An Analysis of the Alignment of Archaeological Sites

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Abstract—There are hundreds, perhaps thousands, of sites of archaeological importance throughout the world. In this study, the alignments of more than two hundred ancient sites were measured and analyzed. Sites are organized into eight geographic regions: South America, Mesoamerica, North America, Europe, the Middle East, Africa, Asia, and the Pacific Ocean. Google Earth imagery and measurement tools were used to estimate the alignment of linear and rectilinear structures at these sites with respect to true (geographic) north. In considering standard celestial and geographic reasons for the alignments, many were found to be oriented to the cardinal directions, in the directions of solstices and other solar events, to lunar standstills, and to certain stars. A number of sites in China and Thailand were likely aligned to magnetic north at the time of construction using a compass. Some sites appear to have been aligned to “sacred directions” that include Islamic qibla and Quechua ceques. Site-alignment statistics reveal similarities and differences between geographical regions in terms of how sites within regions are aligned. Perhaps the most unexpected finding is that the alignment of about half of the sites could not be explained in terms of any of the explanations considered.

Keywords: archaeoastronomy; solstices; archaeological alignment; sacred places; sacred directions; lunar standstills

INTRODUCTION

Evidence throughout the world suggests that human civilizations have a tendency to build their cities, and sacred and other places of importance, in specific directions. Many of the oldest pyramids and temples are aligned to the cardinal directions—north, south, east, and
west, sometimes with uncanny precision, such as the pyramids on the Giza plateau in Egypt (Lehner, 1997). The Angkor temples in Thailand (Magli, 2016) and certain earthen mounds in China also are aligned to the cardinal directions, as were early Chinese cities (Sparavigna, 2013). Although the cardinal directions can be determined readily from the motion of the sun and stars, there is evidence that the Chinese used the magnetic compass in some cases to align places of importance based on principles of geomancy and Feng Shui (Charvátová et al. 2011).

There are many places that are aligned to the cycles of the sun and moon, specifically to the northernmost and southernmost rising and setting of the sun and moon, called solstices and lunar standstills, respectively. Stonehenge is aligned both to solstices and to lunar standstills (Hawkins, 1965). Some Egyptian temples, most notably the Temple of Amun-Re at Karnak, are aligned to the winter solstice sunrise/summer solstice sunset (Shaltout & Belmonte, 2005). The head of the Great Serpent Mound in Ohio points toward the summer solstice sunset (Hardman & Hardman, 1987). Some of the most sacred places on earth are aligned to the moon, including the Kaaba in Mecca (Hawkins & King, 1982) and the Golden Temple in Amritsar.

There is evidence that some sites may have been aligned to the point on the horizon where certain stars and planets of importance once rose. Examples include the ancient city of Teotihuacan, north of Mexico City, thought to be aligned to the Pleiades (Aveni, 2001) and the Temple of Hathor at Dendera in Egypt, aligned to Alkaid, a star in Ursa Major (Shaltout & Belmonte, 2005). The Caracol at Chichen Itza is believed to have been oriented to observe the planet Venus.

The misalignment of certain places with respect to the cardinal directions has been explained in terms of local factors including topography and landscape. A part of Mexico City surrounding the ancient Aztec capital of Tenochtitlan is aligned in a direction slightly south of east. One theory is that the site was rotated in order to compensate for the shift in the position of the sun when it rose over Templo Mayor on the equinox rather than directly east at the horizon (Aveni et al., 1988). Ridderstad (2009) proposes a number of reasons why Knossos on the island of Crete is misaligned by about 10° south of east.

Finally, there are sites aligned toward places of spiritual importance. Today many mosques face toward Mecca. However, there are
other sacred directions called qibla that are also used to align mosques (King, 2018). In Peru, imaginary lines known as ceques (Krupp, 1994) emanate out from the center of the city of Cuzco in all directions, one of which passes through the Inca fortress of Sacsayhuamán.

This paper analyzes the alignments of more than two hundred archaeological sites from across the world. The next section, Alignment Hypotheses, defines eight hypotheses against which alignments are assessed. The following section, Alignments of Archaeological Sites, presents our findings organized by geographic region. And the last section, Analysis of Alignments, summarizes the results of our analysis. Based on the distribution of site alignments, we show that there are interesting similarities and differences among geographic regions. Surprisingly, the alignment of about half of the sites considered in this study cannot be explained by any of the hypotheses considered.

ALIGNMENT HYPOTHESES

From a review of the archaeological and archaeoastronomical literature, eight basic explanations were identified to account for the orientation of an archaeological site: 1) to cardinal directions (i.e. facing north, south, east, and west), 2) to solstice sunrise or sunset directions, 3) to sunrise or sunset directions on days when the sun passes directly overhead, 4) to directions of major and minor lunar standstills, 5) to a planet, 6) to a star or constellation, 7) to magnetic north, and 8) in the direction of an earth site of religious or spiritual importance. We also discuss other explanations such as landscape and topography.

Cardinal Directions

The cardinal directions can be established either by observing the motion of stars at night or the path of the sun during the day or over the course of the year. A site aligned to the cardinal directions faces sunrise and sunset twice a year on the spring and autumn equinoxes.

Solstices

Many ancient sites reference the directions of the sun on the first day of summer and winter (solstices). To determine if a site is aligned to the solstices, define the following angles:
**α** – azimuth angle of the sun (measured clockwise with respect to true north),

θ – elevation angle of the sun above the horizon,

ϕ – latitude of the site,

δ – solar declination. The tilt of the earth on its axis, the obliquity, ε, is what causes the seasons.

The solar declination is the tilt of the earth toward the sun, which varies with the season, \(-ε ≤ δ ≤ ε\), reaching its largest and smallest values on the summer and winter solstices, respectively. On the spring and fall equinoxes, δ = 0°.

The following solar path equation (Figure 1) relates the solar azimuth, the solar elevation, the latitude of the site, and the solar declination:

\[
\cos \alpha = \frac{\sin \delta - \sin \theta \sin \phi}{\cos \theta \cos \phi} \quad (1)
\]

and can be used to calculate the azimuth angle of the sun at sunrise and sunset on the summer solstice

\[
\alpha_{ss} = \cos^{-1} \left( \frac{\sin \delta}{\cos \phi} \right) \quad (2a)
\]

\[
\alpha_{ss} = -\cos^{-1} \left( \frac{\sin \delta}{\cos \phi} \right) \quad (2b)
\]

and on the winter solstice:

\[
\alpha_{ws} = \cos^{-1} \left( -\sin \delta/\cos \phi \right) \quad (3a)
\]

\[
\alpha_{ws} = -\cos^{-1} \left( -\sin \delta/\cos \phi \right) \quad (3b)
\]

The obliquity changes slowly over time, less than 2° over a period of 41,000 years. The present value is 23.43°. Due to changes in obliquity, solar alignments established in the distant past no longer line up exactly. By inverting Equation 1 we can determine when an alignment at a given angle would have lined up with a solstice or some other event by solving for the obliquity as a function of azimuth angle at sunrise or sunset:

\[
\delta = \sin^{-1} \left( \cos \alpha \cos \phi \right) \quad (4)
\]
It is noted that these equations do not take into account the local horizon, which may be affected by mountains and hills that cause the sun and moon to rise later and set earlier than over a flat horizon, and do not model atmospheric refraction that affects the appearance of celestial objects close to the horizon, both of which can be important factors in the alignment of certain sites.

**Zenith Passage**

At the equator, the sun passes directly overhead at noon on the equinox. Within the zone of the tropics, the sun can still pass overhead on certain other days. This occurs on days when the solar inclination is equal to the site’s latitude. An alignment occurs either at sunrise or sunset when

\[ |\phi| = 90^\circ - |\alpha| \]  

(5)
Lunar Standstills

The plane of the moon’s orbit is tilted by 5.1° relative to the ecliptic. Because of its orbit, the moon can rise and set more northerly and more southerly than the sun. Due to the effects of the sun’s gravity, the moon’s orbital plane does not stay fixed in space but precesses, causing the monthly angles of moonrise and moonset to change over an 18.6-year cycle. Every 18.6 years the moon rises at its maximum northerly direction, which is known as a major lunar standstill. A minor lunar standstill occurs 9.3 years later when the moon rises at its minimum northerly direction. The moonrise and moonset azimuth angles at a standstill are

\[
\alpha_{m\uparrow} = \cos^{-1} \left( \frac{\sin \mu}{\cos \theta} \right) \quad (6a)
\]

\[
\alpha_{m\downarrow} = -\cos^{-1} \left( \frac{\sin \mu}{\cos \theta} \right) \quad (6b)
\]

where \( \mu \) is the lunar declination which is \( \mu = \pm (\varepsilon + 5.1°) \) for a major standstill and \( \mu = \pm (\varepsilon - 5.1°) \) for a minor standstill.

Figure 2 shows several examples of sites aligned to the sun and moon.

Planetary Alignments

The motion of the planets is along the imaginary line defined by the plane of earth’s orbit around the sun known as the ecliptic. As a result, a planet can appear to rise anywhere between the summer and winter solstice sunrise directions and set anywhere between the summer and winter solstice sunset directions. For example, the maximum northern and southern setting directions of Venus observed at the Caracol in Chichen Itza are the same as the solstice sunset directions.

Stellar Alignments

It is convenient to think of the stars existing on the inside of a celestial sphere. As earth revolves on its axis, stars appear to rotate around the celestial poles. In addition to obliquity, the earth’s axis precesses in a 26,000-year cycle about the ecliptic pole. The direction in which a star rises and sets on the horizon depends on its location on the celestial sphere, the latitude of the site where it is observed, and the time of observation with respect to the precessional cycle.
Alignments of Archaeological Sites

A) Angkor Wat—Cardinal Directions
B) Karnak—Solstices
C) Ziggurat of Ur—Major Lunar Standstills
D) Koh Ker—Zenith Passage

Figure 2. Examples of sites aligned to the sun and moon. There are two sets of lines in B) through D), since solstices, lunar standstills, and zenith passages occur twice a year. Photo credit: Apple Maps.

Alignments to Magnetic North

There is evidence that ancient sites in certain parts of the world were aligned using a magnetic compass. Unlike the geographic poles, the magnetic pole is constantly in motion (Figure 3). In order to determine the alignment of a site to a pole (or any reference location on the surface of the earth), let A, B, and C be the locations of a site, the geographic North Pole, and the magnetic pole at a given time, respectively (Figure 4).
If \((\lambda_A, \varphi_A)\) and \((\lambda_C, \varphi_C)\) are the latitudes and longitudes of the site and reference locations, define the angles

\[
\begin{align*}
    a &= \frac{\pi}{2} - \lambda_C, \\
    c &= \frac{\pi}{2} - \lambda_A, \\
    B &= \varphi_C - \varphi_A
\end{align*}
\]  

(7)

We wish to solve for the angle A (the azimuth angle of the reference location from the site) as a function of the locations of A and C on the sphere. Starting with the sine and cosine rules for spherical triangles:

\[
\frac{\sin A}{\sin a} = \frac{\sin B}{\sin b} = \frac{\sin C}{\sin c}
\]  

(8)

and

\[
\cos b = \cos a \cos c + \sin a \sin c \cos B
\]  

(9)
Alignments of Archaeological Sites

Using the estimated location of the north geomagnetic pole at a given time, it is possible to approximate the compass direction of magnetic north at a site at that time (Figure 5A).

Alignments to “Sacred Directions”

As noted above, Equation 11 can compute the azimuth angle at any location to any other location on the surface of the earth and can be used to evaluate alignments to “sacred directions” that include Islamic...
qiβla and Quechua ceques (Lon, 2005). For example, using Equation 11 it can be determined that the Rock of the Dome in Jerusalem is aligned in the direction of Petra in Jordan (Figure 5B).

ALIGNMENTS OF ARCHAEOLOGICAL SITES

The selection of archaeological sites from across the world is a challenging exercise in itself. More than two hundred sites were identified from a variety of sources including UNESCO’s World Heritage Center, Wikipedia, Google Earth, and scientific and popular literature. The selected sites contain linear and rectilinear structures that are well-resolved and visible in overhead imagery. Google Earth imagery and measurement tools were used to measure heading (azimuth) angles. Alignments are indicated in Tables 1–8 according to the following key:

Cardinal directions, i.e. geographic poles, and equinoxes (E)
Magnetic pole at the time of construction (X)
Zenith passage (Z)
Solstices (S)
Major and minor lunar standstills (M,m)
Stellar alignments (st)
Alignments to “sacred directions” (D)

Figure 5. Sites aligned in other directions.
Measured angles of rectangular structures and rectilinear features are listed two ways: by a NW to NE facing angle between $-45^\circ$ and $+45^\circ$ and a NE to SE facing angle between $45^\circ$ and $135^\circ$.

In a previous aerial archaeological study using Google Earth (Lepionka & Carlotto, 2015), heading measurement errors were found to be as small as $0.1^\circ$ between widely spaced, well-defined, point-like features. Measurement errors at some of the sites considered here could be somewhat higher, particularly for ruined structures that lack a well-defined edge and for smaller structures with short edges. In this study, a structure is classified as being in alignment with a cardinal or other direction if the sides of the structure are within approximately $1^\circ$ of that direction. For solar and lunar alignments, a site is considered aligned to a solstice or lunar standstill if a structure at the site, or an alignment between structures at the site, is within the range of solstice or lunar standstill directions at that latitude over the earth’s 41,000-year obliquity cycle.

In general the alignment hypotheses represent eight mutually exclusive directions or ranges of direction at a particular site (although at certain latitudes minor lunar standstill moonrise/moonset directions and zenith passage sunrise/sunset directions can overlap). In addition to these eight alignment hypotheses (plus “unknown”), there are sometimes other explanations for the alignment of the site as noted in the tables and discussed in the accompanying text.

**Africa**

Table 1 lists the sites examined in Africa, most of which are in Egypt. About half of the sites are aligned to the cardinal directions. Most of these are pyramids in Lower Egypt. Shaltout and Belmonte (2005) analyzed the orientation of more than one hundred temples in Upper Egypt and Lower Nubia to discover that they face many different directions with a somewhat greater concentration of alignments in the east–southeast direction. This is in agreement with our finding of sites aligned to solstices and major and minor lunar standstills. Their principal conclusion is that local topography (the course of the Nile River) was more important than astronomy in aligning the foundations of the temples. Our finding that half of the sites examined in Egypt do not appear to be aligned to obvious astronomical events is consistent
**TABLE 1**

Alignments of Sites in Africa

| Name                                      | Latitude  | Longitude | North | East | Alignment |
|-------------------------------------------|-----------|-----------|-------|------|-----------|
| Algeria, Jabal Lakhdar                    | -25.063404 | 5.168731 | -5    | 85   | E         |
| Egypt, Abu Rawash, Pyramid of Djedefre     | 30.032626  | 31.074714 | 0     | 90   | E         |
| Egypt, Abu Sir, Pyramid of Neferibre      | 29.893770  | 31.201454 | 0     | 90   | E         |
| Egypt, Abu Sir, Pyramid of Neferikare     | 29.893509  | 31.202249 | 0     | 90   | E         |
| Egypt, Abu Sir, Pyramid of Sahure         | 29.697622  | 31.203367 | 0     | 90   | E         |
| Egypt, Abydos, Temple Ramses II           | 26.180426  | 31.916280 | 44.2  | 134.2| S         |
| Egypt, Abydos, Osirion                    | 26.184099  | 31.918465 | 36.3  | 126.3| S         |
| Egypt, Abydos, Pyramid of Ahmose I        | 26.175056  | 31.937822 | 36    | 126  | E         |
| Egypt, Abydos, Temple Seti I              | 26.184968  | 31.919183 | 36.3  | 126.3| E         |
| Egypt, Cairo, Mosque of Ibn Tulun         | 30.028691  | 31.249394 | 69    | 51   | S         |
| Egypt, Dahshur, Pyramid of Senusret III  | 29.818888  | 31.225550 | 0     | 90   | E         |
| Egypt, Dashur, Bent Pyramid               | 29.790449  | 31.209324 | 0     | 90   | E         |
| Egypt, Dahshur, Pyramid of Amenemhat II  | 29.805807  | 31.220308 | 0     | 90   | E         |
| Egypt, Dahshur, Reel Pyramid              | 29.808882  | 31.206113 | 0     | 90   | E         |
| Egypt, Deir el-Bahari, Mortuary Temple of Mentuhotep II | 25.737375  | 32.606178 | 23.2  | 113.2| S         |
| Egypt, Deir el-Medina, Temple of Hathor  | 25.728846  | 32.602128 | 40    | 50   | S         |
| Egypt, Dendera, Sacred Lake               | 26.141807  | 32.669532 | 16.1  | 106.1| E         |
| Egypt, Dendera, Temple of Hathor          | 26.141914  | 32.670205 | 18.9  | 108.9| S, m      |
| Egypt, Edfu Temple of Horus               | 24.976747  | 32.873087 | 12.8  | 102.8| S         |
| Egypt, Elephantine, Temple of Khnum       | 24.084490  | 32.886266 | 42    | 48   | S         |
| Egypt, Giza, Kharif                      | 29.975726  | 31.308060 | 0     | 90   | E         |
| Egypt, Giza, Khufu                       | 29.979067  | 31.134040 | 0     | 90   | E         |
| Egypt, Giza, Menkaure                    | 29.975811  | 31.131242 | 0     | 90   | E         |
| Egypt, Kom Ombo                          | 24.452085  | 22.982353 | 43.3  | 133.3| S         |
| Egypt, Lish, Pyramid of Amenemhat I      | 29.574802  | 31.225304 | 0     | 90   | E         |
| Egypt, Lish, Pyramid of Senusret I       | 29.560160  | 31.221130 | 0     | 90   | E         |
| Egypt, Luxor West, Temple Ramses III     | 25.719683  | 32.600711 | -42   | 48   | S         |
| Egypt, Luxor, Karnak, Temple of Amen Re   | 25.718484  | 32.659044 | 26.6  | 116.6| S         |
| Egypt, Meidum Pyramid                    | 29.388368  | 31.157503 | 0     | 90   | E         |
| Egypt, Pyramid of Teti                    | 29.575142  | 31.221847 | -12.5 | 77.5 | S         |
| Egypt, Saqqara, Mastaba of Shepseskaf     | 29.838852  | 31.215273 | 0     | 90   | E         |
| Egypt, Saqqara, Pyramid of Deiab-tesi     | 29.850983  | 31.220924 | 0     | 90   | E         |
| Egypt, Saqqara, Pyramid of Djeser         | 29.871397  | 31.215322 | 5     | 95   | S         |
| Egypt, Saqqara, Pyramid of Khendjer       | 29.833369  | 31.224042 | 0     | 90   | E         |
| Egypt, Saqqara, Pyramid of Pezi II        | 29.840246  | 31.214946 | 0     | 90   | E         |
| Egypt, Saqqara, Pyramid of Qakare Ibi     | 29.841590  | 31.217712 | -10   | 80   | E         |
| Egypt, Saqqara, Pyramid of Usas           | 29.868182  | 31.215012 | 0     | 90   | E         |
| Egypt, Saqqara, Pyramid Userkaf           | 29.873332  | 31.219334 | 0     | 90   | E         |
| Egypt, Shunet El Zebib                    | 26.189510  | 31.090955 | -41.7 | 48.3 | S         |
| Egypt, Siwa Oasis, Arnun Temple           | 29.201375  | 32.516151 | 3     | 93   | S         |
| Egypt, Temple of Edfu                     | 24.578097  | 32.873475 | 3     | 93   | S         |
| Egypt, Temple of Esna                     | 25.293444  | 32.556125 | -23   | 67   | M         |
| Egypt, Temple of Hathor, El Kab           | 25.135550  | 32.828651 | -44   | 46   | S         |
| Egypt, Temple of Isis at Sherur           | 25.861040  | 32.776808 | 10    | 100  | S         |
| Egypt, Temple of Ramses II               | 25.737588  | 32.610283 | 41    | 131  | S         |
| Egypt, Zawyet El Aryan, Layer Pyramid     | 29.932820  | 31.161262 | -12   | 78   | E         |
| Ethiopia, Bete Geyorgs                    | 12.031714   | 39.041190 | 5.8   | 95.8 | m         |
| Ethiopia, Yeha Temple                     | 14.285703   | 39.019114 | 11.4  | 101.4| S         |
| Sudan, Dangeli, Amun Temple               | 18.131307   | 33.958600 | 16.5  | 106.5| S         |

E = cardinal directions, i.e. geographic poles, and equinoxes. M,m = major and minor lunar standstills. S = solstices. st = stellar alignments (aligned to Alkaid in Ursa Major).
with this conclusion. The Temple of Hathor at Dendera was very likely aligned to the star Alkaid in the constellation Ursa Major, which is associated with the Egyptian goddess Hathor.

If no alignment is given, the explanation is unknown. In some cases, there may be more than one explanation for an alignment.

Asia

Table 2 lists sites examined in Asia. Many of the sites in China considered here are ancient earthen mounds that are aligned either to the cardinal directions or thought to have been aligned in the direction of the magnetic pole at the time of construction (Charvátová et al., 2011). Some of the sites considered in Thailand are temples that could also have been aligned to the north geomagnetic pole (Iyemori et al., 2011). Magli (2016) determined that a very clear pattern of cardinal orientation and alignment occurs in numerous temples in and around Angkor. Although some sites appear to reference the solstices in their construction and many are aligned to one another in solstitial directions, none of the sites themselves are aligned to the solstices. Unlike in Egypt, we were unable to find any sites in Asia oriented to solstices. Several were oriented, however, in directions that correspond to lunar standstills. Three sites located in the Tropic of Cancer might have been aligned to the sun on so-called “zenith passage days” when the sun passes directly overhead. McKim Malville (2015) analyzed 31 sites in India and found that two-thirds were aligned to the cardinal directions, solstices, and zenith passages. About half of the sites examined in other parts of India did not have an obvious explanation for their alignment.

Europe

Table 3 shows the alignments of ancient sites in Europe. Unlike Africa with many of its sites aligned in the cardinal directions and Asia with many of its sites aligned either to true (geographic) north or geomagnetic north, about half of the sites examined in Europe are aligned to solstices and lunar standstills. Palantine Hill, which was the earliest settlement in ancient Rome, is aligned to major lunar standstills. The Parthenon, which sits atop the Acropolis, is not aligned to solstices or to lunar standstills. Dinsmoor proposed that it was aligned to the
TABLE 2
Alignments of Sites in Asia

| Country          | Site                      | Alignments          |
|------------------|---------------------------|---------------------|
| Cambodia, Koh Kon| 13.79520                | 106.537453          |
| Cambodia, Preah Khan of Kompong Svay | 13.405820 | 106.757420 |
| China, Chau Hsia Museum of Emperor Deshong of Tang | 34.707380 | 108.826530 |
| China, Chau Hsia Museum of Emperor Kang Sun of Tang | 34.579963 | 108.642353 |
| China, The Lahu Altar | 34.653869 | 101.746123 |
| China, Tomb of Count Ban | 34.379801 | 106.704492 |
| China, Tomb of Emperor Ao of Han | 34.400055 | 106.764606 |
| China, Tomb of Emperor Cheng of Han | 34.374896 | 106.698901 |
| China, Tomb of Emperor Gao of Han | 34.434951 | 106.876647 |
| China, Tomb of Emperor Han of Han | 34.422095 | 108.841317 |
| China, Tomb of Emperor Jing of Han | 34.440023 | 106.940784 |
| China, Tomb of Emperor Ping of Han | 34.397774 | 106.712423 |
| China, Tomb of Emperor Wen of Sui | 34.287500 | 106.022890 |
| China, Tomb of Emperor Wu of Han | 34.338085 | 106.569644 |
| China, Tomb of Emperor Xuan of Han | 34.310063 | 109.023132 |
| China, Tomb of Emperor Yuan of Han | 34.930063 | 105.794114 |
| China, Tomb of Emperor Zhao of Han | 34.361753 | 106.640106 |
| China, Tomb of Empress Du | 34.230825 | 105.136814 |
| China, Tomb of Empress Dowager Bo | 34.220993 | 105.096541 |
| China, Tomb of Empress Fu | 34.403608 | 106.773545 |
| China, Tomb of Empress Li | 34.380527 | 106.560302 |
| China, Tomb of Empress Li | 34.433824 | 105.881279 |
| China, Tomb of Empress Shangguan | 34.363135 | 106.630958 |
| China, Tomb of Empress Wang (a) | 34.393142 | 106.733835 |
| China, Tomb of Empress Wang (b) | 34.446291 | 106.947500 |
| China, Tomb of Empress Wang (c) | 34.728951 | 101.028396 |
| China, Tomb of Empress Xu (a) | 34.376648 | 106.684740 |
| China, Tomb of Empress Xu (b) | 34.127340 | 105.053786 |
| China, Tomb of Empress Zhang Yan | 34.432195 | 106.836941 |
| China, Tomb of Marquis Zhang Ao | 34.427745 | 108.851209 |
| China, Tomb of Proconsul Chengzao of Emperor Taizong | 34.631800 | 106.491140 |
| China, Tomb of Princess Xinwang of Emperor Taizong | 34.628090 | 108.498880 |
| China, Yarang Valley, Takhto | 42.950102 | 109.061138 |
| India, Amritsar, Golden Temple | 31.636599 | 74.476511 |
| India, Chidambaram, Chidambaram Nataraja | 11.399234 | 79.093715 |
| India, Chunar, Srikshetram Temple | 10.749866 | 79.699558 |
| India, Kanchipuram, Ekambareswar Temple | 12.847302 | 79.095525 |
| India, Khajuraho, Gwalior | 23.866907 | 75.213776 |
| India, Madhya Pradesh, Shah Bahu Temple | 15.018556 | 79.883959 |
| India, Madhya Pradesh, Tigaon Temple | 23.699160 | 79.069018 |
| India, Mahabaleshwar, Shiva Temple | 12.636492 | 79.199267 |
| India, Rameshwar Mandir | 19.215000 | 73.462012 |
| India, Sriganganagar | 28.745988 | 75.220286 |
| India, Udaipur | 27.957203 | 73.760000 |
| India, Varanasi, Kashi Vishwanath Temple | 25.387000 | 83.080500 |
| Indonesia, Gunung Padang | 6.994518 | 107.055383 |
| Irwin Monastery, Kandia | 42.356888 | 116.183406 |
| Japan, Okinawa City | 34.687298 | 128.552626 |
| Malaysia, Thulathoo | 0.592017 | 72.997197 |
| Pakistan, Harappa | 30.628104 | 72.863909 |
| Russia, Parnas, Bathn | 50.653271 | 97.348872 |
| Thailand, Angkor Wat | 13.412489 | 103.866988 |
| Thailand, Ayutthaya, Wat Phra Mahathat | 13.594043 | 106.567059 |
| Thailand, Kae Klung Nai, Sri Thep | 15.460521 | 101.164681 |
| Thailand, Prasat Hin Phnom | 15.520090 | 101.493681 |
| Thailand, Prasat Muang Chan | 14.469059 | 102.982606 |
| Thailand, Prasat Si Songphran Nong | 14.525024 | 102.940273 |
| Thailand, Prasat Si Sakharam Mahathat | 14.946574 | 106.793832 |
| Thailand, Wat Phra Si Rattana Mahathat | 14.796763 | 100.613862 |

D = alignments to “sacred directions”. E = cardinal directions, i.e. geographic poles, and equinoxes. M,m = major and minor lunar standstills. S = solstices. st = stellar alignments. X = magnetic pole at the time of construction. Z = zenith passage.
sunrise on the birthday of the Greek goddess Athena (Hannah, 2013). That the Acropolis also appears aligned in the same general direction and predates the Parthenon by hundreds, perhaps thousands, of years would seem to challenge that dating and the reason for its alignment. Maravelia (2002) proposes that the alignment of a number of tholus tubes in Mycenae are based on topographical not astronomical considerations.

**North America**

Most of the Native American/indigenous sites examined in North America are aligned to the cardinal directions, solstices, or lunar standstills (Table 4).

### TABLE 3

**Alignments of Sites in Europe**

| Location | Alignments | E | Artifice |
|----------|------------|---|----------|
| Bovila, Pyramid of the Sun | 43.97759 18.17014 | E, E | Not established |
| Greece, Athens, The Parthenon | 37.97551 23.72609 | E, E | Not established |
| Greece, Delphi Amphitheater | 38.48247 22.50057 | E, E | Not established |
| Greece, Knossos | 35.32967 25.13602 | E, E | Not established |
| Greece, Mycenae, Lion Gate | 37.73072 22.75600 | E, E | Not established |
| Greece, Mycenae, Tomb of Agamemnon | 37.75675 22.75687 | E, E | Not established |
| Greece, The Temple of Artemis | 37.99061 27.36821 | E, E | Not established |
| Italy, Rome, Circus Maximus | 41.88948 12.48521 | E, E | Not established |
| Italy, Rome, Palantine Hill | 41.88948 12.48759 | E, E | Not established |
| Italy, Sardinia, Monte d’Alcòddi | 40.79075 8.46205 | E, E | Not established |
| Malta, Gozo, Ggantija Temple | 36.04726 24.26015 | E, E | Not established |
| Spain, Mosque-Cathedral of Cordoba | 37.87906 4.77937 | E, E | Not established |
| Spain, Naveta d’Es Tudons | 40.09307 3.89163 | E, E | Not established |
| Turkey, Haga Sophia | 41.01314 26.95182 | E, E | Not established |
| Turkey, Hattusa | 40.01394 34.61545 | E, E | Not established |
| UK, Calanais Standing Stones | 56.19766 6.74522 | E, E | Not established |
| UK, Glastonbury Tor | 51.14444 2.98661 | E, E | Not established |
| UK, Stonehenge | 51.17886 1.82613 | E, E | Not established |

**TABLE 4**

**Alignments of Sites in North America**

| Location | Alignments | E | Artifice |
|----------|------------|---|----------|
| Canada, Ab, Raffiand-Guardian | 50.02036 105.13353 | E | Not established |
| US, California, Morro Inlet, B1 | 33.80406 114.53205 | E | Not established |
| US, California, Morro Inlet, B2 | 33.80406 114.53205 | E | Not established |
| US, Georgia, Ormogen National Monument | 31.83868 85.60014 | E | Not established |
| US, New Mexico, Chaco Canyon, Pueblo del Arroyo | 35.06085 107.96350 | E | Not established |
| US, Ohio, Great Spirit Mound | 39.52942 81.40100 | E | Not established |
| US, Illinois, Cahokia, Merri Mound | 39.66015 89.06246 | E | Not established |

E = Cardinal directions, i.e. geographic poles, and equinoxes. M = major lunar standstills. S = solstices.
Pacific Ocean

About half of the sites in the Pacific appear to have astronomical alignments (Table 5). The Ahu platforms on which the Easter Island Moai look out to the sea were built in a variety of orientations around the island. Three of the alignments may be astronomical. The Temple of Nan Dawas at Nan Madol in Micronesia is aligned in the direction of the zenith passage sunrise. A megalithic structure called the Ha’amonga’a Ma’iu Trilithon along with most of the structures on the island of Tonga are aligned in a northeast direction that has no known explanation.

![Image](image)

**TABLE 5**

**Alignments of Sites in the Pacific Ocean**

| Location                        | Latitude   | Longitude  | E  | m  | S  | Z   |
|---------------------------------|------------|------------|----|----|----|-----|
| Chile, Easter Island, Ahu Akivi | -27.115014 | -109.395043 | 2.7 | 87.3 | E  |
| Chile, Easter Island, Ahu Nau Nau| 27.074425  | -109.322455 | 19.6 | 70.4 | m  |
| Chile, Easter Island, Ahu Tahai  | 27.140076  | -109.427314 | 8.3  | 98.3 |    |
| Chile, Easter Island, Ahu Tongariki| 27.125774  | -109.276933 | 30   | 120  | S  |
| Chile, Easter Island, Ahu Vinapu | 27.174098  | -109.405737 | 8.1  | 98.1 |    |
| Micronesia, Nan Madol           | 6.844537   | 158.335795  | 33   | 57   | M  |
| Micronesia, Nan Madol, Temple of Nan Dawas| 6.844537 | 158.335795 | 7    | 97   | Z  |
| Samoa, Pulemelei Mound          | 13.735337  | -172.324399 | 7.3  | 82.7 |    |
| Tonga, Ha’amonga’a Ma’iu Trilithon| 21.136606  | -175.048087 | 32.7 | 122.7 | *  |

* Entire island of Tonga aligned in the same direction. E = cardinal directions, i.e. geographic poles, and equinoxes. M,m = major and minor lunar standstills. S = solstices. Z = zenith passage.

The Middle East

Only four of the sites examined in the Middle East have an apparent explanation for their alignment (Table 6). The Kaaba in Mecca analyzed in detail by Hawkins and King (1982) was found to be most accurately aligned to the moon, which is one of several directions or qibla that are sacred in Islam. The Ziggurat of Ur (Sparavigna, 2016) and the Great Mosque of Sana’a in Yemen also are aligned to the moon. The Dome of the Rock in Jerusalem is oriented toward Petra in Jordan.

South America

About a third of the sites examined in South America are aligned to the cardinal directions, solstices, or lunar standstills (Table 7). Another third appear to be aligned to face either the city of Cuzco in Peru’s Sacred Valley or the city of Caral in the Supe Valley. A number of lines
Alignments of Archaeological Sites

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Alignments of Sites in the Middle East

| Country               | Latitude  | Longitude | Orientation       |
|-----------------------|-----------|-----------|-------------------|
| Iran, Chogha Zanbil   | 32.008907 | 48.521593 | -43.5° 46.5°      |
| Iraq, Dur-Kurigalzu   | 33.353671 | 44.202164 | -39.6° 50.4°      |
| Iraq, Tower of Babel  | 32.536284 | 44.420803 | -11.3° 78.7°      |
| Iraq, Ziggurat of Ur  | 30.962711 | 46.103126 | -33.3° 56.7°      |
| Jerusalem, Dome of the Rock | 31.778087 | 35.235306 | -7.3° 82.7°      |
| Jerusalem, Western Wall | 31.776657 | 35.234470 | -12.1° 77.9°      |
| Jordan, Petra, Temple of the Winged Lions | 30.330297 | 35.442554 | 17.5° 107.5° |
| Jordan, Qasr Al-Abd, Irak Al-Amir | 31.912785 | 35.751941 | -15° 75°    |
| Jordan, Umayyad Mosque in Amman | 33.511593 | 36.306657 | -6.4° 83.6°    |
| Lebanon, Baalbek, Temple of Jupiter | 34.006694 | 36.203826 | -12.2° 77.8° |
| Saudi Arabia, Mecca, Kaaba | 21.422510 | 39.826174 | -54.9° 55.1° |
| Turkey, Harran       | 36.865021 | 39.031565 | 9.6° 99.6°      |
| Yemen, Great Mosque of Sana’a | 15.353123 | 44.214876 | -25° 65°       |

* Oriented in the direction of Petra. D = alignments to “sacred directions”. M = major lunar standstills.

Alignments of Sites in South America

| Country               | Latitude  | Longitude | Orientation       |
|-----------------------|-----------|-----------|-------------------|
| Belzita, Chisana Labyrinth | -15.990237 | -68.209562 | 44° 134° D      |
| Belzita, Puma Punku   | -15.561720 | -68.580046 | 7° 92°           |
| Belzita, Quiminari    | -16.359407 | -69.371270 | -20° 70°         |
| Belzita, Uruquintu    | -16.504933 | -68.674887 | 12° 92°          |
| Peru, Caral-Supe      | -20.893458 | 77.520540 | 19.5° 109.5° S  |
| Peru, Caral-Supe, Huaca Pyramid | -20.893458 | 77.520540 | 19.5° 109.5° S  |
| Peru, Chan Chan      | -8.302558  | 79.070870  | 19.5° 109.5° m  |
| Peru, Chavin         | -9.546257  | 77.370502  | 14.7° 104.7° D  |
| Peru, Cusco          | -15.51887  | 71.375952  | Center of Quechua castles or pathways           |
| Peru, Huayna Pampa   | -9.875388  | 78.816395  | 0° 90° E        |
| Peru, Huayna Pampa, Temple of the Moon | -13.151591 | 71.540407 | M Faces north to view full range of lunar motion |
| Peru, Nazca Lines    | -14.721525 | 75.714850  | 13.8° 109.3°    |
| Peru, Ollantaytambo, Temple of the Sun | -13.257936 | 72.267219 | 35° 55° |
| Peru, Sacsahuaman    | -13.509390 | 71.389316  | D “Heart” of a puma represented by the city of Cuzco |
| Peru, Sacsahuaman    | -13.509390 | 71.389316  | D “Heart” of a puma represented by the city of Cuzco |
| Peru, Wariwawampe   | -10.465490 | 78.366467  | -24.1° 65.9°      |
| Peru, Chachapu       | -6.720360  | 75.951706  | 0° 90° E        |

D = alignments to “sacred directions”. E = cardinal directions, i.e. geographic poles, and equinoxes. M,m = major and minor lunar standstills. S = solstices.

and geoglyphs in Nazca appear to point toward, away from, or at right angles to Cuzco. The alignment of sites to Cuzco is consistent with a set of directions that emanate from Cuzco called ceques. The remainder of the sites in South America have no obvious explanation for their alignment, including the large megalithic structures at Machu Picchu, Ollantaytambo, Tiwanaku, and Puma Punku, whose origins are poorly understood.
Mesoamerica

In analyzing the alignments of Mayan sites, Aveni found that 16 percent are aligned west of north, while the other 86 percent are aligned east of north (Aveni, 2001). He concludes that an eastern skew was a standard architectural practice over a wide area in Mexico. A peak around 25° south of east suggests that many sites were aligned to solstices. As shown in Table 8, more than 75 percent of identified alignments lie in solar or lunar directions. What is particularly interesting about Mesoamerica is the large fraction of sites whose alignments are unknown. Fuson (1969) suggested the possibility that Mayan temples were aligned to magnetic north using a compass. Carroll (1979) analyzed about four dozen Mesoamerican sites and found that almost all of them were not aligned to magnetic north, based on their assumed date of construction.

| TABLE 8 Alignments of Sites in Mesoamerica |
|---------------------------------------------|
| Bello, Altun Haa | 17.763990 | 88.347061 | 7.6 | 97.6 | D | Oriented in the direction of Uxmal |
| Belmopan | 17.388382 | 88.146351 | 10.3 | 79.7 | D | Oriented in the direction of Uxmal |
| Chichen Itza | 12.979547 | 88.941315 | 18 | 108 | m |
| Guatemala, Mixco Viejo | 14.871668 | 90.646167 | 13.5 | 103.5 | D | Oriented in the direction of Uxmal |
| Guatemala, Tikal | 17.258994 | 88.636164 | 8.4 | 98.6 | |
| Guatemala, Yaxchilán | 16.989655 | 90.627093 | 30.4 | 120.4 | D | Oriented in the direction of Chichen Itza |
| Honduras, Copán, Step Pyramid | 14.640000 | 88.140000 | E | Multiple orientations between -4 and +48° |
| Mexico, Azcapotzalco | 19.505000 | 93.700000 | 20.3 | 110.3 | E |
| Mexico, Altzomoni | 23.743444 | 103.945600 | Multiple alignments |
| Mexico, Bonampak | 16.760000 | 91.060000 | 38 | 128 |
| Mexico, Calakmul | 18.105192 | 98.016297 | 3.8 | 98.8 |
| Mexico, Coba, Calakmul | 19.123508 | 98.635750 | 0.3 | 60 |
| Mexico, Chichén Itza | 18.627675 | 98.707093 | 8.8 | 96.8 |
| Mexico, Chichen Itza | 20.600000 | 88.700000 | 21 | 111 | M2 | Also canals, crop cycles, Venus min/max settings |
| Mexico, Chimalnatan, C3 | 18.446236 | 90.128978 | 34.7 | 55.3 | M |
| Mexico, Chimalnatch, C1 | 18.444654 | 90.104511 | 20.7 | 118.7 |
| Mexico, Chichén Itza | 19.058305 | 88.302906 | 25 | 115 | S |
| Mexico, Coba, Great Pyramid | 20.492974 | 87.741915 | 39 | 51 |
| Mexico, Campeche | 18.278330 | 93.003517 | 24 | 124 |
| Mexico, Cuxtalpan, Archeological Site, Cuxtalpan | 18.951530 | 90.128988 | 15.4 | 105.4 | m |
| Mexico, Cuililuch | 19.401521 | 91.167198 | 7 | 97.6 |
| Mexico, El Cerro Archeological Zone | 20.551536 | 90.444027 | 7.4 | 97.4 |
| Mexico, El Tajín, Pyramid of the Niches | 20.480500 | 97.278245 | 14.5 | 106.5 |
| Mexico, El Tajín, Southern Ballcourt | 20.480508 | 97.278247 | 0 | 90 |
| Mexico, El Tajín, Tajín-Chico | 20.480508 | 97.278240 | 40 | 130 |
| Mexico, El Tajín, North Ballcourt | 19.900196 | 93.035508 | 26 | 110 |
| Mexico, La Ventilla | 18.101916 | 94.040296 | 12.2 | 78.9 | D | Oriented in the direction of Copan |
| Mexico, Mayapan | 20.528523 | 90.605900 | E | Multiple orientations between -3 and +20° |
| Mexico, Mérida | 20.629496 | 96.593948 | 12 | 102 |
| Mexico, Monte Albán, Building I | 17.041712 | 96.741810 | 4.5 | 86.45 |
| Mexico, Monte Albán, Building I | 17.041712 | 96.741810 | 4.5 | 86.45 |
| Mexico, Palenque, North Group | 17.483978 | 90.463320 | 10.1 | 100.1 |
| Mexico, Palenque, Temple of the Inscriptions | 17.480000 | 90.000000 | 20.6 | 110.6 |
| Mexico, Tenan | 19.104245 | 99.397003 | 14 | 104 |
| Mexico, Texcoco | 19.425000 | 99.319189 | 7 | 97 |
| Mexico, Teotihuacan | 19.025100 | 99.448189 | 11.6 | 105.6 |
| Mexico, Tulum | 19.400694 | 89.175150 | 8.5 | 98.5 |
| Mexico, Yaxchilán | 20.004515 | 93.345050 | 15.47 | 105.47 |
| Mexico, Yaxchilán | 20.210000 | 93.430000 | 62.3 | 112.3 |
| Mexico, Uxmal, Palace of the Governors | 20.309444 | 90.713189 | 30 | 120 |
| Mexico, Uxmal, Pyramid of the Magician | 20.309444 | 90.713189 | 30 | 120 |
| Mexico, Uxmal, Temple Mayor | 20.309444 | 90.713189 | 15.8 | 108.6 |
| Mexico, Xochicalco, Grand Pyramid | 18.803889 | 99.295157 | 0 | 90 |
| Mexico, Xochicalco, Temple of Quetzalcoatl | 18.803889 | 99.295157 | 15.4 | 105.4 |

D = alignments to "sacred directions". E = cardinal directions, i.e. geographic poles, and equinoxes. M,m = major and minor lunar standstills. S = solstices. st = stellar alignments. Z = zenith passage.
ANALYSIS OF ALIGNMENTS

The graphs in Figure 6 plot the distribution of site alignments within each of the eight geographic regions. Site distributions are con-

![Figure 6. Site-alignment distributions.](image)
verted to probabilities (relative frequencies) over the set of alignments \{E,S,M,X,D,Z,\text{st}\} where “M” represents both major and minor lunar standstills. If \(\tilde{r}(i)\) and \(\tilde{r}(j)\) are the alignment probabilities within two geographic regions, we define the similarity between the two regions by

\[
d(i, j) = \| \tilde{r}(i) - \tilde{r}(j) \|
\]

Table 9 lists similarities between regions in terms of their alignment probabilities.

Figure 7 depicts the similarity between geographic regions using a distance-preserving nonlinear mapping algorithm (Carlotto, 1993). Regions on the edge of the map are the most distinct from other regions in terms of their alignment statistics. For example, South America is different from the other regions in terms of the large number of sites that are aligned to other sites. Africa, mainly Egypt, is distinguished by its many pyramids aligned to the cardinal directions. Asia is unique in that most of its sites are aligned either to true north or to geomagnetic north. Most sites in Europe are aligned to solstices or lunar standstills, while sites in the Middle East are aligned only to the moon. Almost all of the sites in North America that were built by indigenous people are aligned to the sun or moon.

**DISCUSSION**

Across all eight geographic regions, 19% of the sites considered are aligned to the cardinal directions, 9% to solstices, 15% to lunar standstill, 5% to the geomagnetic pole at the time of construction, 5% to other sites, 4% to zenith passages, and 1% to stars. About 42% of the sites (95 out of 224) are anomalous in that they cannot be explained by
any of our alignment hypotheses. Some of these sites may have aligned for other reasons, e.g., the alignment of the Parthenon to the sunrise on Athena’s birthday or to conform to the landscape and topography as at Teotihuacan. Other structures such as Hindu temples in India (Daware, 2017) may have been aligned at the discretion of the builder without any obvious plan. It is also possible that some sites may not have been purposefully aligned at all.

That the alignment of so many sites cannot be explained is surprising. About half of the sites, on average, within all of the geographic regions (with the exception of North America) cannot be explained in terms of alignment (Figure 8). This would suggest that the reason for the non-alignment could be global and not local in nature. This possibility is considered in a subsequent paper.

REFERENCES

Aveni, A. F. (2001). *Skywatchers: A revised and updated version of Skywatchers of Ancient Mexico*. University of Texas Press.

Aveni, A. F., Calnek, E. E., & Hartung, H. (1988, April). Myth, environment, and the orientation of the Templo Mayor of Tenochtitlan. *American Antiquity, 53*(2), 287–309.
Carlotto, M. J. (1994, June). Nonlinear mapping algorithm and applications for multidimensional data analysis. *Journal of Visual Communication and Image Representation, 5*(2), 127–138. https://doi.org/10.1006/jvci.1994.1012

Carroll, T. J. (1979). *Were ancient Mesoamerican buildings oriented to magnetic north?* [Bachelor’s thesis, Massachusetts Institute of Technology]. http://hdl.handle.net/1721.1/68219

Charvátová, I., Klokočník, J., Kolmaš, J., & Kostelecký, J. (2011, January). Chinese tombs oriented by a compass: Evidence from paleomagnetic changes versus the age of tombs. *Studia Geophysica et Geodaetica, 55*, 159–174. 494{en-dash}511. https://www.jstor.org/stable/2561728

Daware, A. R. (2017, May 24–28). Orientation of Hindu temples—India. *International Conference on Science and Engineering for Sustainable Development, Bangkok, Thailand.*

Fuson, R. H. (1969, September). The orientation of Mayan ceremonial centers.

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**Figure 8. Geographic distributions of unknown-alignment sites.**
Annals of the Association of American Geographers, 59(3), 494–511. https://www.jstor.org/stable/2561728
Hannah, R. (2013, December). Greek temple orientation: The case of the Older Parthenon in Athens. Nexus Network Journal, 15(3), 423–443. https://doi.org/10.1007/s00004-013-0169-1
Hardman, C., Jr., & Hardman, M. H. (1987). The Great Serpent and the sun. Ohio Archaeologist, 37(3), 34–40. https://kb.osu.edu/handle/1811/55883
Hawkins, G. S. (1965). Stonehenge decoded. Doubleday.
Hawkins, G. S., & King, D. A. (1982, June). On the orientation of the Kaa-ba. Journal for the History of Astronomy, 13(2), 102–109. https://doi.org/10.1177/002182868201300204
Iyemori, T., Hashizume, M., Saito, A., Nose, M., Choosakul, N., Tsuda, T., & Odagi, Y. (2011). Geomagnetism and the orientation of temples in Thailand. Journal of the Siam Society, 99, 139149. http://www.siamese-heritage.org/jssp-pdf/2011/JSS_099_0j_Toshihiko_GeomagnetismAndOrientationOfTemples.pdf
King, D. A. (2018). Bibliography of books, articles, and websites on historical qibla determinations. https://www.davidaking.academia.edu/research
Krupp, E. C. (1994). Echoes of the ancient skies: The astronomy of lost civilizations. Dover.
Lehner, M. (1997). The complete pyramids: Solving the ancient mysteries. Thames & Hudson.
Lepionka, M. E., & Carlotto, M. J. (2015). Evidence of a Native American solar observatory on Sunset Hill in Gloucester, Massachusetts. Bulletin of the Massachusetts Archaeological Society, 76(1).
Lon, I. D. (2005). El sistema de ceques del Cuzco. http://www.monografias.com/trabajos32/sistema-ceques/sistema-ceques.shtml
Magli, G. (2016). Archaeoastronomy in the Khmer heartland. https://arxiv.org/abs/1604.05674
Maravelia, A.-A. (2002). The orientations of the nine tholos tombs at Mycenae. Journal for the History of Astronomy Supplement, 33 (Archaeoastronomy, 27), 63–66.
McElhinny, M. W., & McFadden, P. L. (2000). Paleomagnetism: Continents and oceans. In R. Dmowska, J. R. Holton, & H. T. Rossby (Eds.), International Geophysics, 73. Academic Press.
McKim Malville, J. M. (2015). Astronomy of Indian cities, temples, and pilgrimage centers. In C. L. N. Ruggles (Ed.), Handbook of archaeoastronomy and ethnoastronomy (pp. 1969–1980). Springer.
Ridderstad, M. (2009). Evidence of Minoan astronomy and calendrical practices. https://arxiv.org/pdf/0910.4801.pdf
Shaltout, M., & Belmonte, J. A. (2005). On the orientation of ancient Egyptian temples: (1) Upper Egypt and Lower Nubia. Journal for the History of Astronomy, 36(3-124), 273–298. https://doi.org/10.1177/002182860503600302
Sparavigna, A. C. (2013). Sunrise and sunset azimuths in the planning of ancient Chinese towns. International Journal of Sciences, 2(11), 52–59. https://doi.org/10.18483/ijSci.334
Sparavigna, A. C. (2016, June 18). A ziggurat and the moon. Philica, Article 618. https://ssrn.com/abstract=2797629