1959]. The first recorded public expression of this precise thesis is contained in a public address delivered at the Cooper Union entitled “The Scope of Architecture” on 20 January 1960 [Kahn 1960]. Kahn’s preoccupation with the thesis dominated his theorising throughout 1960, leading to a Voice of America broadcast on 21 November 1960 [Kahn 1961a], the revised transcript of which was published in April 1961 as “Form and Design” in *Architectural Design* [Kahn 1961b] and reprinted in the book by Vincent Scully entitled *Louis I. Kahn* [Kahn 1962]. Kahn’s distinction between universal “forms” and the circumstantial outcomes of the “design” process provides a basic framework by which to appreciate his statements regarding proportion.

Where proportion has traditionally been thought of as the terrestrial adumbration of an unseen realm, Kahn does not appear to associate proportions with the universal realm of “form”. Rather, he associates proportions with the circumstantial “design” process. In the same year that he published “Form and Design”, Kahn stated that, “[d]esign is a material thing. It makes dimensions. It makes sizes” [Kahn 1991a, 141]. “Form”, on the other hand, “is not design, not a shape, not a dimension. It is not a material thing” [Kahn 1991a, 141]. By associating dimensions with the idiosyncratic “design” phase, Kahn appears to be saying that dimensions, and therefore proportions, are simply a matter of personal preference, and are subject to everyday concerns, such as cost or construction systems. If architects would like to establish mathematical relationships between key proportions, then they are free to, but in doing so they would not be adumbrating the universal realm of “form”. This aspect of Kahn’s theory leads the philosopher Arthur Danto to remark that his work is closer to “the spirit of Plato than architects whose buildings look like diagrams for geometric theorems” [Danto 1999, 188]. According to Danto, Kahn, like Plato, is more concerned with the essential elements required of such things as political states, beds and art museums, in order for these things to exist at all.

While, to Kahn’s way of thinking, proportions may not point to anything higher than an architect’s own taste, this does not mean that they could not form a vital aspect of Kahn’s own sensibility. Unfortunately, Kahn’s theoretical pronouncements provide no clear sense of his personal preference. On one occasion, Kahn specifically states his preference for buildings *without* mathematical proportions. He states that

... to make a thing deliberately beautiful is a dastardly act; it is an act of mesmerism which beclouds the entire issue. I do not believe that beauty can be created overnight. It must start with the archaic first. The archaic begins like Paestum. Paestum is beautiful to me because it is less beautiful than the Parthenon. It is because from it the Parthenon came. Paestum is dumpy – it has unsure, scared proportions. But it is infinitely more beautiful to me because to me it represents the beginning of architecture. It is a time when the walls parted and the columns became and when music entered architecture. It was a beautiful time and we are still living on it [Kahn 1986, 91].

In the context of this quotation, the phrase “to make a thing deliberately beautiful” refers to the application of sophisticated proportional systems to architectural compositions, since what differentiates the temples at Paestum from the Parthenon are their “unsure, scared proportions.”

While not rejecting the use of proportions outright, Kahn subordinates this device to a sense of the “archaic.” The Temples at Paestum are championed for their chronological – and, in a sense, their ontological – proximity to architecture’s mythical beginnings as a poetic discipline.

While the above statement highlights Kahn’s fascination with the origins of building types and institutions generally, it does not give a complete picture of his ruminations on the topic of proportion. For a more complete appreciation of Kahn’s attitude, a number of statements regarding music must be taken into consideration.

For Kahn, the principles guiding architectural production apply equally to musical composition. This is made clear in a statement he makes in 1964, in which the relationship which he purports to exist between particular “designs” and their corresponding “forms” is extended to particular pieces of music and their underlying structures. “If I were a musician,” Kahn argues,

... and I were the first person to invent the waltz,
the waltz doesn’t belong to me at all,
because anyone can write a waltz –
once I say there is a nature of musical environment
which is based on three-four time.
Does that mean I own the waltz?
I don’t own the waltz
any more than the man who found oxygen owns oxygen [Kahn 1991b, 177].

Kahn’s feigned modesty in this quotation belies the fact that he was actually a talented musician. In his youth, and without the benefit of formal training, Kahn had helped support his family by playing the piano at a local cinema [Tyng 1984]. There is also evidence to suggest that he may have taken an interest in the traditional relationship between architecture and music. In February 1956, during a period of profound transition in Kahn’s work, the architectural theorist Colin Rowe wrote to Kahn to thank him for an evening of intense discussion which they had spent together [Rowe 1956] and to inform Kahn that he would be sending him a copy of Rudolf Wittkower’s book, *Architectural Principles in the Age of Humanism* (the 1952 second edition). A major portion of Wittkower’s book discusses the musical consonants that regulate the proportions of Palladio’s villas, a fact that Rowe may have considered when informing Kahn that in Wittkower’s book, “I think that you will discover attitudes with which you are profoundly in sympathy” [Rowe 1956].

Keeping in mind that Kahn’s theoretical pronouncements are often oblique (as though he were avoiding any binding contracts with himself), two of his statements do seem to echo Wittkower’s analysis of Palladio. In the following statement, Kahn imagines a space having the character of a sound:

I imagine myself composing a space lofty, vaulted, or under a dome, attributing to it a sound character alternating with the tones of the space, narrow and high, with graduating silver, light to darkness [Kahn, cited in Robinson 1997, 12].

In “Form and Design”, Kahn also writes that “[t]o the musician a sheet of music is seeing from what he hears. A plan of a building should read like a harmony of spaces in light [Kahn 1961b, 149].

Kahn’s conception of space in aural terms recalls the connection made by architects of the Neoplatonic tradition between spatial proportions and musical consonants, as described in Wittkower’s book.¹ Indicative of one who boasts that he only tends to read the first few pages of books, Kahn appears to appropriate a simplified version of Wittkower’s thesis into his own theory,

by attributing a sound character to space. Notably, in the introductory pages to *Architectural Principles*, Wittkower discusses Alberti's belief that "in music the very same harmonies are audible which inform the geometry of the building" [Wittkower 1971, 9].

At this point and despite Kahn's references to music, it is important not to overstate his interest in proportional systems. Kahn's "Form and Design" thesis confers a higher status to the inseparable combination of fundamental elements that constitute a type, while relegating dimensions to the so-called "design" process. In this sense, the act of inscribing proportions sits on par with relatively mundane tasks, like meeting a client's budget, or adhering to building regulations.

Yet there is another statement of Kahn's that leaves open the possibility that proportions might perform a higher, or numinous, role in his architecture. In "Form and Design," Kahn argues 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" [Kahn 1961b, 149]. One paragraph later, he reiterates this view, arguing that

... a building has to start in the unmeasurable aura and go through the measurable to be accomplished. It is the only way you can build, the only way you can get it into being is through the measurable. You must follow the laws but in the end when the building becomes part of living it evokes unmeasurable qualities. The design involving quantities of brick, method of construction, engineering is over and the spirit of its existence takes over [Kahn 1961b, 149].

Precisely how a building can evoke "unmeasurable" qualities is never spelled out. Other scholars have argued that Kahn does this through his control of light.² Yet there is no reason to exclude mathematical proportions from Kahn's repertoire of numinous devices.

From Kahn's complex, oblique and at times contradictory pronouncements, one plausible interpretation emerges, which – as will be seen shortly – seems to reckon with the mathematics of the Kimbell Art Museum. Firstly, it must be recognised that Kahn is more interested in fundamental spatial arrangements, and so the inscription of proportions is not so much an imperative as it is a matter of personal preference. Also, as something that would occur during Kahn's "design" phase, the process of making dimensions would at times be overridden by the client's budget, or other circumstantial factors, rather than the desire to achieve harmonious proportions. Having said this, there is evidence to suggest that Kahn might welcome the presence of proportions, especially those with a musical basis (such as 1:2, 2:3 or 3:4) – where they can be achieved in conference with competing circumstantial factors. Their presence could even evoke what Kahn calls "unmeasurable" qualities. Finally, in light of Kahn's remarks about the Parthenon, we can assume that he would be more interested in relatively simple ratios, and would be unlikely to delight in complex or overly sophisticated proportions. Notably, none of Kahn's statements champion proportions produced using geometry, such as $\sqrt{2}$ or $\sqrt{3}$, which, if they are to be found in his buildings, would need to be treated as either secrets, or accidents.

The 2' square grid

Part 2 of this paper will present the findings of a geometrical analysis of the Kimbell, highlighting Kahn's apparent use of approximate (though *very* close), $\sqrt{2}$ and $\sqrt{3}$ rectangles and their attendant grids in the overall planning of the Kimbell. However, in the context of the preceding textural analysis – which highlighted the importance to Kahn of music – a small number of precise harmonic proportions warrant closer investigation.

Anyone who has tried to design a building with an array of geometrically constructed proportions, would be aware of the tendency of such practice to produce very fussy dimensions. Indeed, any geometrically derived system will need to be compromised at the level of internal walls or fenestration, unless, of course, the architect is willing to calibrate their dimensions to the nearest half inch, or centimetre.

However, the dimensions of the Kimbell are anything but fussy. In plan, for example, they are exclusively in whole feet. The sanctity of this rule effectively precludes the existence of many *precise* ratios incorporating irrational numbers. Rather, the building contains a number of numeric, or modular, ratios involving small rational numbers. In plan, the internal proportions of the bays are 5:1. In section, the internal proportions of each bay are 5:3 (measuring to the springing point of the cycloid shells), while the internal proportions of the interstitial spaces linking each vaulted bay (or “servant” spaces as Kahn called them), are, in section, 1:2.

Such elementary proportions are made possible through a relentless adherence to an imperial module, the foot. Moreover, the plan conforms to a square grid, 2' x 2'. Were such a grid laid over the plan, it would pick up every column and wall. Even the floor pattern, comprising 6' x 2' travertine floor tiles, snaps to the grid. Smaller elements, such as 1' x 1' pieces of parquetry, or the 1" x 1" mosaic tiles in the toilet cubicles, can also be seen in the light of an all pervasive imperial module, in the service of simple drawings.

Further to his use of an imperial module, Kahn further simplifies dimensions by tending to use values with common factors. The 5:1 planar proportion of the vaults reflects the simplest of measurements – 100' x 20'. The sectional proportions of 5:3 reflect simple dimensions again, 20' x 12', while the 12' high “servant” spaces are simply 6' wide, yielding an harmonic proportion of 1:2. Similar combinations of whole feet dimensions, featuring numerical values with many factors, are to be found throughout the Kimbell.

Kahn's adherence to a 2' x 2' square module, the resultant commensurability of dimensions in the Kimbell, and the corresponding lack of *precise* proportions resulting from geometrical constructions, makes perfect sense when seen in relation to Wittkower's thesis regarding the architecture of the Italian Renaissance. In *Architectural Principles*, Wittkower states that the central issue of Renaissance architecture is the commensurability of ratios and that recent scholars obscure this fact “by insisting on the theoretical and practical advocacy of incommensurable, i.e., geometrical proportions by Renaissance architects” [Wittkower 1971, 158]. “It seems almost self evident,” he argues,

... that irrational proportions would have confronted Renaissance artists with a perplexing dilemma, for the Renaissance attitude toward proportion [...] was aimed at demonstrating that everything was related to everything by number [Wittkower 1971, 158].

Since Kahn owned a copy of Wittkower's book, and since Wittkower's thesis is almost as valid for the Kimbell as it is for a Palladian villa, it would be reasonable to conclude that Wittkower's book had some effect on the Kimbell's dimensions. The fact that Renaissance architects believed harmonic proportions adumbrated a Platonic realm, in much the same way as Kahn thought buildings could evoke the “unmeasurable”, adds further weight to this interpretation.

Archival evidence

However, one major obstacle stands in the way of this analysis, and that is the office correspondence for the Kimbell, which contains compelling evidence that the client, and not the architect, made crucial decisions regarding not only rough sizes or areas, but actual dimensions.

For a comprehensive account of the Kimbell's design and construction, based on archival records and interviews, the reader is referred to Patricia Cummings Loud's text, the *Art Museums of Louis I. Kahn* [Loud 1989]. Loud outlines an iterative and protracted process that typifies Kahn's working method. The present paper will only refer to a small number of key documents which relate specifically to dimensions.

The office correspondence reveals no record of a conscious attempt to establish harmonic consonants. On the contrary, it shows that many dimensions were established in conference with the client, the gallery director Richard Brown, who regarded himself as Kahn's "sparring partner" [Brown 1967b] and who persistently pressured Kahn to reduce the overall size of the gallery. His disposition can be summarised in a letter he wrote to Kahn on 12 July 1967 regarding a design iteration that was to be 400' square:

Within that big square you wind up with an awful lot of cubic space that must be heated, air-conditioned, illuminated, etc.; and acres of floor and wall surface that must be cleaned, waxed, mopped, resurfaced upon occasion, etc.; all of which costs money and labor to do, and I want as much money as possible saved from maintenance so I can buy more and more art as the years roll by, not just keeping up the house [Brown 1967a].

In the same letter, Brown raised what he calls the issue of scale, writing that "The Grand Canyon is vast and its scale is exactly right [...]; size and scale are in balance" [Brown 1967a]. He contrasts it with a small Rococo church, that helps the user "feel as secure and intimate with God and the universe as does a warm bath behind a door bolted against any possible intrusion" [Brown 1967a]. The letter goes on to state that Mr. and Mrs. Kimbells' paintings "are very 'gentile', 'polite' representations of fair ladies, tender little children and singularly pure young men" [Brown 1967a]. These arguments form a lengthy preamble to a list of size-paring instructions, including a suggestion that the gallery walls be lowered from 15' to 12', and that the upper most height of the vaults be lowered from 30'. Subsequent iterations of the design feature 12' high walls as requested, and a much shallower vault, based on a cycloid. Astute readers will have noted that 12' is the short side of the aforementioned 5:3 sectional ratio.

In a hand-written letter and sketch, dated 11 May 1968, Brown noted that the design at that date was as long as the Dallas International Airport terminal, a building "notable for its affect of huge scale!!!" [Brown 1968]. Effacing himself and his aversion to monumentality, Brown signed the letter "Richard the Chicken Hearted." In subsequent iterations, the gallery bays are reduced from 120' to 100'. (At the simple level of building technology, it can also be observed that 100' happened to have been the maximum distance that concrete walls or vaults could be produced without requiring expansion control joints). Under similar pressure from his client, Kahn reduced the width of the bays from 30' to 20'. There is no evidence that Kahn chose this dimension for its 5:3 relationship to the 12' wall height, or its 1:5 – that is, its modular – relationship with the length of the bays, though the fact that 20 is a factor of 100, and has the number 4 as a factor in common with 12, may have influenced his choice. This distance also reflects Kahn's belief – based on an assertion by the American architect Clarence Stein (1882–1975) – that 20' is a minimum

width for any space containing artworks. According to his wife, Kahn had not allowed artworks to be hung in their home because it was not 20' wide.

While there is no direct archival evidence to suggest that Kahn consciously sought harmonic proportions, the office files do testify to his commitment to the imperial module. The day-to-day negotiations and directions between Kahn, other members of the design team, and Richard Brown, were conducted and documented via written correspondence, and it would have been a matter of convenience that sizes be expressed in terms of whole feet. Unlike other kinds of communication, including the transfer of electronic drawing files, or the exchange of plans, letters are a poor means of communicating fussy dimensions. To reduce the likelihood of error, Kahn fostered a kind of written discourse in which dimensions were exclusively expressed in whole feet, and where, by implication, plans and sections would adhere to an invisible imperial grid.

A few examples of this rule have been seen in Brown's letters to Kahn, but other examples abound. A raft of major dimensional changes were negotiated in various letters between Kahn's associate Marshall Meyers and the partnering architects in Texas [Meyers 1969; Meyers 1967]. Smaller dimensions are discussed in another letter in which Meyers is asked to nominate which columns need to be 3' by 2' for structural reasons, as opposed to the 2' square column used generally in the project [Harden 1969]. Columns measuring 2'-6" are not considered, though they are likely to have been adequate structurally. In another letter, the partnering architects mentioned that the suspended floor slab could be 10" thick, with sheer heads at the top of each column [Gerin 1969]. Wishing to maintain the imperial module in section (and wishing to keep cleaner lines), Kahn opted for a thicker slab, 1' in depth.

Conclusions based on the textural analysis

Despite the burdens of modern practice, Kahn was able to accommodate traditional design parameters in his own work. He achieved harmonic proportions by limiting the way in which dimensions were communicated on a day-to-day basis in written correspondence. For architects, exchanging letters with clients and a broader design team is an everyday occurrence, whereas plans are exchanged far less frequently. In the case of the Kimbell Art Museum, one limitation of letters – that they cannot easily communicate fractional dimensions – contributed to that building's geometrical strength, by giving it a 2' square grid, which locks in an array of harmonic proportions.

Were it not for his client's fiscal constraints, Kahn would surely have made the Kimbell a much larger gallery. It might have had bolder proportions, such as a square section, but circumstances led to less striking proportions, based on musical ratios. The fact that any proportions resulted from the complex interplay of client's, consultants' and architect's input, can, at least in part, be attributed to Kahn's subtle manipulation of day-to-day correspondence. Where many commercial architects would sacrifice timelessness for timeliness, Kahn appears to have managed both.

When seen in terms of his theoretical pronouncements, it could be argued that Kahn strove for harmonic proportions as part of a quest to evoke an "unmeasurable" realm of inspiration. This is the realm of Kahn's so-called "forms", and can be likened to Plato's realm of ideal Forms. While nothing can be taken from Kahn's words to suggest that he was interested in geometrically-derived proportional systems, the fact that he engages with the Neoplatonic tradition on one front suggests that he may have engaged with other Neoplatonic concerns. This line of thinking will be pursued in Part 2 of this paper, which identifies the Kimbell's geometrically constructed proportions.

PART 2

Geometrical proportions in the Kimbell

Those who are familiar with recent publications about Kahn will be aware of Klaus-Peter Gast's book, *Louis I. Kahn: the Idea of Order* [Gast 1998]. In it, Gast argues that Kahn continues the Neoplatonic tradition by consciously inscribing his buildings with a hidden geometry, and by using the square and its derivations as a motif in his work. However, as Fleming has argued previously, Gast's analysis of the Kimbell is by no means exhaustive, and may contain inaccuracies [Gast 1998; Fleming 1999]. According to Gast, the distance by which the external dimensions of the rectangular plan of the Kimbell Art Museum falls short of being a double square, determines the width of the gallery's many bays. This claim simply does not tally with Kahn's working drawings, according to which the Kimbell is 318' wide (measuring from north to south) and 174' deep (measuring from east to west).³ To be a double square, the building would need to be 348' wide, that is, twice as wide as its depth of 174'. The difference between its actual width and the width it would be were it a double square is 30' and this is the distance Gast refers to in his analysis as *x*, which should also be the width of the gallery's bays. However, the bays are not 30' wide. They are 20' wide – or 22' when measuring from the centres of the supporting columns. This represents a discrepancy of between 8' and 10' (or 40% to 50% of 20').

For the purpose of this study, it was deemed necessary to conduct a fresh geometrical analysis, and to inform the reader of its parameters and limitations. Padovan [1999] argues that the two major approaches in securing precise information regarding proportioning systems are numerical calculation and geometric construction or deconstruction. Whenever possible, both procedures should be utilized, and ideally, the analyst would also prefer *in situ* measurements personally carried out. However, with the advent of modern architectural drawing techniques, we do have fairly truthful drawings and measures carefully considered by the architect and associates, and we can reasonably consider the accuracy of the building's proportioning as written and drawn.

Additionally, there is general agreement that percentage deviations may be indicated in scholarly works to assist everyone in knowing how much the actual structure varies from the ideal proportioning system. The formula for determining percentage deviation is:

$$\text{Measured (or Actual)} - \text{True (or Ideal)} / \text{True} \times 100$$

The deviation can be either high or low (+ or –). The understanding is that the closer the actual answer is to the ideal, the more the probability that the ideal measurement being considered was actually used. It isn't "proof positive", but it is suggestive of intention. The only time we are positive is when we hear or read about that intention directly from the creator of the work.

Using a procedure that Reynolds has previously shared with *NNJ* readers [2001], the overall plan was analysed, with specific attention to the internal volumes. In other words, arcs and compass points were focussed on internal wall faces, rather than column centres or external surfaces. The celebrated architectural space of the museum is framed by the internal surfaces of its walls, and so the thickness of those walls is of less significance.

The analysis began with the most elementary of analytical procedures, which identified, almost instantly, geometric proportions in the Kimbell's three major wings, those being the southern and northern wings each comprising five vaulted bays (excluding the porches), and the central wing, containing three vaulted bays (also excluding the porches). The five-bay northern and southern wings form rectangles of approximately $\sqrt{2}$ proportions. They have internal dimensions of 100' x

140', yielding a ratio of 1:1.4. This falls very close to a $\sqrt{2}$ rectangle, of 1:1.414. The three-bay central wing has internal dimensions of 86' x 100', yielding a ratio that falls very close to the rectangle of the equilateral triangle, which is .866025:1. The fact that the eastern-most vaults of the northern and central wings are partitioned off from the gallery, making these ratios imperceptible to the viewer, raises the possibility that the presence of these ratios is a matter of coincidence. Were these ratios precise to a number of decimal points, then it would also be easier to argue that they are intentional. This is, after all, a building made using reinforced concrete technology, which could easily accommodate precise dimensions. However, achieving precise dimensions would also have required very fussy dimensions, and, as we saw in Part 1 of this paper, the Kimbell's dimensions are anything but fussy. They are exclusively in even numbers of whole feet. If we accept the pre-eminence and practical benefits of a 2' grid, then the percent deviations between the actual and ideal proportions mentioned are less significant than they may at first appear. For instance, each is accurate to the nearest foot, if not a fraction thereof.

The next step in the analysis was to pursue a simple hypothesis; in deriving the final form of the southern wing, Kahn may have exploited one of the primary features of a $\sqrt{2}$ rectangle, that, when it is divided in half on its long side, each half is also a $\sqrt{2}$ rectangle. The $\sqrt{2}$ rectangle is the only rectangle that does this.⁴ The following analysis of the southern wing does indeed support that hypothesis, revealing what some readers will agree is a reasonably elegant marriage between a classical proportioning system and the final built form.

Fig. 1

The $\sqrt{2}$ rectangle is made from the side and the diagonal of the square. As seen in fig. 1, when the side of the square AZ is 1, the diagonal AM is equal to $\sqrt{2}$, or 1.414... . We then generate the

$\sqrt{2}$ rectangle APRZ. This unique relation between side and diagonal in the square is further developed when we find that where the side of the square passes through the diagonal, at Q, this interaction divides the rectangle exactly in half at GN, precisely into two $\sqrt{2}$ rectangles, AGNZ and GPRN. Looking solely at the square, this intersection would yield a reciprocal $\sqrt{2}$ rectangle, $1/\sqrt{2}$ or 0.707... /1, within the square. This division at Q yielding the line GN was referred to as the “Sacred Cut” by Tons Brunés [1967].

In this same construction, it is also essential to note that rectangle KPRM that sits over the square AKMZ is the “theta”, or θ , rectangle. Its ratio is 1:2.414..., or a $\sqrt{2}$ with a square added to the *short* side of the $\sqrt{2}$ rectangle. It is interesting that the θ rectangle contains the two component parts of the generated $\sqrt{2}$ rectangle.

In fig. 2, the technique of “Rebattment” is shown. Rebattment is taking the short side of a rectangle and rotating it onto the long side in order to “cut off” a square in that rectangle. Here, AZ is rotated onto AP and ZR to produce the square, AKMZ, and PR is placed onto those same two long sides to produce the square GPRN. In this figure, the pairs of diagonals, AM with ZK and GR with NP, have been drawn in to clarify these two squares, whose centers are O and Q. When this rebattment technique is done in the $\sqrt{2}$ rectangle, the squares overlap to produce the specific rectangle GKMN. This is the 1.707... This rectangle, like the θ , is also a square and a $\sqrt{2}$, but here, the square has been applied to the *long* side of the $\sqrt{2}$, not the short side. As a result of the 1.707 in the middle, θ rectangles are generated in the top (KPRM) and the bottom (AGNZ).

Fig. 2

When diagonals are generated in the two θ rectangles, we locate their centers, X and Y, as can be seen in fig. 3. When midlines EF and CJ are drawn through these centers, they generate the

square ECJF. It is generated into the center of the $\sqrt{2}$ rectangle APRZ. The center O is the center of the square *and* the $\sqrt{2}$ rectangle. It is critical to note that these qualities are unique to the $\sqrt{2}$ rectangle, that they are key elements in the $\sqrt{2}$ proportioning mechanism. These particular elements are:

- The square, 1 x 1
- The $\sqrt{2}$ rectangle, 1.414... x 1
- The θ rectangle, 2.414... x 1
- The square plus the $1/\sqrt{2}$, 1.707... x 1

Fig. 3

In any rectangle, by developing the basic elements in squares and rectangles, various grids and intersections are created. It is these intersections and interior line lengths, called *caesurae* (as in music, they are breaks) that develop the proportioning systems that are unique to the specific ratio being utilized. In the $\sqrt{2}$ rectangle, the square, $\sqrt{2}$, θ , and the $1/\sqrt{2}$ are the primary elements found in the grid system. These intersections and caesurae are then used to design and develop the space, the specific compositions and arrangements that we see. Each architect, designer, and artist is free to develop particular grids for specific needs. Should the Kimbell have been geometrically regulated, then what choices might Kahn have made for his $\sqrt{2}$ (and, as we shall see, the $\sqrt{3}$) rectangles?

Fig. 4

A plausible utilization of the aforementioned grid systems in laying out the upper level plan of the Kimbell, is described in fig. 4. The centrally-placed master square ECJF of the grid provides for the placement of the two side galleries, as can be seen along the top CJ and the bottom, along GN, of the square. Furthermore, the intersections of the diagonals FC and EJ of this square, with the diagonals of the two θ s, along AN and MP, generate the “eyes”, or intersections, at points **a** and **b**. The caesura ST is drawn through these points, and define the ends of the two staircases with the edges SF and TJ. (We will see the completion of these stairwells in the next grid.)

The development of the entire southern wing may have followed a similar procedure. In fig. 5 it can be seen that:

- The rebattment technique may have been used to create the two master squares, AKMZ and GPRN.
- The two θ rectangles AGNZ and KPRM could have been defined with their diagonals in order to generate the third master square ECJF in the center of the rectangle.
- The diagonals of all three squares have been drawn in.
- The grid is now complete.

While on the topic of the stairs, it is worth noting that their rectangular area appears to have been completed by the points **d**, **e**, **m**, and **n**. Furthermore, the walking areas leading to these stairs, made of stone rather than wood, along the very long, thin rectangles EUVF and BCJS are also developed by these particular grid elements.

Also, of points **d**, **f**, **q**, **o**, **m**, **n**, **p**, **r**, **g** and **e**, specifically **o**, **m**, **n** and **p** appear to have been used for the double square **omnp** the upper level of the conservator's courts. All these points are generated from the diagonals of the three master squares and the two θ s, top and bottom. The line **op** that completes this double square is made by simply passing the caesurae **dm** and **en** through the diagonals, FC and EJ, of the central square, ECJF. Line **op** also passes through OO, the center of the upper master square, GPRN. Kahn continues his unifying thought by making this conservator's court two squares. These courts could have been any rectangle he desired, but Kahn kept his theme of the primacy of the square by making **omnp** a double square. The point has been made by Gast and others that squares are both a motif and generative figure in much of Kahn's work.

This thought is an apt entrée to an analysis of the light court on the western side, center (at the bottom of the wing). This court is also a square **uvw**. This space appears to have been made from an intersection of the diagonals of the three master squares of the $\sqrt{2}$ rectangle. The points **h**, **k**, **l** and **j** were used for the left and right edges, **uv** and **xw**. The westernmost edge **ux** is defined by UV. The easternmost edge **vw** is made from the horizontal midline LD of the base master square AKMZ. The center Q is also the midpoint of the edge **vw**. The points **s** and **t** further define this court's architecture elements. Points **s** and **t** are made from the intersection of the base GN of the top master square GPRN.

Furthermore, these court openings could be linked by being at the opposite vertexes Q and OO of the dynamic square QqOO. The internal square **hklj** is in fact the same size as the light court.

Fig. 6 examines the northern bay. It is also an approximate $\sqrt{2}$, but is very slightly larger than its southern mate. Also, a slightly different grid appears to have been used. Here, the two θ s AGNZ and KPRM frame the central area GKMN, which is the $1/\sqrt{2}$ we have already mentioned above. The diagonals of the two master squares AKMZ and GPRN intersect at points Q and O. These points, combined with the points **b**, **c**, **f** and **g**, where the diagonals of the θ s intersect the diagonals of the squares, provide for the large light court square **mnpr** in the very center of the floor plan. It can also be seen the various changes in the materials of the walking spaces of the floor utilize the intersections within the two θ s, at points, **f**, **h**, **g**, **b**, **a** and **c**, as well as the centers of the two squares **e** and **d**. The width EG is but one example. In both $\sqrt{2}$ bays, the grids are relatively simple and elegant. More importantly perhaps is how simple they are to perceive.

Another way of looking at the grid in this North bay is to see WPRX as a double square ($\sqrt{4}$), rectangle EWXF as a $\sqrt{2}$, and to see the very wide rectangle at the base AEFZ as a double θ (1:4.828...). The $\sqrt{2}$ rectangle is very flexible; yet another reason why it has been a favourite of designers over the centuries.

Finally, my original thought about whether Kahn may have exploited the characteristic aspect of $\sqrt{2}$, that it divides into two $\sqrt{2}$ s, was answered when I examined the central bay. It measures out to be 100' x 86'. The point of interest here is that the ratio, 0.866... to 1 (or 1.154... to 1, depending on whether you're using the short side or long side as your unity; these are simply reciprocals of each other) is known as the "rectangle of the equilateral triangle". It is also what is known as *ad triangulum* geometry. In what may betray a sense of humour geometrically, Kahn

appears to have selected the rectangle that consists of *two* $\sqrt{3}$ s and interjected it between two $\sqrt{2}$ s! If he did, then he achieved a clever, elegant, and ingenious solution to a plan that calls for variation within symmetry, that the central rectangle be in harmony with, but different than, its flanking bays on the northern and southern sides.

Fig. 7

The two $\sqrt{3}$ rectangles are tangent on their *long* sides. In Figure 7, the rectangle AKMZ is the *ad triangulum* rectangle, with rectangles AKRP and PRMZ both being $\sqrt{3}$ s. ARZ is the equilateral triangle, and so is KPM. By bisecting (again, the theme of two) the angles A, Z, K and M, two other $\sqrt{3}$ rectangles AJLZ and GKMN are also generated. The underlying materials on the floor are placed along this $\sqrt{3}$ grid, and are also still yet aligned with their $\sqrt{2}$ s on either side. Of note is that the $\sqrt{3}$ contains three $\sqrt{3}$ s within its perimeter, just as the $\sqrt{2}$ has two $\sqrt{2}$ s. The agreement of these interior rectangles with the number under the radical sign is a quality of all root rectangles (a $\sqrt{4}$ has four $\sqrt{4}$ s within, and so on). Looking to the top right $\sqrt{3}$ rectangle ORML a smaller $\sqrt{3}$ rectangle ORST can be seen. Point F is where a diagonal TR and a reciprocal line OU intersect. These intersections are sometimes referred to as “occult centers” because they are “hidden from the

eye". In this grid, they provide for the width EW, as point E is also an occult center. As can be seen, EW becomes an integral part of the grid. And in what is perhaps most interesting, in a $\sqrt{3}$ rectangle the occult centers break the rectangle into *fourths*. In a $\sqrt{2}$, the occult centers divide the rectangle into *thirds*. This is another quality of the root rectangles: whatever the number is under the radical sign, the occult centers always yield the next number up fractionally. So, EW is one fourth of OR. Fourths bring us back to squares: 2^2 , or 2×2 , is four. Four happens to be the number of root rectangles used in the plan: two $\sqrt{2}$ s and two $\sqrt{3}$ s. Like many artists, designers, and architects at the time, Kahn may have known all these things though popular books such as the widely circulated the *Elements of Dynamic Symmetry* [Hambidge 1967].

Given the many unknowns, including the range of possible applications of $\sqrt{2}$ and $\sqrt{3}$ grids, this analysis cannot be considered definitive. Neither can its weakness be disguised. Some readers might argue that an experienced geometer can find proportions where they don't exist. It remains problematic also that the easternmost vaults of the northern and central wings are partitioned off from the gallery, rendering proportional relationships in these wings imperceptible to the viewer.

Within the confines of a research paper, it would have been impossible, and tedious, to have presented the hundreds of accompanying percentage deviation calculations that would complete this analysis; and indeed, it needs to be said that – with the exception of the squares, which are precise – the proportional relationships that have been identified here are not true to more than one decimal place. Close inspection of the figures reveals that some construction lines miss their relevant wall surfaces by up to (but at least no more than), one foot. In other words, the grid fits as well as could be expected given the overriding presence of a 2' square grid and a whole foot dimensioning system; and that really is the salient point. The extremely close alliance of the central wing to a $\sqrt{3}$ rectangle, which is then flanked by near perfect $\sqrt{2}$ rectangles, and the approximate conformity of the internal layout to grids which proceed naturally from those figures, presents what amounts to an object lesson in proportioning when tempered by a dimensional grid. It also presents a scholarly conundrum. If the presence of approximate $\sqrt{2}$ and $\sqrt{3}$ proportions, and their attendant grids, is the result of what must have been a tireless effort by Kahn or members of his staff, then no record, either oral or written, has been found to corroborate such a thesis. If this analysis is correct, then why didn't Kahn mention his fascination with classical proportioning grids? Perhaps one of his office staff added this layer of refinement? Amidst the many tasks facing the design team leading to the production of construction drawings, could the act of refining a plan have taken so little time as to not warrant mentioning, thus leaving no written trace of the event?

Conclusions based on the geometrical analysis

With the Kimbell Art Museum, Kahn managed to reconcile a number of competing demands. First and foremost, this is a building in which technological ambition meets head-to-head with fiscal constraint. The building's roof is made from post-tensioned curved concrete beams spanning an incredible 100'. Within that complex roof structure, a sophisticated network of ducts and electrical services is carefully integrated, and remains virtually imperceptible to the viewer. The building meets a number of other demanding criteria related to security, egress, access, catering, archiving, the preservation of precious artworks, and, most significantly, a limited budget.

Yet Kahn, or whoever might have been responsible for incorporating *ad quadratum* and *ad triangulum* systems, appears to have taken the time to, in effect, salute two of the most famous root rectangle systems used in antiquity and the classical periods in art history. This would seem to

be a totally appropriate geometric context in which to provide for the geometric structure of an art museum.

Nores

1. Inspired by figures including Pythagoras, Plato and Saint Augustine, architects of the Neoplatonic tradition applied to buildings the same proportions that underpin musical harmony, in the belief that those proportions are of transcendent origins and order the cosmos.
2. At least two scholars state that Kahn's control of sunlight has a numinous, or transcendent effect, See [Geldin 1991, 17]; see also [Dean 1978, 87].
3. See the drawing titled: "A4: Upper Level Floor Plan", Louis I. Kahn Collection, University of Pennsylvania and Pennsylvania Historical and Museum Commission.
4. A wide variety of rectangles used throughout history, like the golden section, the $\sqrt{3}$, and the whole number/musical ratios, have particular qualities that set them apart from all other rectangles. These qualities are then used as "tools" in various proportioning systems and grid structures. LeCorbusier's golden section-based Modulor system is but one more recent example.

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