

Sundial in Traditional Architecture: Shrine of Imam Ali in Najaf Al-Ashraf as "Case Study"

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Article Info	Abstract
<p>Received 02/11/2024</p> <p>Revised 01/12/2025</p> <p>Accepted 28/12/2025</p>	<p>Building the shrines of Muslim imams in Iraq has a profound spiritual impact on the souls of its pioneers. Therefore, the designer was interested in creating an atmosphere that matches the spiritual and worship situation and linking it to a sustainable astronomical design in the architecture of the shrine of Imam Ali (peace be upon him). This was mentioned vaguely. Therefore, the research problem emerged about the relationship between the design of traditional sundials symbolically and sustainably. The goal is to reveal the relationship of the architectural design of the shrine's architecture to the cosmic phenomenon represented by sundials. The current study adopts the analytical approach through two axes. Theoretical section: Collecting data related to sundials. In the practical study, five sundials in the shrine's architecture were examined practically and in accordance with astronomical laws, and photographs were taken that confirmed the operation of the sundials in a sustainable manner annually.</p>

Keywords: Astronomical design, Courtyard, Imam Ali shrine, Iwans, Sundial design, Technical sustainability.

1. Introduction

It is mentioned that the architecture of the shrine in Najaf was designed by Sheikh Al-Bahae [1],[2]. Nothing else is mentioned, and the subject matter remains a mystery even for this source, as confirmed by the historian (Baraqi) that the design of the shrine is the work of Sheikh Al-Bahae (Al-Baraqi) [3]. He also did not elaborate on the subject of this design work. On the other hand, it is mentioned that the building of Shah Safi al-Din is exquisitely luxurious in shape that the greatest architect of the current era could not plan, with the knowledge of the times of demise and its difference in summer or winter, and what art professors stand with. From the arbitration of the emergence of the sun in the holy shrine and what he adhered to in terms of interview and artistic homonyms [1]. He touched upon the existence of engineering arbitrations without explaining anything about the work of these arbitrations in a more precise way than the subject of noon, and he did not confirm how this information works. On the other hand, it is mentioned that there are several phenomena, including the eastern wall of the shrine, which serves as a sign to determine the time of noon over the seasons of the year in two places. The first place is in the three curved arcs on the clock door. When the sun reaches the middle of its middle arc, it is noon. The second place is the four Iwans when the sun

ascends to the floor of these Iwans by four fingers from their edge. It is the time of noon on all days of the year [4]. Rather, it needs study and actual field investigation along with other scientific, mathematical, and astronomical examinations in order to be assured of these insinuations authorized by the previous literature. It turns out that there is actually a research problem, as studies lack information on how they work. Accordingly, the present study sheds light on that, either to prove it or to refute it.

There is an epistemological need for the relationship between the sundial design and cosmic phenomena, which represents the aim of the present study to reveal the creativity of the sundial of the architecture of the Imam Ali (peace be upon him) shrine in Najaf as a sustainable symbol and to determine the relationship between design and the cosmic phenomenon. To obtain the aim of the present study, the study adopted an inductive-analytical methodology with two proxy axes:

- The theoretical axis: Information and data were collected, and the theoretical basis for a theoretical framework was established.
- The practical axis: Investing the theoretical base extracted from the first axis and employing it by examining the five sundials and through daily observation and photos taken,

results analysis, and discussion to reach the final conclusions of the present study.

Mystery shrouds a number of secrets of the architecture of the shrine of Imam Ali (peace be upon him) in the city of Najaf, Iraq, whose sustainable techniques are unverified. Its secrets remained unrevealed for centuries due to a lack of documents and a lack of interest by researchers.

2. Literature Review

Previous studies have shown that Muslim architecture is a clear example of how mathematical systems and repeated number sequences are able to influence the decorations and construction of buildings. In Islamic art, the idea, number, and pattern overlap with each other and affect the development of each of them [5]. The Arab-Islamic art established the rules of aesthetics. The abstract art, which is where the plastic arts approach each other through their reliance on engineering mathematical sciences, has retained its importance and position [6]. In addition, Islamic architecture applies to buildings associated with belief in thought and practice with the aim of serving an Islamic purpose [7]. Islamic architecture is a fact discovered by visiting the Islamic environment. It is felt before meeting any person or seeing any written sign. It is felt in every building, in every decoration, and at the level of the city as a whole. This feeling is called Islamic architecture, which is termed the architecture of unity [8].

2.1. The geometric dimension of Islamic architecture and its relationship to astronomy and mathematics

Architectural monuments of artistic pieces and decorations dominate traditional Islamic architecture, and they are undoubtedly made by craftsmen. At the same time, they are experts in engineering and have an active role in creating and using these styles of architectural art. Mathematicians also contributed, as Abu Al-Wafa Al-Buzjani (ca. 940) mentions. 998) In his book *Engineering Constructions*, the design of the northern dome in the Juma Mosque of Isfahan goes back to the secret of this cooperation between craftsmen and mathematicians, as he emphasized that technicians are those who apply practical engineering and those who deal with it are qualified in theoretical engineering [9].

The background of the Muslim artist is familiar with mathematics, as symmetry was used in various forms in many Islamic buildings, such as muqarnas, and this indicates the optimal use of mathematics, which is considered an art that enjoys beauty and freedom [10].

Throughout history, craftsmen have also decorated Islamic architecture with Islamic geometric patterns with high symbolism that are related to the faith and serve an important aspect of it, which is creating a sacred space and alerting to the presence of God and his call to prayer [11].

The group of symbols and decorations that were embodied in the domes or minarets, as well as in the prayer niche, represented a spiritual and ideal state of divine power, and together they aimed to create a spiritual atmosphere commensurate with the intangible state of faith. All of this is a

definition and representation of the spirituality of Islam through Islamic inscription, which is a manifestation of Unity in a world of diversity [12].

2.2. The relationship between astronomy, cosmic phenomena, and sundials

The intersection between the common application of mathematics to study the various properties of quantities, shapes, and formulas in the field of astronomy, which includes the study of celestial bodies and phenomena, both of which have different branches, such as cosmology, astrophysics, geometry, and calculus. Astronomers have used these mathematical methods to this day, as well as in engineering aspects. It uses shapes from mathematics. They were and still are two related sciences [13].

The lives of Muslims and others were also linked to special times of worship, whether daily or seasonal. In this case, the day and night were divided into 12 hours, and it was called civil time, along with the chronological and seasonal forms. The third form depended on astronomical concepts, and for this reason, the variables occurring daily with the moon, sun, and planets were considered signs. Positive or negative for certain actions, and thus enables the individual to organize his life in accordance with the celestial bodies, and it is called cosmic time. This is why mathematics is considered not only with art, but also with astronomy, which is the oldest science, and the ancient Greeks acknowledged that they were traced back to their Babylonian ancestors. Astronomy was linked with mathematics, and therefore many astronomers are known for their contributions to time calculation, calendars, and weather forecasting, which is related to agriculture and irrigation. Navigation, trade, and medicine. He also designed some of the globes and sundials [14].

Many previous studies have elaborated on Islamic architecture, but have neglected the important aspect of it, which is the astronomical phenomena in it. Several studies have been conducted in this manner and have shown that there are attempts to monitor and control the locations of celestial bodies, but they have not examined any connection with the traditional architectural masses within Islamic astronomical architecture. Credit goes to the Muslim scholars who built astronomical observatories and invented their instruments between the eighth and the thirteenth centuries. Among the most prominent of these scholars are Al-Khawazmi, Al-Battani, and Al-Sufi, who translated Ptolemy's *Almagest*. He authenticated it, as well as Ibn Yunus al-Sadafi, Lamsri, al-Biruni, and Omar Khayyam. They all contributed to this science, built observatories, and verified the movement of the stars and their positions. The applications that must be used as a result of astronomy are the Islamic lunar and solar calendar, which is linked to the times of prayer and fasting, as well as to the direction of the Qibla, and the condition. What is also important here is the direction of the mosques when they are built. They must be directed towards the Qiblah in Mecca [15].

The connection of astronomy with celestial bodies is linked to the science of timings and astronomical phenomena, as Muslims produced for us the science of determining time, by which the times of prayer and fasting are determined, and the

setting of time. Astronomical phenomena and tables regulating worship times have spread in some of the mosques, shrines, and hospices of the Islamic world. On this basis, the architectural masses were designed in order to link them to the celestial bodies and what is related to them in terms of the movement of the sun and the moon, monitoring and directing the Qiblah, in addition to the times of worship in general. The sundial was a marker for knowing the times of prayer. Sundials differed; some were horizontal, some were vertical, and some were in the same mass, and this is what distinguished the architecture of the shrine of Imam Ali (peace be upon him) in Najaf [16].

The astronomical tools, such as the sundial and the astrolabe, which consist of disks, were used to measure and observe celestial bodies, as well as to measure heights above sea level. They were also used for navigation and calculating longitude and latitude north and south of the equator. These tools were found in the courtyards of mosques, on their facades, or in public squares. It indicates knowing the exact direction of the Qibla, in addition to prayer times and Celestial stars monitoring [15].

3. Theoretical Framework

3.1. Cosmos and symbols of traditional architecture

This section is devoted to extracting research indicators through previous studies that dealt with the cosmology of traditional and symbolic architecture, in addition to environmental techniques. Ardalan's study confirms that Islamic architecture, like all other traditional buildings, is linked to cosmology. Traditional human lives are in a universe that is full of meaning. The cosmos reflects the divine order that is also reflected by the human being, which is a cosmic unit. Law and proportion represent a cosmic reality through arithmetic, geometry, and symmetry that have a relationship with space as well [17]. The main lines of the building are, in a relative way, a real and realistic issue. It can be expressed in (Neoplatonic) or (Pythagorean) terms, while it is seen for practical purposes as a geometric matrix of lines within which the building and all its elements settle. The main lines can be seen as a means of purity and Platonic perfection (Intellectual Construct). In this view, the building is merely an approximate visual and a specific detail of the invisible integrated world that controls creation in the material world. This double behavior towards the main lines can be seen as a means to encourage careful design and also to strengthen the sacred contents [18]. It is also shown that symbolism is one of the functions of architecture, called the symbolic function, which is the requirement for the identity of the individual or group. It includes beliefs, customs, and existential features that represent and cover some moral and symbolic aspects. These two aspects mean the interdependence of the identity of the individual and society with the entity and features of origin [19].

3.2. Environment and Symbol Technology

Recently, a branch of the philosophy of technology developed that is concerned with technology itself and aims to understand every practice from the design, creation, and nature of things thus created. In turn, this technology seeks continuity with the

philosophy of science and with many other fields. Technology development is the result of a process that originates within engineering practice and is guided by standards. Technology has been linked to the surrounding natural and human factors. The natural factors are represented by the surrounding environment in which the technological entity is born and grows. As for human factors, they are represented by society, its direct and indirect needs, and necessities, its ideals and values, which are reflected in its intellectual systems embodied in belief, science, and art [20].

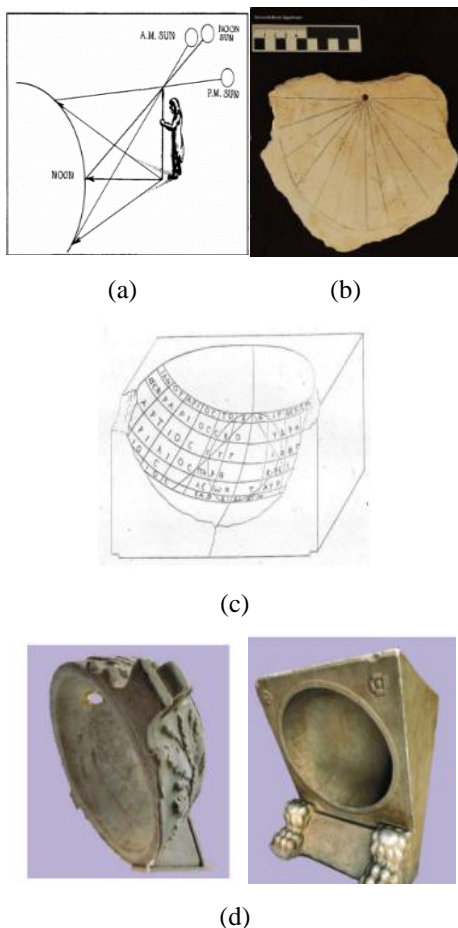
In contrast to the above, studies show the various applications of technology that have affected the values of societies [21]. The condition of old technology is different; we are facing one party, who is the designer, and he is the executor at the same time. On the one hand, the will is one because it belongs to one party, and on the other hand, this will often coincide with the general will of society. The work of technological architecture is a means of converting design ideas into a physical reality [22]. Accordingly, it is shown that the application of urban design and its understanding to those who need it touches upon the dimensions of the theory and practice of urban design functionally, socially, temporally, and perceptually in a visual way, in addition to the production of place, design governance, and technological impact with climate adaptation [23]. Invention and development have their own internal laws that humans follow while working in the technical field. That is, the idea of the thing made (its essence) among the Greeks must be a free organism that decides itself in its behavior in the direction of development as it is predetermined and fixed [24].

One of the most important contemporary concepts in today's ecology, and closely related to technology, is the concept of sustainability. In its general sense, sustainability is the ability to survive. In the environment, the word describes how life systems remain diverse and productive over time [25]. From the foregoing, it is found that the subject of architectural products must be compatible in one way or another with topics related to the social or religious situation or custom and experiences and that its symbols stem from the same ideological directives, so the architect Sheikh Bahai emphasized the use of the building block and its orientation in a manner that is commensurate with some of the topics of faith. The Islamic society benefited from the human scale being a tool for expressing these symbols. Thus, the architectural block within its urban fabric became a basic reference for symbols that reflect the presence in life and its functional, social, temporal, and perceptual understanding in a visual way. The urban environment and its important effects in conveying meanings carry everything that suggests that it is permanently present and is linked to public places with religious and sacred urban spaces, as it provides a comprehensive overview of the possibility of the architectural designer who brought architecture to a state through which he extrapolates the cosmic and ideological manifestations in a practical and scientific copy. One of these symbols is the multiple sundials to be mentioned later [26].

3.3. Ancient Solar Sundries

A sundial dating back to about 3500 BC is a stick or scorpion fixed to the ground or wall that casts its shadow on the ground or wall. People generally relied on the passage of the sun across

the sky to tell the time. The sundial was one of the most important early devices for telling time in several ways, including the shade, which man realized as soon as he noticed the change in the length of the shade of trees, rocks, and mountains with the apparent movement of the sun from east to west. Lengthwise, but in the opposite direction until sunset, as shown in Fig. 1 (a), the oldest sundial in the world, from the Valley of the Kings in Egypt (circa 1500 BC), as in Fig. 1 (b) [27]. The Greek historian Herodotus (484-425 BC) stated that the sundial originated in Babylon. The Babylonian astronomer Berosus (290 BC) invented a variant of this sundial by cutting off a portion of the spherical surface south of the circular arc, followed by the tip of the shadow on the longest day of the year. In Greece, a hemispherical sundial was invented, consisting of a cubic block in which a semi-circular hole was invented by the Greek astronomer Aristarchus around 280 BC, as shown in Fig. 1 (c) [28]. The sundial was also invented by the Roman mathematician and astronomer, Theodosius of Bithynia, and adopted by the Romans as a sundial in Rome in 293 BC [29]. Besides using light to indicate time, a streak of light may form by allowing sunlight to pass through a small hole. The light spot can be as small as the hole in its upper part, as in Fig. 1 (d), as per the Pantheon slot. As for the Greeks, they developed the sundial, where the octagonal tower of the winds was built in Athens, and it dates back to about 100 BC. It contains eight flat sundials, as in the figure [29].



(e)

Figure 1. Types of ancient solar sundries: (a) graphic showing the movement of a stick shadow from sunrise to sunset; (b) oldest sundial in the world Rohr; (c) Hemispherical sundial; (d) a sundial is a hemispherical object that passes light through a small hole; (e) the wind tower sundial in Athana [27], [30]-[32].

3.4. Solar Sundries in The Islamic Environment

Just as Muslims learned the basic principles of solar sundial design from the Greeks, they increased the variety of designs available through the use of trigonometry. For example, they invented a ubiquitous sundial with a hand parallel to the Earth's polar axis [33]. The first person to use the sundial to determine the true noon was the Prophet Muhammad al-Mustafa (peace be upon him and his household), who ordered the construction of a wall on the west side of the Medina Mosque above the midday line, which is located on the surface of the midday circle. He announced to the people that the beginning of the true noon is the meridian, which is when the shadow of the western side is absent and returns to the eastern side [34]. When they see the shadow of the eastern side of the wall, they can perform the noon prayer. As for the afternoon prayer, it is when the length of this shadow is equal to the height of the wall, which means that it is 7 feet. If the shadow covers that distance, they know that the time for the afternoon prayer has arrived, so they perform it. The sundial has been used historically as an astronomical tool to determine the time based on the length of the scorpion's shadow in all Islamic societies. Institutions have been formed in particular to sponsor these activities related to the timing in mosques. It has also been reinforced with mathematical astronomy and trigonometry due to the importance of the topic [34].

4. Research Materials

4.1. Types Of Solar Sundries in The Islamic Environment

The sundials were divided into two parts: the horizontal sundial and the vertical sundial. For example, the Umayyad Mosque in Damascus contains both. The vertical sundial is attributed to Ibn al-Shater, who studied in Cairo [35], as shown in Fig. 2 (a). There is a horizontal sundial [27], as in Fig. 2 (b). In Aleppo, there is a horizontal sundial [36], as in Fig. 2 (c). The column is a 53 cm diameter disc made of white marble covered with a copper dome located on a short stone pillar, and it is intricate to tell the time [37], as in Fig. 2 (d). In addition, there are many sundials, both horizontal and vertical, including those in the Kairouan Mosque [37], as shown in Fig. 2 (e). Also, the Torgul Beg Tower in the capital, Tehran, Iran [38], is the tomb of Tuğrul Beg, founder and sultan of the Great Seljuk Empire, who died in this city in 1063 AD. This 20-meter-high tower has a

polygonal exterior plan with 24 corners. These angles give a folded appearance to the external form that provides the structural support for the building. The tower has technology with unique features that reflect the beautiful rhythm of the thought of its designer, such as the sundial features hidden in the heart of its Iwans. Hence, the ancients used the shadows in these buildings and sunlight corridors designed to follow the

tower that the sun floods because the sun in each tower has a certain height in the sky relative to the horizon and a certain inclination, so the shadows change over the entire building. These changes can be used to determine the time of noon in addition to determining the days and constellations, as in Fig. 2 (f) [38].

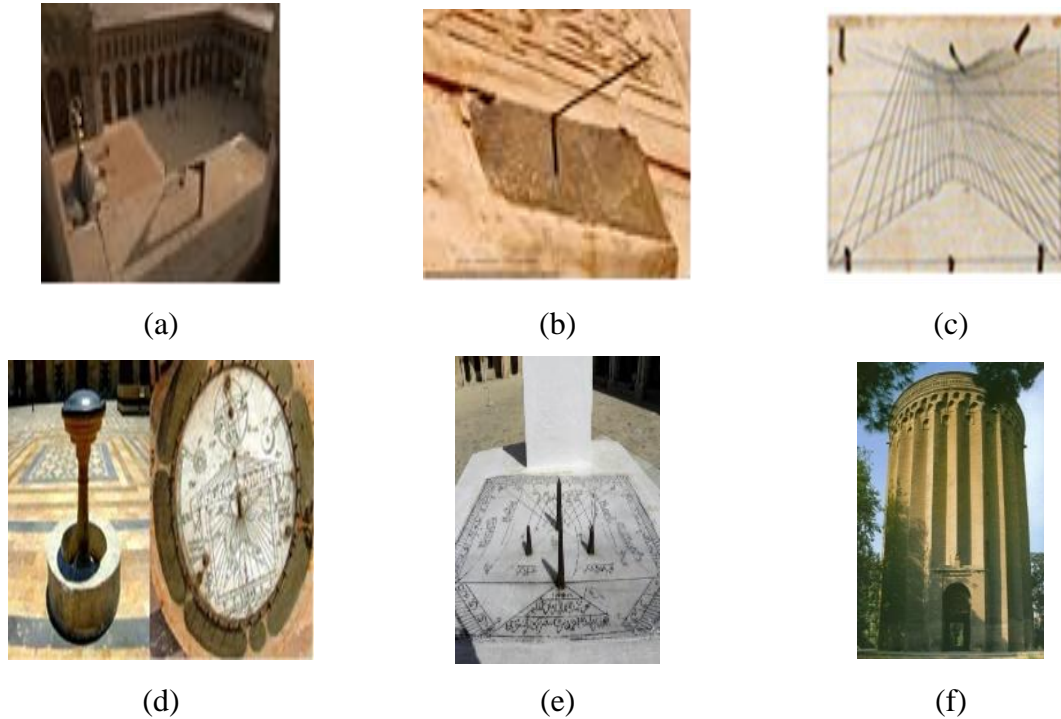


Figure 2. Types of solar sundries in the Islamic environment: (a) vertical sundial of Ibn Al-Shater in the Umayyad Mosque, Damascus; (b) Horizontal sundial in the Umayyad Mosque, Damascus; (c) Horizontal sundial in the Umayyad Mosque, Aleppo; (d) Vertical sundial in the Umayyad Mosque, Aleppo; (e) Vertical sundial in Kairouan Mosque, Tunisia; (f) Vertical sundial in Tuğrul Beg Tower, Tehran [27], [36]-[38].

Table 1. Shows the realized values

Sundial place	Horizontal	Vertical	Checked value
Sundial in Valley of the Kings, Egypt	H		A scientific, practical, and creative aspect that represents the values and needs of society. It invested in technological and sustainable astronomical engineering at its time and still is.
Spherical sundial, Vatican, Musei Vaticani		V	
Roofed spherical sundial, Museo Arqueológico Nacional, Madrid		V	
Sundials in the Tower of the Winds		V	
Ibn al-Shater’s vertical sundial in the Umayyad Mosque, Damascus, Syria		V	
The horizontal sundials of the Umayyad Mosque in Damascus, Syria	H		
The horizontal sundials of the Umayyad Mosque in Aleppo, Syria	H		
The vertical sundials of the Umayyad Mosque in Aleppo, Syria		V	
A vertical sundial to set the times in the courtyard of the (Uqba bin Nafie) mosque, which dates back to thirteen centuries ago.		V	
Kairouan Mosque – Tunisia			
A vertical sundial in the Tugrul tomb tower in Tehran, Iran		V	

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4.2. Sundials in the building of the shrine of Imam Ali (PBUH)

The present study found that there are five sundials in the architecture of the shrine of Imam Ali at Al-Najaf Al-Ashraf. They are unparalleled in all the mosques of the Islamic world, which reflect the views of the spiritualities, beliefs, cultures, and religions of people.

5. Methodology

Accordingly, the present study took several measures, including field observations, taking documented photos, and adopting mathematical calculations using some astronomical equations using the Excel program.

which were not previously identified and were not documented by anyone before with this scientific and architectural formula. It is the result of the discovery of a previous study by the researcher [4].

6. Case Study

The mathematical operations confirmed the validity of the findings of the research mechanism, which is important for architects and those interested in Islamic architecture and Islamic heritage in the holy places and the religious institutions that sponsor the affairs of the architecture of shrines in addition to the honorable visitors, as well as its importance in relation to the religious city and its urban design adjacent to it. The present study found several sundials that can be observed in several directions in the space of the Imam Ali shrine architecture.

1. Eastern sundial in the building of the shrine of Imam Ali (PBUH)

It consists of two unconventional sundials that are not found in buildings in general, as well as cosmic buildings.

- The first sundial is the blue braid, which is located on the right side of the wall of the interior of the entrance to the clock gate located on the eastern side of the space of the shrine building. The clock gate appears from the inside, not lit before noon, and then the right part of the blue braid is lit from the inside. The illumination gradually starts from the bottom of the braid to the top, as in Fig. 3 (a). This sundial begins its work when the sunlight shines on the blue braid of the entrance from the right side of the entrance to the sacred shrine. When the brightness of the sunlight that starts from the base of the braid reaches more than half of it towards the direction of the upper one, it is midday and the time of the noon prayer, as shown in Fig. 3 (b). When the sun reaches the brightness of the entire blue braid until it reaches the top, until the arch of the blue braid is pointed, then the light of the sun moves and begins to rise little by little to the other side of the left blue braid from the left of the interior to the space of the shrine building. The light of the sun covers

the entire part of the braid from the left side, and then the time for the afternoon prayer begins, as shown in Fig. 3 (c). This sundial is within the building of the entrance, so it is distinguished from other sundials of the Islamic world as well as the other cosmic buildings. It works daily both horizontally and vertically in its reading in azimuth time. Here, the present study confirms that this sundial works in a complex form, composed of horizontal grooved rings, because the sundial is divided into several horizontal parts, and it is more like regular degrees and a time scale. The present study considers it a unique innovation and creativity of its architect, Sheikh Al-Baha'i, who designed the shrine in (1614 A.D.-1023 A.H.).

- The second sundial is located in the Iwans of the eastern wall from the inside, specifically on the edge of the first step, entering the space of the shrine building from the left side of the interior from the eastern gate. On the edge of the stairs, whenever the shadow of the wall of the Iwan reaches the edge of the staircase of the Iwan, the time of azimuth comes, and the noon prayer becomes due, as shown in Fig. 3 (d), (e), and (f) in Table 1.

2. The northern sundial in the building of the shrine of Imam Ali (PBUH)

It is a special sundial for the two solstices and the two equinoxes

- The sundial of the Iwan wall of the outer wall of the mausoleum is exactly opposite the Iwan of the mosque of Imran bin Shaheen. It is a sundial that approaches the shadow of the Iwan wall, the northern side of the wall of the mausoleum, at the time of the azimuth hour, as shown in Fig. 4 (a). It is a horizontal sundial.
- Iwans of the northern inner side of the wall of the shrine of Imam Ali and Iwans Imran bin Shaheen Mosque. These Iwans cast a shadow on its inner wall at noon. It is a vertical sundial, and it is an astronomical phenomenon that occurs four times annually in the solstices and equinoxes, as in Fig. 4 (b) and Fig. 4 (c). The shadows of the arches are seen in the middle of the wall from the inside, in particular, because the architectural block of the shrine building was designed by Sheikh Al-Baha'i as an astronomical observatory [4].

3. The southern sundial, The gold gargoyle.

The gargoyle of gold is located on the wall of the southern side of the space of the shrine building. It is the only gargoyle on the roof of the shrine, which is a sustainable sundial. The shadow of the gargoyle, one day, marks the pointed arch of the Iwan, which is located under the gargoyle when the shadow indicator reaches the letter "alif" in the verse written below the gargoyle at azimuth time. As in Fig. 5 (a), it indicates the straying of an hour before the prayer. When the shadow of the letter Alif of the Quranic Ayah is on the wall and on the straight edge of the arc of the Iwan, which is the perfect

azimuth, then it is the noon prayer. This has been verified in the field and mathematically by astronomical mathematical equations along days of the year by the researcher. Fig. 4 (b) indicates that the sun shines in the middle of the dome and has a relationship with the gold gargoyle and the pomegranate of the dome from the top vertically and on one hypothetical line at the time of full azimuth daily and throughout the year, which proves that the designer has mastered his creativity and immortalized his hidden work for many, especially the people of the city or its visitors, and even the architects. Fig. 4 (c) shows the movement of the shadow of the

golden gargoyle to the left, where the afternoon prayer is. Figure 4 (d) shows the azimuth time on the day of the summer solstice when the shade of the sundial falls on the wall of the Iwan and then descends to the floor of the Iwan, as in Fig. 4 (e). The researcher used the camera column of the shrine flags with the imaging team to make sure that the sun's rays fell on the sundial and descended to the floor of the Iwan during the summer solstice, which is on June 20 and 21 in 2017, when the Earth's rotation is at an angle of about 23.4 degrees around the sun.

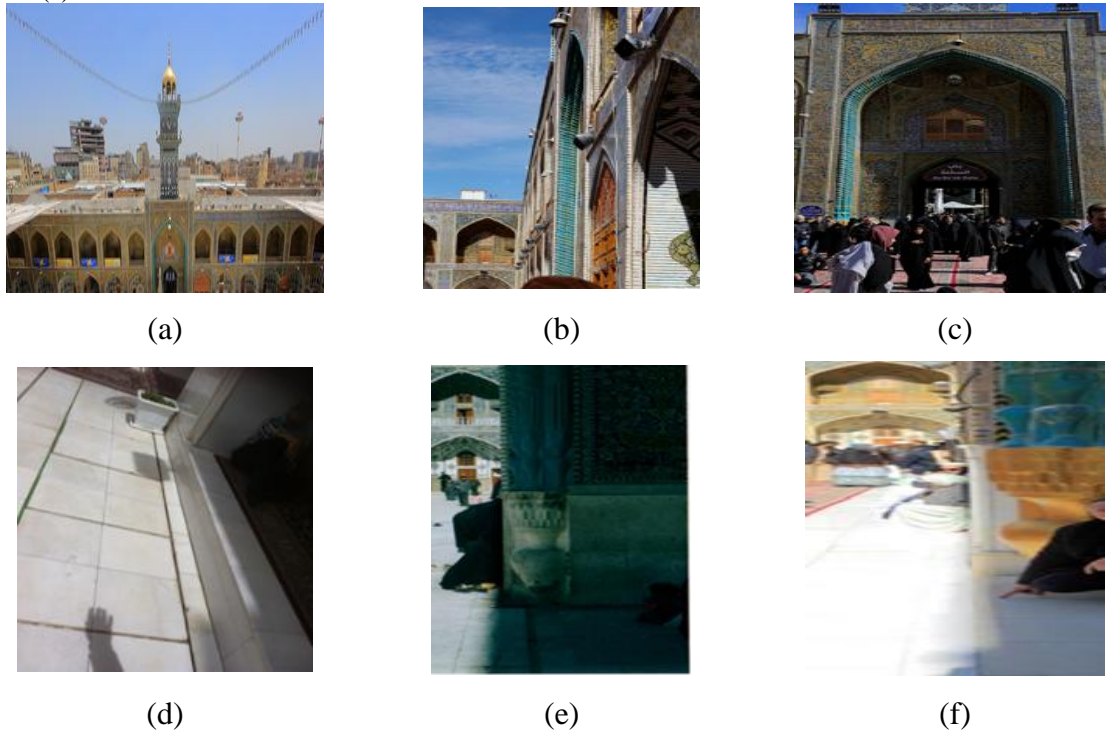


Figure 3. The Eastern sundial; (a) vertical sundial in the door of the clock at its blue plexus; (b) Azimuth time when sunlight rises over the blue plexus; (c) after azimuth when sunlight covers the entire blue plexus on both sides; (d) horizontal sundial in the shadow of the Iwan ceilings on the left side of the clock door; (e) horizontal sundial in the shadow of the Iwan ceilings on the left side of the clock door; (f) Horizontal sundial in the shadow of the Iwan ceilings on the left side of the clock door (In these figures (a, b, c) they show the location of the sundial on the wall of the eastern side of the interior of the courtyard at noon, when the time for the noon prayer comes, and the right part of the blue braid becomes illuminated (b). As for the afternoon prayer, it occurs when the left part of the blue braid becomes enlightened (c). Shapes (d, e, f) on the same eastern wall, but the time of noon and noon and afternoon prayers is determined when the shadow of the eastern wall falls on the edge of the Iwan's stairs. These are sustainable daily astronomical phenomena. (Photographed by the researcher)

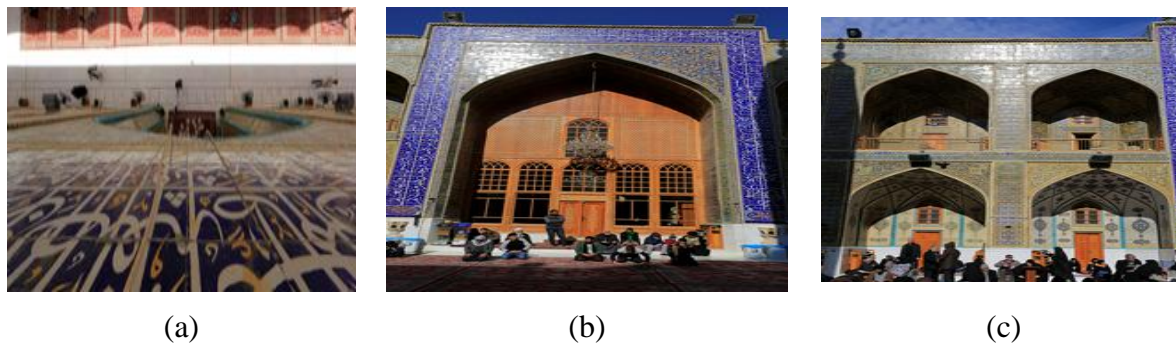


Figure 4. The North sundial at azimuth hour is perfect; (a)(b)(c) vertical & horizontal sundial. Figure (a) horizontal sundial, the shadow of the wall of the shrine on the northern side of the courtyard and opposite the northern wall at noon indicates the time of

the two noon prayers only on the days of the two solstices and equinoxes. In these figures (b, c), a vertical sundial, it is a horizontal sundial, the shadow of the wall of the Iwans on the north side at the two solstices and equinoxes. They show when the time for the noon and afternoon prayers comes, when the shadow of the iwan is at the middle of all iwans. (Photographed by the researcher)

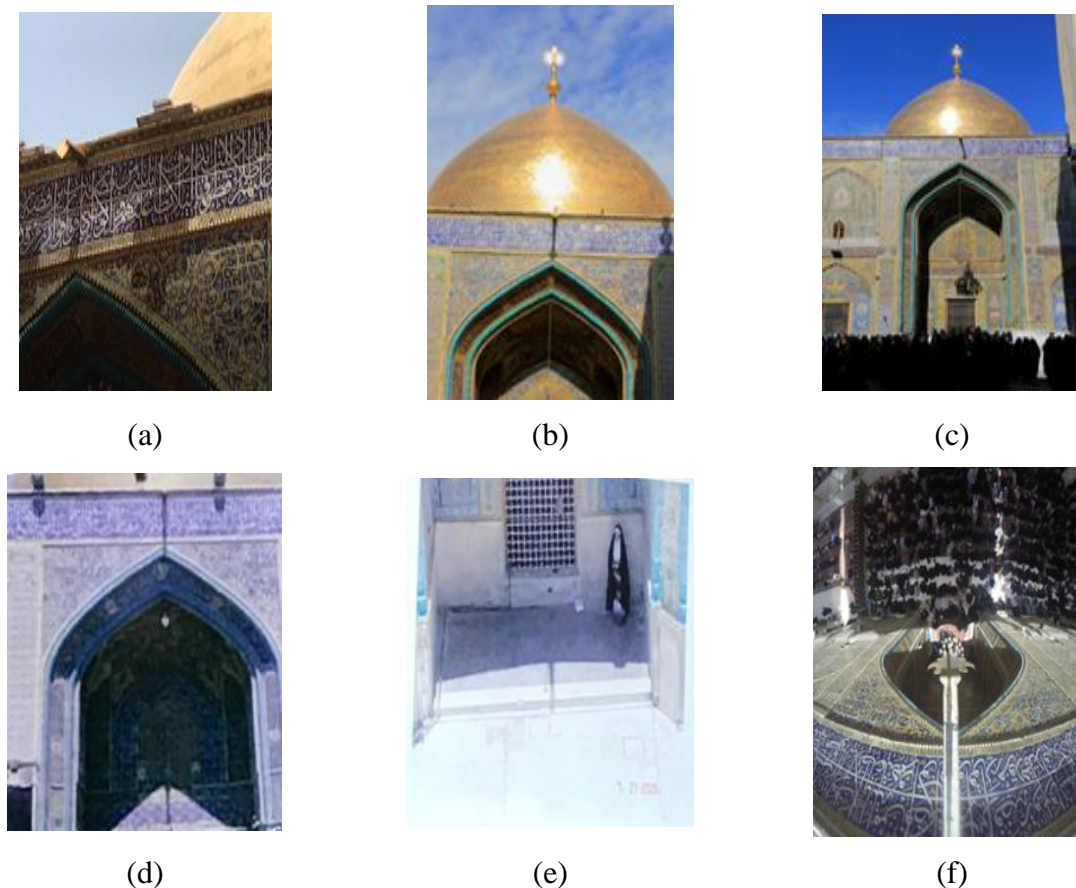


Figure 5. The southern sundial; Figure (a) Vertical sundial, shadow of a gold gargoyles on a pointed arch Before noon; Figure (b) the azimuth hour is perfect, and the shadow of the golden gargoyles is on the pointed arch; Figure (c) The shadow of the gargoyles moves to indicate the afternoon prayer; Figure (d,e,f) exactly the azimuth hour, and the shadow of the golden gargoyles on the point of the arch;(d,e,f) The phenomenon of the shadow of the gargoyles is only in this case on the summer solstice, when the shadow of the gargoyles reaches the floor of the iwan, and it is a unique phenomenon in the architecture of the shrine of Imam Ali (PBUH)). (Photographed (a, b, c,f)by the researcher) Photographed (d,e) by Shyek Fares Semssim)

3. Results and Discussion

Table 1 shows the results of examining the types of sundials, their type of work, horizontal, vertical, or joint, and the value achieved from their purpose.

Fig. 1 shows that the result of examining the sundials is present in previous civilizations, in its simple or primitive form, in which there are arcs and degrees related to the equinoxes and solstices, in addition to the hours of the day.

Fig.2 shows that the sundial took on an important character in the lives of Muslims as it is an indicator of daily devotional practices. There were several innovations in their designs, horizontal or vertical, or both, and in different cities for the same purpose, in addition to the type of sundial, whether horizontal or vertical.

Fig. 3 confirms that the result of the sundials found in the building of the shrine of Imam Ali (peace be upon him),

specifically in the eastern wall from the inside, is two sundials. The other is the astray when it reaches the level of the Iwan by four fingers, as shown in Fig. 3 (d), (e), and (f). These two sundials operate daily and all year round because the construction of the shrine is an astronomical observatory.

Fig. 4 shows that the result of the sundial of the northern side, in particular, is in the days of the two solstices and the two equinoxes.

Fig. 5 shows that the result of the sundial of the gold gargoyles is daily before the azimuth hour, at the azimuth hour, and after the azimuth hour. As for Fig. 5 (d) and Fig. 5 (e), they show that the result of the examination is the phenomenon of the fall of the sundial during the summer solstice only every year on the wall and floor of the Iwan, which is a rare streak that occurs on two days a year. With a lens. As for the research, it was examined from the top of the shrine surface, and the camera holder was used with a long crowbar and was placed on the top

of the gargoyle, so the holder and the camera fell on the same gargoyle in a straight and identical manner as in Fig. 5 (e), with the lens of the shrine, the media department. The result of the examination confirms that these Fig. 5 (a) - Fig. 5 (c) are a sundial that works every day and all year round. Fig. 5 (b) - Fig. 5 (f) are also daily sundials. Fig. 4 (a) - Fig. 4 (c) only occurs on the days of the solstices and equinoxes of each year. It is a unique phenomenon in this part of the architecture of the Holy Shrine, and the present study has documented these phenomena from astronomical sundials, specifically in an applied and scientific manner for the first time. The result of the examination by astronomical and mathematical laws and the use of the Excel program confirmed the correctness of the work of the sundial of the gold gargoyle, specifically, as an example of the other five sundials. It confirms the seriousness and quality of research on the level of astronomical architecture in general and the architecture of the shrine of Imam Ali (peace be upon him) in particular, which remained a puzzling mystery until the present study was conducted.

The present study used reference to astronomical sources using the equations as follows [39,] [40]: taking into account the lines of longitude and latitude and the times of sunrise, noon, and sunset, and from them the shadow occurring at the time of noon was accurately determined using the Excel program, and from it the figures. 6-14 were extracted, which illustrate the accuracy of the astronomical phenomenon in the shrine’s architecture.

$$time (hour) = 3 - 19 \tag{1}$$

$$hour\ angle\ w = (A18 - 12) \times 15 \tag{2}$$

$$Linda\ angle = 32.02654167 \tag{3}$$

$$Latitude\ for\ imam\ Ali\ Holy\ place = 32.0265416667 \tag{4}$$

$$alpha\ solar\ angle\ at\ time = ASIN(SIN(C18 * 3.14/180) * SIN(D18 *)) \tag{5}$$

These laws show the extraction

$$time = ASIN \left(\sin \left(C2 * \frac{3.14}{180} \right) \times \sin \left(D2 * \frac{3.14}{180} \right) + \cos \left(C2 * \frac{3.14}{180} \right) \times \cos \left(B2 * \frac{3.14}{180} \right) \right) \tag{6}$$

$$Azimuth = A \cos \left(\sin \left(C18 \times \frac{3.14}{180} \right) \times \cos(D18) \right) \tag{7}$$

$$Azimuth\ correction = IF(18 < 0; F18; 360 - F18) \tag{8}$$

$$= 1.1 \times \frac{\sin((98 - E2) \times \frac{3.14}{180})}{\sin(E2(3.14/180))}$$

$$Shadow\ of\ gold\ gargoyle = 1.1 \times \sin \left(\frac{(98 - E18) \times 3.14 / 180}{\sin \left(\frac{180}{180} \right)} \right) \tag{7}$$

$$op = on + np\ length\ of\ shadow = -0.36838162 \tag{8}$$

The Sun's declination angle is $\delta = -23.5^\circ$ on the winter solstice.

The Sun declination angle has the measurement: $\delta = 0^\circ$ on the days of the vernal and the autumnal equinox [41]:

$$\alpha = 90^\circ - (\phi - \delta)$$

$$The\ sunrise\ equation = \cos \omega = -\tan(\phi) \tan(\delta)$$

The results of the figures after using the Excel program show clear results for all figures. Figs. 1 and 2 show the hourly angle indicators. Figs. 3 and 4 are related to the equinoxes and the solstices, and the length of the shade of the sundial. It appears that the length of the shadow is clear. As for Figs. 7 and 8 show the length of the shadow on the summer solstice in the azimuth hour of 5/21 of each year, with the time clock and the hourly angle with the azimuth hour. The gargoyle on the summer solstice and the proportional relationship with the time clock and the hourly angle. Fig. 9 illustrates the relationship between the time clock and the lag of the gutter, as shown in Fig. 5 (b). As a final result, these sundials, about which not much is known, will serve as a global guide and tourist guide, in addition to their devotional function, as their creator wanted them to be for the entire population of the fabric adjacent to the architecture of the holy shrine of Imam Ali (PBUH).

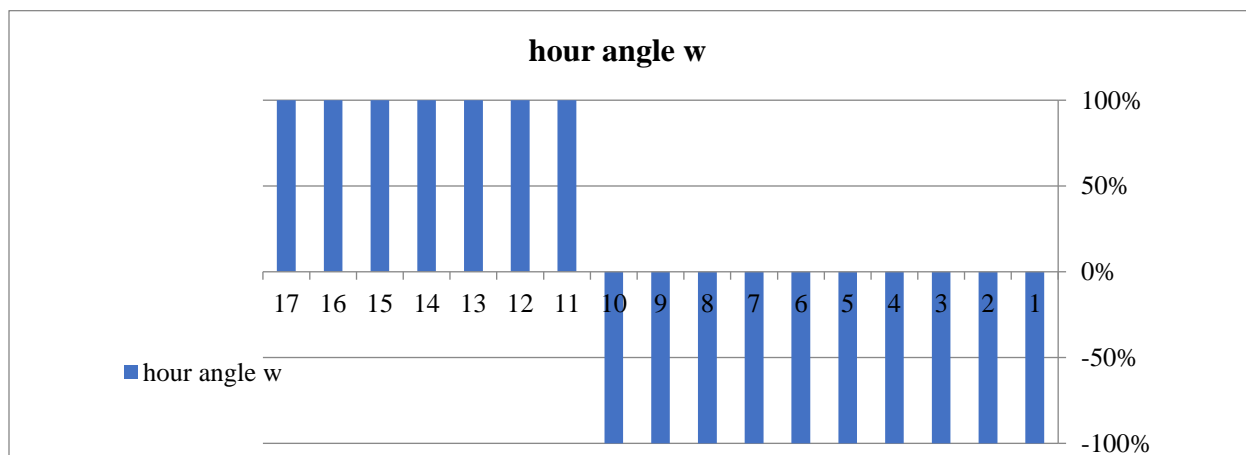


Figure 6. Hour angle diagram

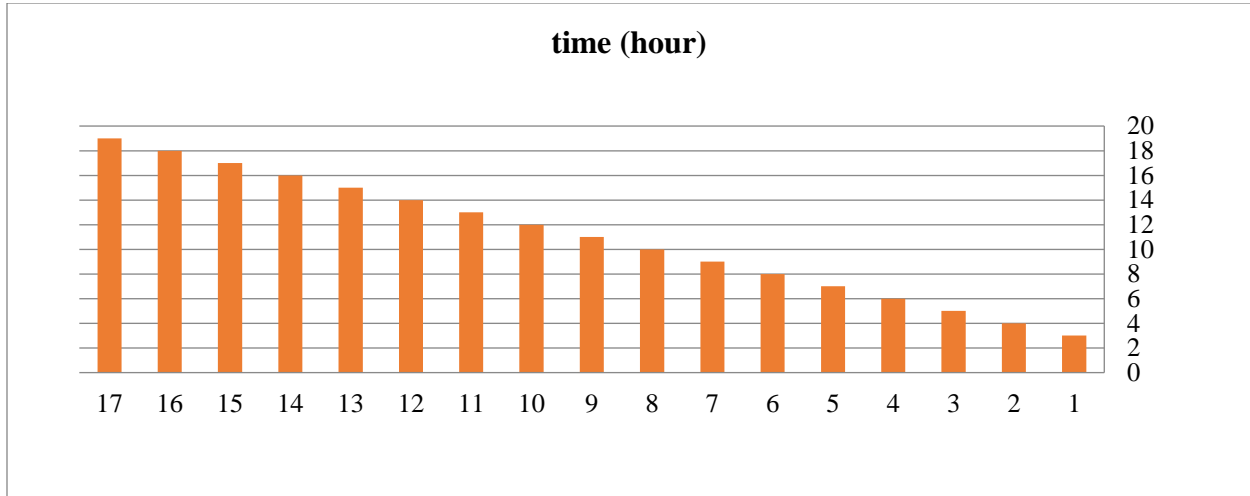


Figure 7. Sunrise to sunset hour diagram

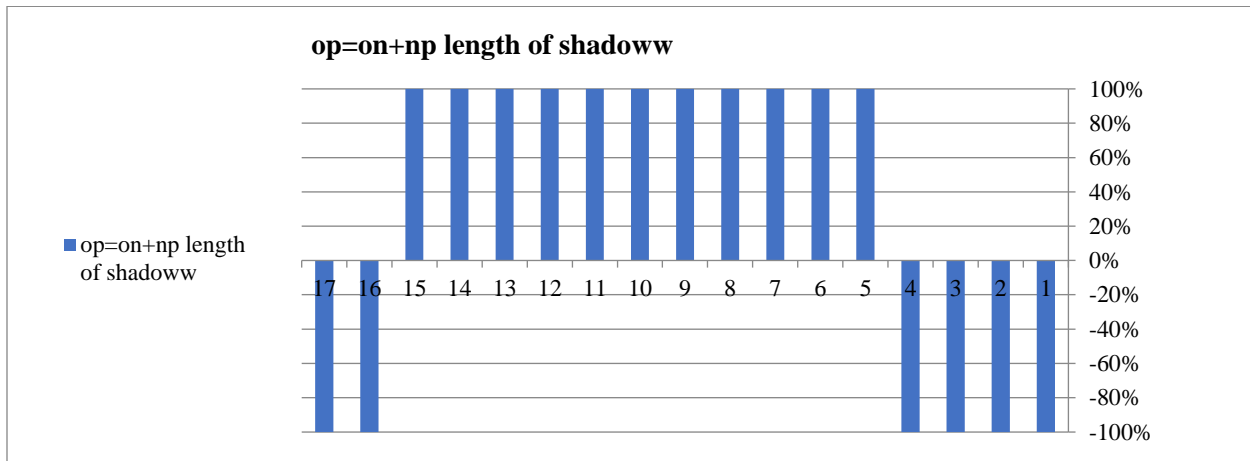


Figure 8. Diagram of the length of the shadow from the Gargoyles

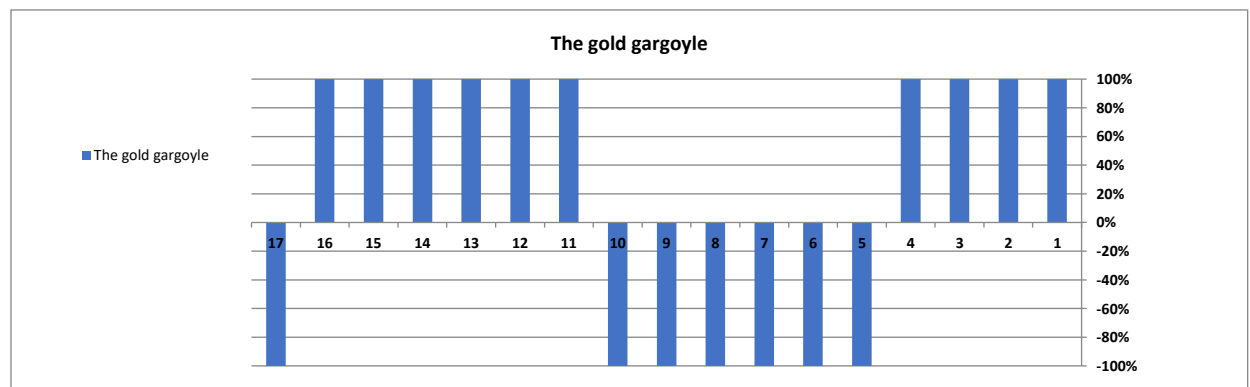


Figure 9. Gargoyles shadow diagram

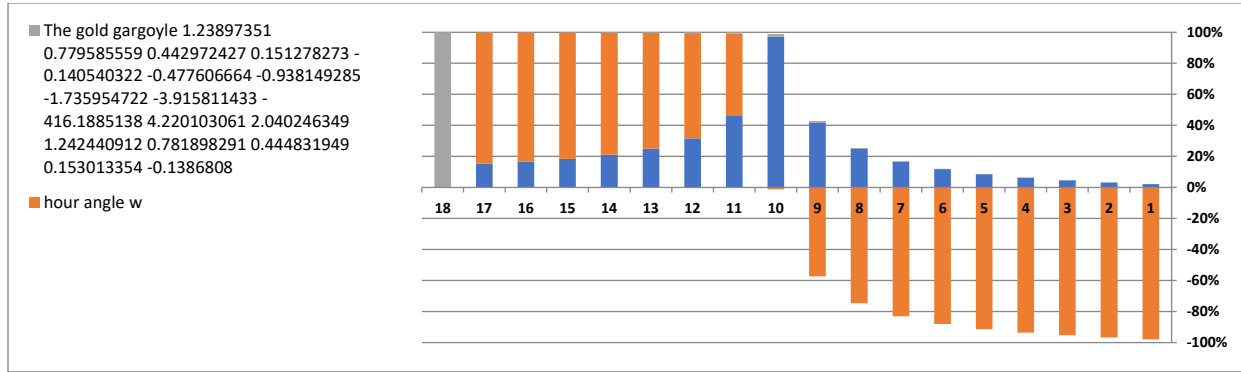


Figure 10. This diagram shows the relationship of the gold gargoyle with the hours of the day and the hourly angle

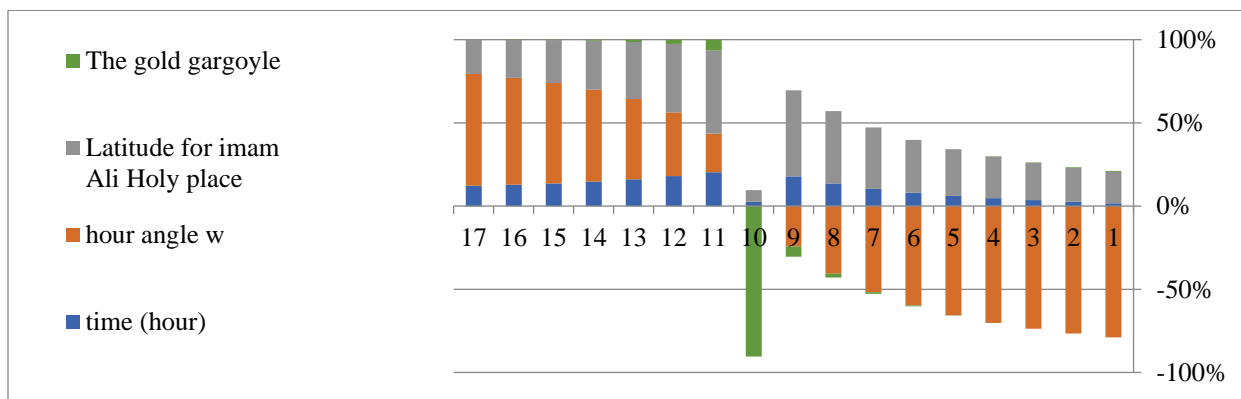


Figure 11. Al Attba Al-Aleweya, the golden gargoyle shadow in the figure Golden gargoyle shadow diagram with hour angle and latitude with daylight time for the diagram is brown, which indicates the correctness of the data

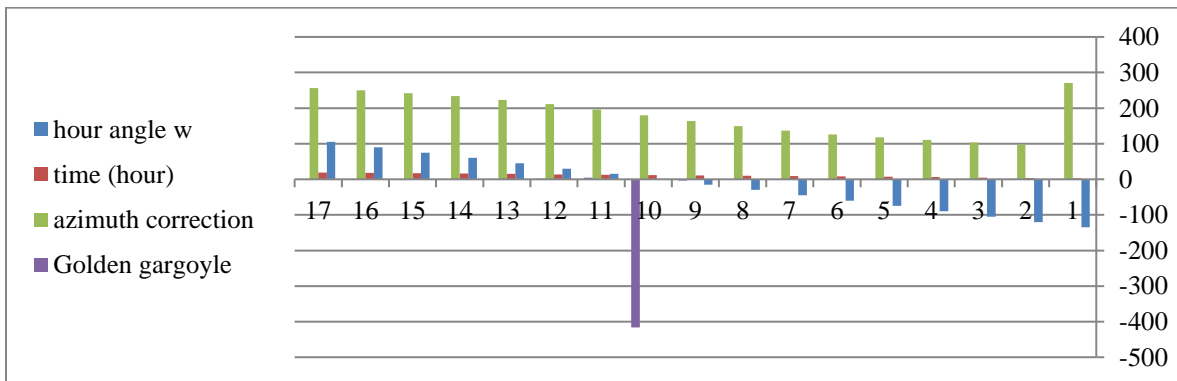


Figure 12. This diagram shows the relationship of the daylight hours with the hourly angle, the azimuth time, and the shade of the gargoyle achieved

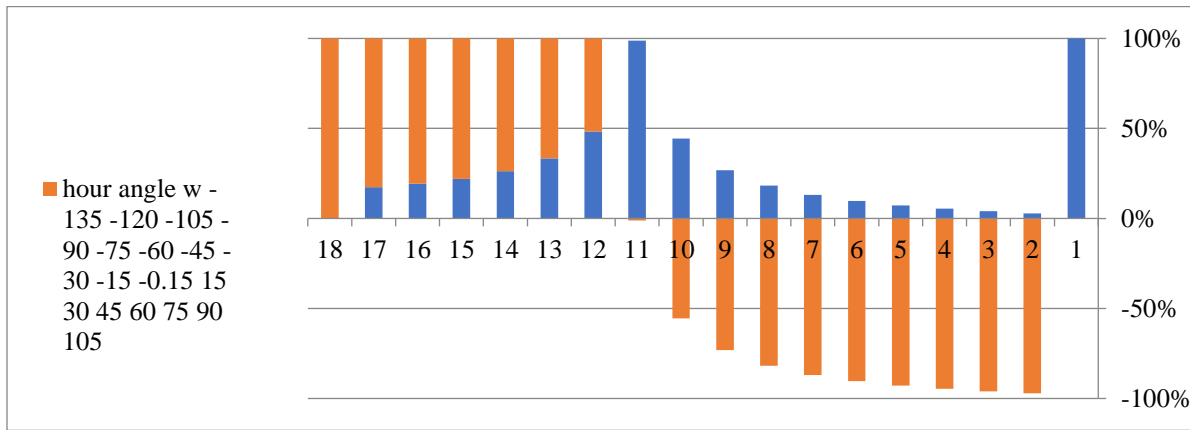


Figure 13. In this diagram, the relationship of the hour angle with the hours of the day is shown

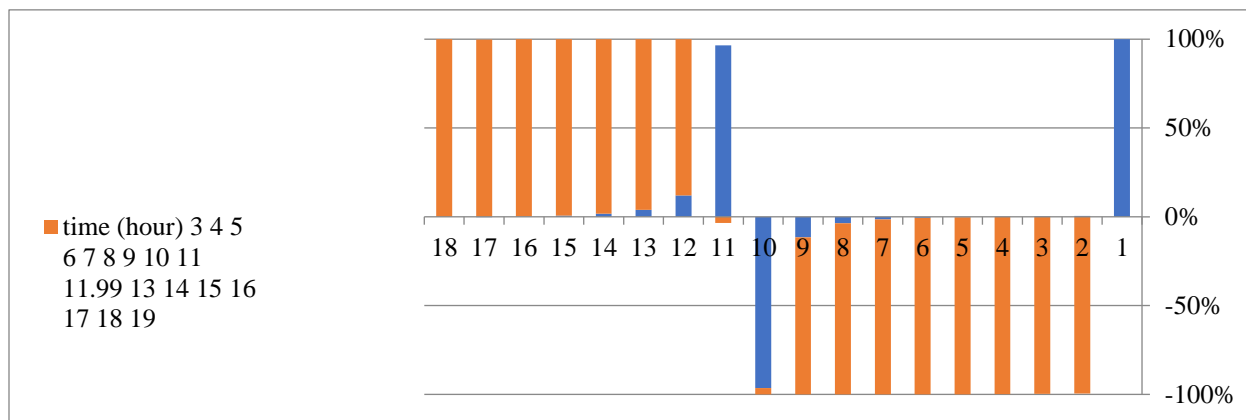


Figure 14. In this diagram, it is shown that the shadow of the gold gargoyle is the longest shadow in the time before the meridian and after the meridian, and at the time of the meridian, it is perpendicular to the pointed arch, which is the shortest shadow

4. Conclusions

This study is a field exploration of the state of the building of the shrine of Imam Ali (peace be upon him) with its various sundials, which confirm the creativity of its designer (1614AD-1023AH), which is approximately (408) years old to the date of 2022AD, which confirms that the sundial is perfect in terms of mathematical and astronomical proficiency calculated with great accuracy, which was confirmed by the present study in terms of observation in kind and taking pictures and the results of the Figures that confirmed the validity of the problem and the objectives of the present study in the mathematical laws. These sundials of the masses and their adjacent fabric store a symbolic state of veneration of the holy shrine of Imam Ali (peace be upon him), in addition to their doctrinal aspect. The survival and operation of these sundials to this day only indicate the importance of the place with the importance of the personality, as the designer exaggerated in giving this block features and symbols that are commensurate with the architecture of the block and its importance in relation to the fabric adjacent to it and the dependence of the entire fabric on it in many respects as it is the city’s ideological, religious and social center, which affects the entire population, being the lung and the largest ideological and social outlet for the entire population of the adjacent fabric. The dependence of the city’s

residents on the sundials of this unique block in its horizontal and vertical designs, diverse in its forms, and simplicity gave indicators of sustainability in this aspect in which it was created. The function of these sundials is to improve performance and control time, which is one of the most important matters in the daily devotional life of the entire urban fabric in the city of Najaf. The performance of these sundials on a day or on some of the solstice and equinox days is a clear indication of the sustainability of this innovative technique.

5. Recommendations

The present study revealed the architectural and artistic creativity of the sundials by the designer, which remained an interesting question for some who wrote about it in brief lines and others who were curious to know but were unable to solve the scientific puzzle. The present study could identify the nature of this riddle and the detection of the mathematical, astronomical cause that clarified the correctness of the work of these sundials. Therefore, the present study recommends the following:

1. Continuing scientific interest in the rest of the parts of the ambiguities present in the architectural block in the

building of the shrine of Imam Ali (peace be upon him) in Najaf, and conducting a careful survey of them leads to revealing the knowledge gap and ambiguity.

2. Carrying out scientific interest calls for a review of all the designs and creations of Sheikh Al-Baha'i and uncovering the mystery that still exists.
3. Directing designers and researchers to benefit from these technical innovations and benefit from them in an environmentally sustainable architecture.
4. Developing virtual simulation programs for students of architecture to demonstrate the ability of our scientists who preceded us in design knowledge and astronomical engineering creativity within architecture and its fabric.
5. Directing the competent media authority in the building of the shrine of Imam Ali (peace be upon him) to the importance of these sundials and benefiting from them in a realistic and sustainable archaeological way through publications.
6. Introducing official delegations and visitors to the reality of the work of these sundials with an indicative file and working to urge visitors who are interested in the astronomical situation, especially during the days of the coups and equinoxes, to visit the holy city of Najaf and learn about these astronomical phenomena in the building of the shrine of Imam Ali (peace be upon him) that is a unique model of its kind in all the world.
7. Directing media to convey the facts of the days of the two solstice and equinoxes and the rest of the work of the sundials and to show them the correctness of their current, accurate work and their application with the modern prayer times that are in force on a daily basis that leads to the greatness of the work of this sustainable technology in this particular architecture.

Conflict of interest

The author declares that there is no conflict of interest, either scientific or financial involvement.

Author Contribution Statements

Mahmood Rezoooky Janjun proposed the research problem, verified the analytical methods, and investigated and supervised the findings of this work.

Neda Abdameer Mubarak developed the theory and performed the computations.

Rawaa Abd Munaf Al-Shlah discussed the results and contributed to the final manuscript.

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