

Critical Investigation of Cheops Pyramid Building in Relation to the Solar Equinox

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Abstract: This paper aims to reveal more of the hidden secrets of the Cheops Pyramid in terms of the descending rays of the sun during the equinox falling upon the azimuth of the diagonal secant position at the solar successions. The methodology used to complete this investigation project is based on the collection and analysis of data related to the erection principles practiced when the pyramid was constructed during the era of the Fourth Dynasty Egyptian Pharaoh Khufu. These principles are the key for the geometrical representations of the balanced states across the residual depictions of the sun's position relative to the Cheops Pyramid during the equinox. This research has found that the apex is an inevitable predetermined inclusion within the theorem of universal expansion. Moreover, the inclinations of the pyramid were set to predetermine the location of its plumb line, thereby serving as a guiding factor in erecting the blocks of the Cheops Pyramid. The main conclusion is that there is a strong relationship between the Cheops Pyramid geometry, the erection of its steps, and the solar equinox. **DOI:** 10.1061/(ASCE)AE.1943-5568.0000503. *This work is made available under the terms of the Creative Commons Attribution 4.0 International license, https://creativecommons.org/licenses/by/4.0/*.

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Introduction

The Cheops Pyramid of the Giza plateau in Egypt is a marvelous structure that may reflect a journey through the stream of time and space. Upon observing the long accumulation of stone layers, from the highest top to the lowest base, an observer may become easily engrossed in this majestic realm of its structural equilibrium and geometrical mysticism.

The constructability factors highlighted in the subsequent sections in terms of the defined methodology for erecting the external slope of the pyramid mainly originated from the deep understanding of the Egyptians of galactical and astronomical incidences, among which the equinox occurs twice a year. The surface geometry of the pyramid is built only based on the convention stating that the pyramidion should always end with the modular erection of building blocks because it becomes inevitable to end it with a cap rather than the building blocks. Therefore, the constitution at the top of the pyramid must be defined. This is because irrespective of the number of blocks used, the volume of the pyramidion is considered negligible and close to zero (Ghoussayni et al. 2018). Building the pyramidion at the ground surface serves as a valuable reference for erecting the slope of the

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pyramids. However, it is considered a mockup structure, based on which the layers of building blocks are assembled.

"The architects of Khufu's vast Pyramid in choosing its slope would not want to encounter the structural problems of the Bent Pyramid and they would surely want to follow the architectural and artistic traditions of the time." "The builders also needed to coordinate thousands of workers on four faces and so simple whole integers for the rise and run would be desirable" (Bartlett 2014).

It is clear that there is a shortage of reported research on the relationship between the Cheops Pyramid geometry, the erection of its steps, and the solar equinox.

The story of the Cheops Pyramid goes beyond its endurance of the harsh natural and environmental conditions, although this endurance makes us admire this long-lasting structure. However, there also exists a state of determination that causes one to think that the framework of this pyramid could only have been created using advanced intelligence and modern technologies.

This pyramid sheds some light on the ancient intelligence that was unexpectedly discovered during recent correlations with dilemmas, specifically when using advanced intelligence. Although the vocabulary of the pyramid holds within its domain consistent fields of resolutions, it tends to explain the universal findings within the sequence of existence that has been sustained through ages. This would add more debatable elements to arguments regarding the crucial assumptions made about the unsettled endings of the universal engagement between space and void. The secrets contained in astronomical findings and the erection principles provided for the structures that we are about to discuss depicts a magnificent story about the intelligence that existed thousands of years earlier, perhaps even before human civilization was born.

By going back to the site of Giza in Egypt it "has been measured with precision, at different times, by expeditions of archaeologists who have reported the results of their surveys in various documents. All surveys measured the dimensions of the three main pyramids on the same vertices originally located by the English archaeologist Flinders Petrie, around 1880." His reports allowed the researchers to determine "the lengths of the bases and heights of the pyramids of Cheops, Chephren and Mykerinos" (Camacho Ríos and Sánchez Luján 2018).

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Fig. 1. (Color) Different states of expanding blocks.



Fig. 2. (Color) (a) Depiction of y = x + z; and (b) depiction of y = x + z, mirrored to the xoz and yoz planes.





This paper reports the findings of research conducted by the authors to explain and clarify the relationship among the Cheops Pyramid geometry by erecting the blocks with predetermined patterns for each of its layers that are in constant relation to the solar equinox.

Research Approach

With the Big Bang, which was a sudden unexpected explosion of matter into the realms of space, a burst against the inevitable state of darkness occurred as light originated at the very beginning



Fig. 4. (Color) (a) Disintegrated states of pixels; and (b) cumulative values of the five states in Fig. 4(a). (Data from Ghoussayni et al. 2018.)

of time and opposed the completely void state. Some researchers like Burago on the theory of the Big Bang (Burago 2017a, b) may apprehend this as a state of an expandable blast as it may be also depicted as a pixelated cube, which is portrayed by the authors as shown in Fig. 1.

The very founding expandable state correlates to the main theology of the earliest idea on existence that the old Egyptians signified its meaning through the state of a Pyramid's Apex. The very nature of Cheop's inclination is attributed to the realms of Sun's position that meaningfully matches with the Sun's Azimuth at the Equinox for this given pyramid.

Hence, the approach to the constructability process of the Cheops Pyramid is very related to its angular inclination that sets a clear path for the adaptability of defined tools that will be explicated in the consequent sections of this paper.

Simply the patterns found in the Great Pyramid of Giza (Cheops) which were explained by the paper on the constructability methods among many other buildings that were revealed were found similar to those exhibited in the course of Egyptian monument building; "it is clear that such recurrences in building design established the fundamental idea that a state of equilibrium is always a condition of symmetrical forms of grid-like modules that turn out to be mathematical patterns from the past." Also, it was highlighted that the structural emphasis in the "method used by the ancient Egyptians who built the Cheops Pyramid" has achieved high accuracy within the projected timeframe (Ghoussayni et al. 2020).

Findings

The geometric representation of the equation y = x + z corresponds to the surface of a quarter pyramid with an inclined base at an angle of 45° [Fig. 2(a)]. It is also pertinent to "assume that the air shafts" in the great pyramid "were tunnels for communication, an 'intercom' between the inside and outside workmen." They are exactly inclined at 45° to the horizontal and are precisely at the same



Fig. 5. (Color) Pyramidal progression from a pixelated square plan.

horizontal level as they "could not be so well aligned except perhaps by the tracking of the stars" (Deif 2008).

The very geometric nature of any given pyramid is that it can be correlated to being transformed from a set of equations to visual impact as illustrates in Fig. 2(a) while Fig. 2(b) depicts the accumulation of four equals sets of quarter pyramids and jointly arranged where Figs. 2(a and b) describe a pyramid where x, y, and z are less than or equal to five modular lengths, but they always have positive values. This is more likely a former ordinance, which was found upon the earlier ramification of the master entities known as constituents. In this paper, these constituents are defined as the postulates outlining the findings on the relationship between the pyramidal apex angle and the solar elevation angle of the Cheops Pyramid in Giza during the equinox. The principle behind this case study is that in the Cheops Pyramid, the state of equilibrium is a condition with symmetric forces from grid-like modules. Originally, i.e., during the construction of the pyramid, these were mathematical patterns without which the structure would possibly have collapsed. By contrast, Isaac Newton established an average length of 0.525 m for the Egyptian Royal Cubit (20.67 in.) (Newton 1737).

The previous Figs. 2(a and b) show the constant geometrical inclination for this given pyramid with the buildability factors of reliability within the progress of works as the pyramid's layers stream up to the Apex. This constancy of inclination is derived from the modular pixelated depiction of layering the blocks that are explicated in other sections of this paper.

In Fig. 3(a), there is a constant relationship between five modules (modular lengths), each with a dimension of 1 Rc (Egyptian Royal Cubit) providing a pyramid with five modular lengths and having a volume of six cubic modules. While simply Fig. 3(b) is showing the geometric parameters derived from Fig. 2(b).

Fig. 3(a) also illustrates a pyramid whose volume of 6 m³ is negligible owing to the least representation of the apex cap. This is based on the understanding that the first cap could not be accommodated with building blocks but with a pyramidion that had a volume of 6 m³.

The volume of a pyramid with a square base is (base \times height) divided by three which is equal to six, where the base is five modules in one direction multiplied by the same value of the other direction. In the same line, the height is five moduli, and if the figures are implied within the volume of the pyramid, the value of one modulus will result in having a value of (0.5235), which is equivalent to 1 RC as shown in Fig. 3(a).

Section of the pyramid with a volume of 6 m^3 and an angular section of the pyramid equal to 53° with a volume of 6 cubic Rc is correspondent to the geometrical sun angle at the Equinox of Cheops location.



Fig. 6. (Color) Coordinate values with the resulted inclination.

The graphical representation of pixel disintegration from cohesive states to individual states, that is, from State 1 to State 5 as shown in Fig. 4(a) corresponds to the planar pixelation of each of the pyramid's layers (Ghoussayni et al. 2018) where the Cumulative values from State 1 to State 5 with the left-hand side being equal to the disintegrated states on the right-hand side; therefore, y=25 on the left is equal to x=25 on the right is shown in Fig. 4(b) (Ghoussayni et al. 2018).

In any balanced state, the equation is always the same where equating the cumulative values of States 1, 2, 3, 4, and 5 gives the result shown in Fig. 4(a). The figure shows the progression of entities through the progressive states. In the pyramid, the problem is "the trouble at the top" (Lehner 1997), namely how the last blocks of masonry were laid near the apex point (Bryn 2010).

Fig. 5 shows the pyramidal progression from a pixelated square plan until it reaches the top, which could not be occupied completely by the masonry blocks. Using the geometric adjacencies of the paramount apex with its four-sided pyramidion at the beginning across the sequence of expandable states indicates that this apex cannot be occupied totally by the building blocks/cubes/ pixels, but rather by an initial pyramidion that has a base comprising 13 square components [see hatched blocks in Fig. 3(a)]; the volume of these components across the aperture/surface of the pyramidion will be calculated to a total of 6 m³ as the volume designating 6 m³ is a negligible volume state. Hence, the calculation

of the five states presented in Fig. 3(a) will necessitate descoping the pyramidion formation; in other words, 6 m^3 must be descoped.

In Fig. 5, the transition of the pixels from a planar state to a pyramid state necessitates being performed given the plumb and inclination that are very much intrinsic to the balance that this grand pyramid is coping too.

In Fig. 5, the third depiction to the right is an advanced correlation to having an arc section that does not cope with the pyramid's section unlike the figure in the middle which would stand as the right depiction for the pyramid's section of this paper.

The following is an enhanced geometrical explication. y = 25 is equivalent to x = 25 (where x is denoted as the volume constructed against the base pixel number denoted as y); after eliminating 6 [which is the volume deduced in Fig. 3(b)] the balanced state will become y = 25, which is equivalent to x = 25 - 6 = 19 [first coordinate (19, 25)]. As 19 is only divisible by itself and 1, the accumulation of states will be a multiple of 19; hence, the other coordinates will become (38, 50) and (57, 75). Fig. 6 shows the graph with these values plotted.

Angular inclination similar to the solar elevation angle at the Cheops Pyramid in the equinox is explained in Fig. 6 as an innovative and newly introduced result. It is also correlated with Fig. 7.

Using the website (Fig. 7) to determine the solar elevation angle (SunEarthTools 2017), it is possible to obtain accurate values of the angles determined in Fig. 6 and following input derived from the tool entertained. In other words, elev. 52.69° is equivalent to the angle obtained from Fig. 6 and the azimuth of 134.88° is equivalent to 45° , which is obtained from Fig. 2(a). By contrast, "the Great Pyramid must have been erected c. 3303 BC, deviating greatly from the agreed date." Although we know that the "face angle is 51:45; being slightly incorrect (the true face angle was still unknown), Al-Falaki preferred to use the value 52:30 as the average face angle of all the pyramids on the plateau and that is his main mistake" (Deif 2008).



Fig. 7. (Color) Values of angular inclination of the Cheops Pyramid during the equinox in the table there will be the values of angular inclination at the Cheops Pyramid during the equinox. [Reprinted from SunEarthTools (n.d.2017), under Creative Commons-BY-SA 3.0 license (https:// creativecommons.org/licenses/by-sa/3.0/deed.en_US).]

Nevertheless, Ghoussayni et al. (2018) determined a face angle of 52.018° after a thorough investigation in 2018.

From Steps to Slopes

"The Orion correlation theory (or Giza–Orion correlation theory)" (Bruce 2012) "posits that there is a correlation between the location of the three largest pyramids of the Giza pyramid complex and Orion's Belt of the constellation Orion and that this correlation was intended as such by the original builders of the Giza pyramid complex."

Ancient Egyptians required many laborers to build the pyramids, as they knew that the time required for building the pyramids was not short; for example, the pyramid of Khufu the Great was built over 23 years, requiring between 20,000 and 300,000 men and it was believed that the slaves constructed the pyramids. However, a study conducted by Professor Donald Redford, an expert in ancient Mediterranean studies, indicated disagreement regarding who worked in building the pyramids. This is because it was mentioned that the peasants were the ones who worked in building the pyramids in exchange for some incentives, such as free food, housing, and clothes, in addition to exemption from taxes (Alagha 2020). The "step pyramid was used to transfer the pyramid's precision system, the building grid vertically and that the blocks seen today," "that do not necessarily align with the underlying mastaba" (Bryn 2010). "The accreditation wall's that formed the face of each mastaba was kept at the same tilted slope as the accreditation walls of the old type, step pyramids. This was done to support temporary ramps from step to step and not to let the core breakthrough the face of the pyramid. The existence of such temporary ramps was first suggested as a construction method for step pyramids by Hoelsher in the book Das Grabdenkmal des Konigs Cephren, frontispiece" (Clarke and Engelbach 1930).

What is about to be shown in the following figure is the assumption that the steps in placing the stone blocks could be correlated to defined pixelated parameters and patterns of defined time and scale. As the form of measurements that it is believed that the old Egyptians had a grand knowledge with the ruler in terms of dimensions and its subdivisions.

The Egyptians must have used the values in Fig. 6 as the angular inclinations because they are similar to the solar elevation angle at the Cheops Pyramid during the equinox. This is because it is quite possible that it was the "mastabas that were first carefully geographically aligned North-South" (Bryn 2010) as the "grid points used to measure out to the face of the pyramid would have been placed at the base" (Bryn 2010) [Point A in Fig. 8(a) and not at the top [Point B in Fig. 8(a)] of each mastaba. "By erecting walls with horizontally laid masonry, they could introduce tolerance between the accreditation layers, thereby transferring the building grid vertically from mastaba to mastaba with a plumb line" (Bryn 2010) [Figs. 6 and 8(a)]. "The outlines of each accreditation wall were carefully measured out on top of each mastaba. Those lines and point could now be adjusted using 3-4-5 triangle and the diagonal. Those lines represented the building grid" (Bryn 2010).

By contrast, the "seqed of Khafra's Pyramid is equal to 220/ 280, the equivalent of 5.5 palms; in other words for each cubit rise, the run is five palms and two digits." One "would assume that Khafra would either have to choose for the seqed of his pyramid five palms and one digit or five palms and three digits for each cubit rise. It seems he settled for the first choice, giving his pyramid a higher slope angle (with no explanation on my part that it should be less due to the increase in Sirius declination)" (Deif 2008).

"By calculating the face's slope which is the reciprocal of oneseventh of its seqed, it will be equal to 1/[(1/7)(5.25)] = 4/3, giving a face angle of 53:7:48 being the exact figure for the second pyramid. It was found that such an angle, which is inscribed in a 3:4:5 triangle, was adopted by at least eight known kings as their pyramids" inner triangle. This led Pythagoras, when visiting Egypt, to call it the *Holy Triangle*. Only two pharaohs used Khufu's face angle of 51:50:34: his father Sneferu at Meidum and Niuserre of the Fifth Dynasty. The same angle was also adopted in two of the smaller satellite queens' pyramids to the east of "Khufu: Hetepheres and Meritit" (Deif 2008).

The following figures show the conventional constructability methods based on previous assumptions of angular inclination for the Cheops Pyramid given the Egyptian ancient form of measurement as Royal Cubits that is enhanced according to our calculations to be an approximate value of 1 RC = 0.526254545454555 m rather than the commonly known measure of 0.525 m.

The verdict of an inclination of 176 RCs corresponds to a projection of 57 m that if the Royal Cubit is calculated with a value of 1 RC = 0.5262545455 m as shown in Fig. 9. The perpetuation of having complete and perfect dimensions was the theme of having a precise result in the construction process.

The precise efficiency whose credits goes back to the pre-engineered path that the Egyptians at that time could envisage





(b)

Fig. 8. (Color) (a) True pyramid of the fourth dynasty with a stepped core (data from Bryn 2010); and (b) pixelated forms of measurements.







Fig. 10. The intersection of the secant (midslope) with the encircled ellipse (by authors).



Fig. 11. (a) Establishing the horizontal line (by authors); and (b) establishing the Bezier Curve from the small concentric Pyramid (by authors).

and highlight the importance of obtaining an asset in the methodology by which the pyramid could be brought to being a perfect character as Fig. 10 denotes and points the horizontal distance in term of Royal Cubits to a value of 55 RC when a point reference results by the indication as an intersection of midslope versus the elliptical enclosure.

In Figs. 11(a and b), drawing a horizontal line through the point at the value of 152 RC along with the inclined distance on the surface of the Pyramid and by establishing the Bezier Curve from the small concentric Pyramid moving to the Geometric form of measuring from Figs. 11(a and b) by establishing a measuring apparatus using an old Egyptian form of measurement, which is the Royal



Fig. 12. (Color) (a) Step type constructability associated with a linear time path (by authors); and (b) 3D visualization for the linear path.



(b)



Cubit is concurrent with the marvel of architectural innovation that is of no coincidence given the reputation of an era that still signifies mathematical mysticism.



Fig. 14. A derivative of Fig. 13 as in correlation with the solar elevation (half of its value) for Cheops at Equinox.

When excavating further into the deep embodiment of solar equinox and sun angle in the form of block piling up succession across the different states of our below and previously defined methods, the question here is simple in its terms and as a render into a progression of constructability, it defines the succession of linear forms of overall planning and perception of the different states of advancement.

The subsequent Figs. 12(a and b) drive us through the previous statements and clarify the methodology of establishing a predominant form of the stepwise in a simple form. The succession of numbers "1," "2," and so on correlates to the block set up from the grand base of a given pyramid and moving up till its peak. By this, we would have it convenient for any interested scholar or researcher and even a normal reader to have fully analyzed the dominant methodology that truly reflects the perception of the Cheops



Fig. 15. (Color) (a) Demonstration of superimpositions in the form of a pyramid; and (b) demonstration of superimpositions of the different layers of a pyramid. (Data from Ghoussayni et al. 2020.)

Pyramid as an everlasting immobilized statue of structural Genuity and its significance over the trail of time and space.

The differentiating values of constructability probably are the least driven factors with the case of the pyramid of Cheops as the solutions were best optimized (Fig. 12) with much better-enhanced engineering methodology that gets the architects to replenish against this massive monument.

The plan does not need only much mediation across the dimensions but the calculations should be cordially understood from a 3D perspective.

The scheme does not only introduce methodologically governance across the different settlings of placing a stone in a stepwise setting but the sequence of placing the stone blocks is the main theme where the subsequent figures show by stepwise numbering the blocks and set the sequential layering without jeopardizing the angular inclination for this given pyramid as shown in Fig. 13.

The residual from the aforementioned figures will result in a derivative figure for block placement and progression as illustrated in Fig. 14.

In Fig. 15, "the expanding modular base and built-up area from the top of the Cheops Pyramid section down to its large base exhibit a set of calculations that can be initialized to account for the total number of building blocks in the Cheops Pyramid" (Ghoussayni et al. 2020). In a similar form, the angle and the slope are being provoked to accommodate the maximum alignment with the solar equinox angle thus sheds a replenishing mark on this marvelous structure.

"This measures the exact arrangement of pixelated spaces and mathematical pattern-like structures. It also predicts the building form that best exhibits an equilibrium state and by which the transfer of the loads can be easily maintained along the vertical alignments of structural elements" (Ghoussayni et al. 2020), which correlates with the specific standards of a perfect inclination that would not have been established without the intact of our research deep into the reason behind this correlation of form versus function. Cheops Pyramid sustains stability and perseverance and provokes the best response to fundamental equations and mathematical states for any given structure.

Discussion and Analysis

The findings that were extrapolated along with the constructability terms of this given pyramid are very entwined with the realms of congruency for the arrangement of the blocks and their positioning sequence that could not have maintained its precise ending at the Apex without the continuous check of its inclination against their given tools that is mostly attributed to the Royal Cubit measures.

The structure of the Cheops Pyramid is explained using the knowledge of geometrical representations along with some resources on pyramid structures, in addition to the available information that describes the findings on the sun path, where the latitude and longitude are given along with the time and date.

The slope of the Cheops Pyramid is correlated with the earliest ideology according to which the earth was created. The surface shape of a pyramid represents the descending rays of the sun during the equinox; hence, it is no coincidence that the inclinations of the pyramid were set to predetermine the location of its plumb line, serving as the guiding factor in erecting the blocks of the Cheops Pyramid.

The very finding is the relation between the superimposition of pixelated patterns of block arrangement at each layer and the grand depiction of balanced states as moving from the bottom and up.

The association of the sun path with the incredible attribution of placing the pyramid's block one over the other signifies an advanced constructability method. It is simply an outstanding ideology on how to plan and execute mega buildings with a very minimal and slight mistake that poses a question on advancement in the construction realm of old civilization which inhabited the Giza plateau.

The methodology established in this paper sheds light on the most probable acknowledgment in indicating the importance of having a modular incubator for the solutions provided given the time and resources constraint within the region. Modular solutions despite their simplicity yet they overtake grand complicated modules like the pyramids themselves.

The distances and elevations are recorded widely according to local tools and types of measurements. Yet the same principle of attributing the erection methodology according to solar disposition is a breakthrough in the field of innovation that the old Egyptians assigned at the time of Pharaos and this is clearly explained in the body of this research paper.

Conclusions

There are clear justifications for the Cheops Pyramid entanglement of its given geometry with the galactical replenishment of the sun's position that is very much known to the current scholars but the new finding of this given paper talks more on the modular positioning of building blocks according to a defined plumb and horizontal run for any given stepwise positioning of modular blocks of stone.

The purity of defined and complete dimensions is the key to a successful project and so did the old Egyptians overtake with high precision of quality matters that replenish their state with full defined building methodology subsequently to the truthful use of continuous pass of knowledge and intended torch of refinement to the perfect display of the image of Cheops Pyramid.

This innovative model displays the techniques which were used in consequent steps, as it embodies a novel of understanding the constructability elements and how it is being detected by the Pyramid's steps with given clear dimensions and patterns. This is considered to be a new conclusion on how to predetermine the framework for erecting the building blocks, to a large extent, from the ground and up to the highest edifice, in addition to the basis of methodological establishment on the commodities of any of ancient Egypt's built structure.

The secret that articulates within the existence of a controlled constructability method with defined perfect numbers of given dimensions around the pyramid's plumb is the earliest intelligence that is designed to emphasize its significance once it comes closer to the continuous state of determination as an advanced ancient civilization.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

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