The Zenith Passage of the Sun and the Architectures of the Tropical Zone

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ABSTRACT. In ancient cultures all over the world, summer and winter solstices and equinoxes had a great importance. These astronomical events had been widely considered in the planning of monuments and other architectures. But in the zone of the Earth delimited by the Tropics of Cancer and Capricorn, we can see another relevant event, the zenith passage of the sun. In this paper we will show that several examples are existing too, of the role of this astronomic event in the architectures of tropical zone. To evidence this role, we will use a software developed for the best solar energy management, which is showing azimuth and altitude of the sun on satellite maps.

Introduction. Zenith is the point of the celestial sphere which is vertically above an observer. Only in the area of the Earth, which is delimited by the Tropic of Cancer and the Tropic of Capricorn, we can see the sun passing through the zenith. Anywhere outside the tropics, this is impossible. Therefore, in the tropical zone the sun has, besides the astronomical events of solstices and equinoxes, also two zenith passages. On the Tropical lines, only one passage is observed, coincident to one of the solstices. On the Tropic of Cancer for instance, it happens on the summer solstice. At the equator, the zenith passage is on the equinoxes.

The zenith passage of the sun, being the moment when it passes through the top point of the sky, is easily observed using a gnomon, that is, by a straight vertical pole, because at that moment it casts no shadow on the ground. Or, if we have a deep water well, we can see the sun reflected at noon by the water at its bottom. Both these facts were well known to ancient people living in the tropical zone. And in fact, Eratosthenes (c.276 BC – c.195/194 BC) used them to calculate the circumference of the Earth [1]. Eratosthenes knew that at local noon on the summer solstice in Syene (the modern Aswan), the sun was reflected by the water of a deep well. By the shadow of a gnomon in Alexandria, he measured the angle of sun elevation at the noon on the same day and found it being 1/50th of a circle. Assuming that the Earth was a sphere and that Alexandria was due north of Syene, he concluded that the meridian arc distance from Alexandria to Syene was 1/50th of the Earth's circumference. From this distance, he evaluated the circumference of the Earth.

Peoples all over the world recognized in the past as very important astronomical events the summer and winter solstices and the equinoxes and celebrated them consequently. It is not surprising then that these astronomical events had been also considered in planning of monuments and other architectures, which are consequently displaying alignments with the direction of sunrise or sunset on these days. As evidenced by several examples [2-11], the planning of the architectonic structure becomes a symbolic local horizon, a microcosm representing the apparent motion of the macrocosm that, thorough the year, is revolving about its “axis mundi”, that is, the axis of the world.

In this paper we will discuss that several examples of the role of the zenith passage of the sun are also existing, displayed by some architectures of the tropical zone. To evidence the role of the zenith passage in the proposed examples, we will use a software developed for the best solar energy management, which is showing azimuth and altitude of the sun on satellite maps.

The Zenithal Sun in America. As previously told, in the tropical zone, to solstices and equinoxes we have also to add, as relevant astronomic events, the zenith passage of the sun. And in fact, we can find that pillars and wells exist, used by people to observe what happens to light and shadows at the zenith passage of the sun.

The people of pre-Columbian Mexico had a specific "astronomical instrument" to observe this passage: a vertical zenith sighting tube inserted in the vault of an underground structure. One of these instruments is at the observatory of Xochicalco, in the Mexican state of Morelos. The image in the Figure 1 (left) illustrates how it looks like the shaft of light passing through the ceiling of the artificial cave of Xochicalco. A vertical opening produces in a dark chamber a perfectly perpendicular beam of light, when the sun is passing through the local zenith. Besides the cave, at Xochicalco there is a white stone pillar in the ceremonial area that could had been used to observe the shadow disappearing when the sun reaches an altitude of 90 degrees (Figure 1, right).

Fig. 1. On the left: the image illustrates how it looks the shaft of light in a cave passing through a tube in its ceiling, when the sun has its zenith passage in the sky. On the right: a pyramid and the ceremonial pillar at Xochicalco, Mexico. Courtesy Maxtreiber, Wikipedia.

For Meso- and South America, several researchers have recognized and evidenced the importance of the zenithal sun [12-18]. In [19,20], it is stressed that among the ancient civilizations that recognized the zenith passage, we have also those of the Andean people of Peru, that incorporated it into their cosmology. The Andean people used pillars, such as the Chankillo Towers [18,21], for solar observations and for their calendars.

Let us add to the pillar shown in the Figure 1, another monument that we can easily imagine the ancient architects had built to observe the zenithal sun and for related ceremonial purposes too: it is the Gate of the Sun at Tiwanaku (Figure 2). Being under the linter of this gate, an observer could see the shadow of it coincident to the base [22].

Tiwanaku is a Pre-Columbian archaeological site in western Bolivia. The site was first described by the Spanish conquistador Pedro Cieza de León. He came to the ruins of Tiwanaku in 1549, while searching for the Inca capital Qullasuyu [23]. During the time period between 300 BC and AD 300, Tiwanaku is thought to have been a ceremonial center for the Tiwanaku Empire to which people made pilgrimages.

Fig. 2. The Gate of the Sun at Tiwanaku.

The Zenithal Sun in Sri Lanka. The zenith passage was important also for people of Asia. And in fact, in [24], we have shown that the archaeological complex of Sigiriya, the Lion Rock, in Sri Lanka has its axis oriented to the sunset of day of a zenith passage of the sun.

Sigiriya is a huge palace built by King Kassapa I (477–495 CE) on the top of a granite rock, the Lion Rock [25,26]. This site is in the heart of Sri Lanka, dominating the neighboring plateau, inhabited since the 3rd century BC, and hosting some shelters for Buddhist monks. A series of galleries and staircases, having their origin from the mouth of a gigantic lion made of bricks and plaster, provide access to the ruins on the rock. From the satellite images, it is possible to see the site surrounded by a wall and the rock inside. At the summit of the rock, there is the fortified palace with its ruined buildings, cisterns and rock sculptures. At the foot of the rock we find the lower city surrounded by walls. The eastern part of it has not yet been totally excavated.

Fig. 3. The Sigiriya archaeological site in Sri Lanka. On the right, the Lion Rock. (Courtesy: Google Earth).

The Gardens of Sigiriya are an important characteristic of the site. They are divided into three distinct forms: the water gardens, the cave and boulder gardens, and the terraced gardens. The water gardens are in the central section of the western precinct. They were built according to an ancient garden form, of which they are the oldest surviving examples.

The design of these gardens is symmetrical, however the axis is not oriented along the cardinal east-west line: the site is inclined of 9 degrees, as we can easily measure from satellite maps (Figures 3 and 4). Since this angle is not negligible, it can correspond to a specific azimuth of the sunset, different from the direction it has on equinoxes.

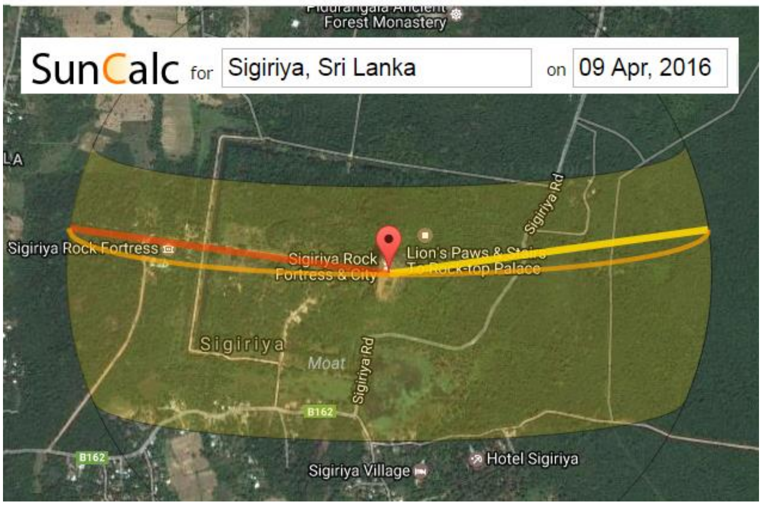

Fig. 4. The direction of the sun on April 9, given by SunCalc.net, at Sigiriya. This site provides a diagram, overlaying a satellite map, showing the sunrise (yellow line) and sunset (red line) of the sun for any day of the year. As explained in SunCalc.net, the thin orange curve is the sun trajectory, and the yellow area describes the variation of sun trajectories during the year. "The closer a point is to the center, the higher is the sun above the horizon". Courtesy: SuncCalc.net and Google Earth.

Let us remember that the azimuth angle is formed by the vector from the observer to the sun rising or setting on the horizontal plane and a reference vector on this plane. There are several web sites that allow to know the azimuth and the noon altitude of the sun and moon at a specific location on a given day of the year. One is the site Sollumis.com. Using it, we can obtain at Sigiriya, the data for the noon altitude and sunset azimuths. We find that we have the zenithal sun on April 9 and on the First of September, and that the sunset azimuth on these day is coincident with the axis of the western gardens. In [24], we have shown this coincidence, also giving the satellite maps and the polar diagrams of the solar azimuths from Sollumis.com. Here we show in the Figure 4 the same by using SunCalc.net software.

On the Tropic of Cancer. Let us consider the very important Buddhist religious center of Sanchi, India, because it has interesting astronomical orientations as discussed by N. Kameswara Rao [27]; the site possesses a particular alignment of stupas with the sunset direction on the summer solstice. Since Sanchi latitude is very close to the Tropic of Cancer, we have also that, on this day, the noon altitude of the sun is about 90 degrees. Therefore, the alignment of stupas is also giving the sunset direction of the day of the zenithal sun [28]. In the Figures 5 and 6, we see the Sanchi religious complex and the directions of sunrise and sunset on solstice.

The first written mention of the passage through the zenith of the sun in Indian literature comes from Varahamihira in the 6th century [29,30], who noted that in the kingdom of Avanti the day of summer solstice and zenith passage were the same (the Avanti Kingdom of ancient India was described in the Mahabharata epic). He further discussed that north of Avanti, no zenith passage occurs. Varahamihira wrote these observations when he was in the ancient city of Ujjain, located at latitude of 23° 10′ 12″ N [29]. In fact, as observed in [29], the ancient India had a "prime meridian" and a north-south "zero" line of latitude crossing at Ujjain and running straight down to the island of Lanka.

Fig. 5. N. Kameswara Rao had investigated the orientation of Sanchi stupas [27], showing that they could had been planned to be oriented towards the moonrise and the sunset on the day of Buddha purnima (purnima means "full moon"), the birthday of Siddhartha Gautama. (Courtesy: Google Earth).

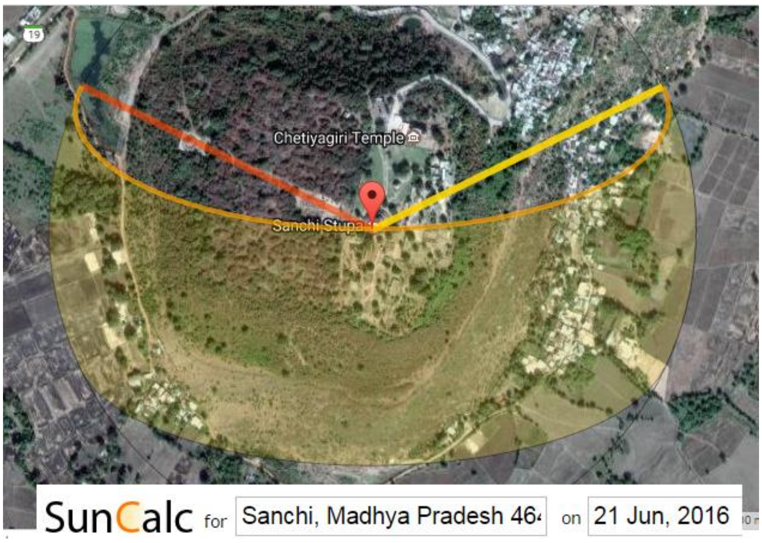

Fig. 6. The image shows the direction of the sunset on summer solstice as given by SunCalc.net. We find the alignment of two stupas along the sunset. Courtesy: SuncCalc.net and Google Earth.

Angkor Wat. A very interesting paper is discussing the importance of the zenith passage of the sun in the architecture of the temples at Angkor Wat, Cambodia (Figure 7). The authors of this paper [29], Edwin Barnhart and Christopher Powell, University of Texas, Austin, in August of 2010 and 2011 investigated the importance of the zenith passage of the sun for the ancient Khmer culture. They concluded the research with a positive answer. "From architectural features and orientations to art panels and monuments, the evidence that zenith passage was recognized permeates the entire city" [29]. According to the authors, their idea "to search for evidence of zenith passage at Angkor" was inspired by prior research in Mesoamerica. In [29], besides discussing the discoveries at Angkor, the authors are proposing that the Hindu culture was also including some references to the zenith passage of the sun.

Fig. 7. On the left, aerial view of the central structure. Courtesy Shyam tnj, Wikipedia. On the right, the Angkor Wat surrounded by a moat used for helping stabilize the temple's foundation [31]. Courtesy: Google Earth.

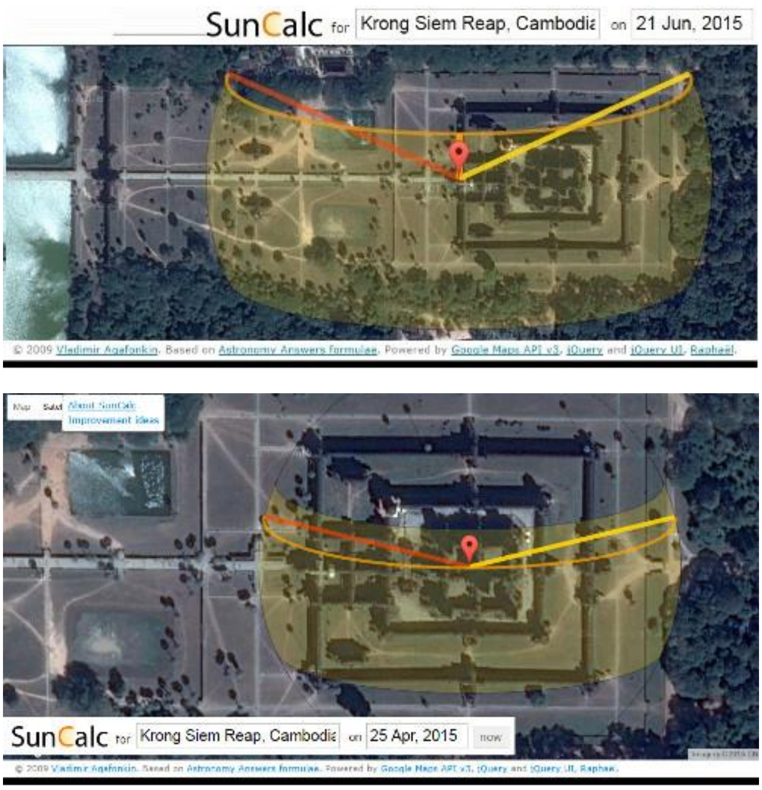

Fig. 8. Alignments on day of the summer solstice (upper panel) and on the day of one of the zenith passage of the sun (25 April). Courtesy: SuncCalc.net and Google Earth. The azimuth of the sunrise on the day of the zenithal sun is about 76.2 degrees.

Barnhart and Powell have discovered that Angkor temples had vertical zenith sighting tubes too. "Though it is not apparent from the outside, each one of the beehive shaped temples of Angkor are hollow on the inside. Walking in and looking straight up, the roof is open all the way up to the top and that top has a hole where the sun shines in. We were told by the temple attendants that the holes on top of the roofs were there because the capstones had all been knocked off by erosion or more commonly by looters searching for jewels. Finding these fallen capstones among the rubble around the temples was our first surprising clue. Most capstones were beautifully carved as lotus flowers and all had a hollow tube running down their axes. Each had a very straight, long tube that would have let only true zenith passage sun light down into the temples. Whether or not this was their intention, functionally this makes every single temple of this kind at Angkor a zenith tube" [29]. Besides the temples which are beautiful artificial caves for the zenithal sun, the authors have observed that this architectural possesses also alignments to mark the zenith passage at Angkor Wat. In the Figure 8, we can see two possible alignments. In the upper panel, it is given an alignment according to the sunrise on the solstice, the lower panel is according to the sunrise on a day of zenithal sun.

The temples of Java. The temples we are considering for our discussion about the connection of the zenith passage of the sun and architecture are the Sewu, Prambanan and Borobudur temples in Java.
The Sewu temple, an eighth century Buddhist temple complex, is predating the nearby Rara Jonggrang, simply known as Prambanan, by over 70 years and the Borobudur by about 37 years. Prior to the construction of these temples, probably the Sewu temple served as the main temple of the kingdom [32]. Since Candi Sewu was built before the other two temples, we can suppose that it was a model for them, in particular for what concerns the number of ancillary temples and stupas (in Java, "candi" means "temple").

Fig. 9. The zenith passage of the sun on 12 October 2016 at the Sewu temple complex. Courtesy SunCalc and Google Earth.

Fig. 10. The solstice and the other zenith passage on 28 February (or first of March, the Photographer's Ephemeris software is giving for these days the same altitude of the sun) at the Sewu temple complex. Courtesy SunCalc.net and Google Earth.

The Sewu temple complex occupies a large rectangular area with the sides oriented along the cardinal directions (Figures 9 and 10). The complex has an entrance at each of the four cardinal points. The main entrance is located on the east side. The temple is composed of 249 buildings, arranged in a Mandala around the main central temple. Along the cardinal north-south and east-west axes of the complex, between the second and third rows of smaller buildings, we find the apit (flank) temples. The complex had a couple of apit for each cardinal direction; only the eastern couple is visible today.

In the Sewu temple complex, the alignment marking the passage through the zenith of the sun is given by the central temple and one of the eastern apit temples [33]. The passage happens on 12 October

2016, and it is displayed by the SunCalc.net software as in the Figure 9. After the zenith passage of October, the sun reaches the solstice of December and then it has the other zenith passage at the end of February (or the first of March), as we can see in the Figure 10.

Counting the days between 12 October 2016 and 21 December 2016, inclusive of both these dates, we have 71 days. From December 21 to the first of March 2017, we have a total of 71 days again. From the first of March to June 21, 2017, inclusive of these days, we have 113 days.

Let us try to connect these numbers to the number of the temples in the complex. Actually, the first and the second rows of the Sewu temple, those inside the couples of the apit temples, are composed by 72 small ancillary temples (Perwara) (see Figure 11). It seems therefore that a connection of the even number of Perwara to the number of the days from the zenith passage of October to the solstice of December is possible.

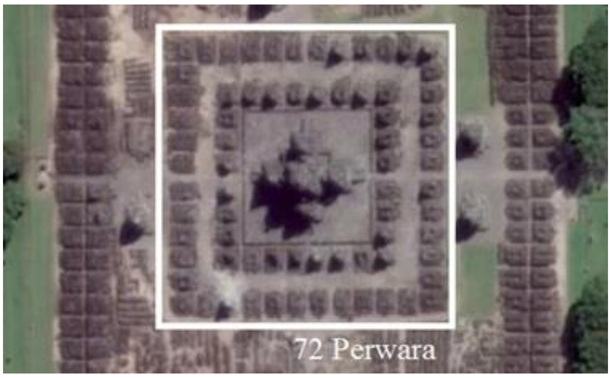

Fig. 11. The central part of the temple contains the main temple and 72 ancillary temples.

Probably, the people who built the temple determined the zenith passage of the sun according to the observation of the stars. For instance, "one can see that a particular star would always rise at a certain point a few days before such or such a zenithal sun, hence it would be possible to know beforehand the exact date of any given sun." [34,35] It means that 71 days are 72 nights (inclusive counting), and this legitimates the use of the corresponding even number, equal to the number of Perwara.

Fig. 12. The Prambanan temple as given by Google Earth.

A link between the number of ancillary temples and the number of the days from the zenith passage of the sun to the June solstice had been proposed for the Prambanan temple [36] (see the temple complex in the Figure 12). In [36], it is told that the temple complex of Prambanan had 224 ancillary temples, connected to the number of 112 days after or before the June solstice. In the case of the Sewu temple, it is the December solstice which is involved.

It is not simple to determine the number of ancillary temples of Prambanan from the satellite images, because many of the smaller temples have been not yet restored. Let us follow the reconstruction suggested by the symmetry that the temple probably had and by the image we find in [37]. We have the Figure 13, in which we can see the 224 ancillary temples.

Fig. 13. Simulation of a satellite view of the reconstruction of the Prambanan temple, as proposed in [37].

Fig. 14. Borobudur in Google Earth.

It seems therefore that the Sewu temple and the Prambanan are linked to astronomy; the Sewu temple is connected to the sun moving about the December solstice, whereas the Prambanan is linked to the sun moving between the zenith passages about the June solstice.

Let us consider the Borobudur temple too (Figure 14). Borobudur is one of the greatest Buddhist monuments in the world. "The temple consists of nine stacked platforms, six square and three circular, topped by a central dome. The temple is decorated with 2,672 relief panels and 504 Buddha statues. The central dome is surrounded by 72 Buddha statues, each seated inside a perforated stupa" [38]. Again, we have the number 72; as we have previously told, it is equal to the even number of the days passing from the zenith passage of October to the December solstice, and also from the December solstice to the zenith passage on the end of February or the first of March.

It seems therefore that, for the people who built the temples, the astronomical year was based on periods of even numbers of days with an inclusive counting: 72 days from the zenith passage of the sun to the December solstice, and from this solstice to the zenith passage of the first of March. Then, there was another set of 112 days, from the zenith passage to the June solstice, and the same from this solstice to the zenith passage of October. Adding these periods we have a total of 368 days. However, the counting was inclusive, and then we have to remove some days. For instance, if we start the count from the zenith passage of the first of March, we have to remove one day for the other zenith passage and two days for the two solstices. We obtain 365 days.

However, let us note that a religious interpretation of the seventy-two temples of the Sewu central structure exists, as for those of Borobudur. "Within the Buddhist Abhidharma philosophical schools, the Sarvāstivādins identified three unconditioned Dharmas whose nature is free from the laws of causation (asaṁskṛta) as well as 72 conditioned Dharmas (see Wayman 1997:269) which are subject to the laws of causation (saṁskṛta). So one might conjecture that these 72 auxiliary shrines had pertained to what Vilāsavajra had called the second circle of Mahāvairocana containing the divinities belonging to the perfectly pure Dharmadhātu of Vairocana" [39].

Let us just add a comment: it is possible that people observed a coincidence between religion and astronomy, and that the conditioned Dharmas were the days conditioned by the zenithal sun.

Summary. The examples discussed above, provide evidence of the importance of the zenith passage of the sun. Many other sites had been discussed in literature and on web sites [40-50]. However, many others require further investigations for what concerns the astronomical alignment.

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