From Persepolis to Ctesiphon: Investigating Continuity in Ancient Iranian Architecture Through the Arch of Ctesiphon

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Abstract: The Arch of Ctesiphon (Taq-e Kasra), situated in present-day Iraq, stands as an iconic testament to Sasanian architectural ingenuity, exemplifying a remarkable continuity of Persian building traditions. Previous studies have mainly focused on symbolic or stylistic interpretations; however, this study employs a rigorous technical and historical approach to re-examine the geometric principles and construction methodologies underpinning the arch. Through digital reconstructions based on field measurements, the analysis reveals that the vault closely adheres to a catenary curve celebrated for its structural efficiency and incorporates golden ratios and pentagonal symmetries into its design. Notably, the arch's dimensions consistently correspond with those used in the Achaemenid Arash, underscoring the continuity of a modular planning system that originated in Persepolitan architectural practices. Additional evidence, including standardised brick dimensions and vestiges of timber reinforcement techniques, further substantiates the idea of a deliberate transmission of technical expertise. These discoveries inform a proposed reconstruction model of the vault's geometry, explicitly anchored in Achaemenid measurement systems and architectural terminology. Beyond its engineering sophistication, as demonstrated in this study, Taq-e Kasra serves as a vehicle of dynastic symbolism. A comparative analysis of other Sasanian architectural projects reveals that the deliberate fusion of Achaemenid motifs with mathematically derived proportions and traditional construction methods represents not mere imitation but a sophisticated reinterpretation. Consequently, rather than indicating a historical rupture, the monument exemplifies a conscious revival and nuanced adaptation of indigenous architectural traditions within the broader framework of Sasanian imperial ideology embodying an enduring synthesis of symbolic continuity, structural mastery, and cultural identity throughout Iranian architectural history.

Keywords

Taq-e Kasra; Sasanian Engineering; Catenary Geometry; Continuity in Persian Architecture; Achaemenid Metrology

1. Introduction

The architectural traditions of ancient Iran evolved through a complex interplay of regional practices, material innovations, and imperial ambitions, resulting in a corpus of built works that reflect both continuity and transformation across historical periods. Among the most architecturally significant periods in this continuum are the Achaemenid (550–330 BCE) and Sasanian (224–651 CE) empires, whose architectural legacies are two of the most influential moments in pre-Islamic Iranian history. While both empires employed architecture as a primary medium for articulating political authority and cultural identity, their respective architectural vocabularies reveal both striking continuities and meaningful divergences.

Achaemenid architecture is recognised as one of the most refined and symbolically charged expressions of imperial design in the ancient Near East. Characterised by its monumental scale, axial regularity, and cosmopolitan synthesis, it embodies the centralised authority of the Achaemenid state and its ideological pursuit of unity through diversity. The imperial complexes at Persepolis, Susa, and Pasargadae exemplify this ethos by integrating architectural elements from across the empire into a coherent visual and spatial language. Hallmarks of Achaemenid architecture include elevated platforms, orthogonal layouts, monumental columned halls (Apadanas), and intricately carved stone reliefs. At sites such as Dahaneh-e Gholaman, however, Achaemenid builders demonstrated an equally sophisticated responsiveness to local conditions, employing mudbrick construction including curved forms well-suited to the arid climate of southeastern Iran. Technologically, their architecture exhibited advanced practices: precise ashlar masonry, the widespread use of metal dowels, modular spatial planning, and aseismic construction methods. Underpinning these techniques was a consistent use of proportional systems and harmonic ratios, which indicated a design philosophy aligning structural rationality with metaphysical ideals. In this way, Achaemenid architecture functioned as a vehicle for expressing both cosmic order and imperial ideology. Even after the fall of the empire, its architectural influence persisted, shaping later developments in Asia Minor, the Hellenic world, the Caucasus, and even reaching into China (Wachtsmuth 1977: 309-320; Veisi et al. 2013: 196; Davtalab 2021: 29; Motamedmanesh 2022: 303-312; Motamedmanesh 2025: 22-23).

In contrast to the orthogonal order and relatively restrained planning of Achaemenid palaces, Sasanian royal architecture signalled a decisive shift toward spatial enclosure and structural dynamism, aimed at cultivating architecturally sophisticated interiors. While monumentality remained a common goal, the Sasanians achieved it through volumetric massing, centralised layouts, and an expressive use of curved geometries. Their architectural style featured large-scale barrel vaults, domes, and iwans elements that fostered interior cohesion and enhanced the theatricality of spatial progression. Constructed predominantly with fired or unfired brick and mortar (i.e. plaster, *saruj*, or gypsum-sand compositions), these methods allowed for both rapid construction and formal complexity, while supporting intricate stucco ornamentation. Although less common, some edifices were constructed entirely of stone, either finely cut or roughly hewn, and then plastered. Departing from the hypostyle schemes of their predecessors, Sasanian architects favoured centralised or axial configurations, typically organised around a domed core or vaulted hall. These arrangements emphasised spatial hierarchy, processional movement, and enclosure, marking both a technical advancement and a fundamental reimagining of architectural space (Reuther 1977: 498-518; Mazhari Motlagh 2010: 42-46).

Despite these differences in material palette, structural strategy, and spatial organisation, both empires share underlying continuities that suggest a persistent architectural logic across centuries. These include a commitment to monumentality, the adoption of advanced techniques, symbolic abstraction, and precise geometric reasoning. Both traditions employed proportional systems to articulate spatial harmony and encode metaphysical meaning. Moreover, their use of architecture as a medium of imperial ideology indicates a shared understanding of architecture as a political and symbolic instrument.

It is within this historical and formal context that the Sasanian Empire especially its architectural output warrants reexamination. As the last major pre-Islamic dynasty in Iran, the Sasanians presided over a vast and culturally diverse territory stretching from the Roman frontiers in the west to Central Asian heartlands in the east. Their extensive architectural heritage encompassing palatial complexes, fire temples, fortifications, and infrastructure projects exemplifies a sophisticated synthesis of innovation, regional traditions, and historical consciousness, reflecting both advanced engineering proficiency and the symbolism inherent in dynastic narratives (Mousavi and Daryaee 2012: 1076; Mazhari Motlagh 2010: 43–44).

A central, yet unresolved, question in Iranian historiography pertains to the extent to which the Sasanians consciously engaged with and drew inspiration from the architectural legacy of the earlier Achaemenid Empire. Scholarly discourses on this issue have traditionally coalesced around two contrasting frameworks. The first, largely informed by classical and post-Hellenistic historiographical traditions, suggests a significant rupture between Achaemenid and Sasanian building practices, attributing observed similarities primarily to geographic proximity or the use of common materials, rather than a deliberate historical awareness. This viewpoint underscores the mediating role of the intervening Parthian period characterised by Hellenistic cultural influences and decentralised political structures as an impediment to direct architectural and cultural continuity. In contrast, the second interpretative framework supports the notion that the Sasanians consciously revived and strategically appropriated Achaemenid architectural forms. Proponents of this view argue that such deliberate referencing was integral to an imperial ideology aimed at asserting dynastic legitimacy and cultural supremacy through explicit historical association. While both perspectives offer invaluable insights, they have primarily relied on textual exegesis, iconographic comparisons, and formal typologies. Consequently, the technical, structural, and geometric aspects of Sasanian architecture elements directly related to processes of design, construction, and embodied knowledge have remained comparatively underexamined. It is precisely this lacuna that the present study seeks to address. By adopting a technical and material-based perspective, it re-examines the question of continuity versus rupture in the longue durée of Iranian architectural history.

Employing an interdisciplinary methodology that integrates architectural engineering, structural morphology, historical analysis, and archaeological evidence, this research focuses on the Taq-e Kasra (Arch of Ctesiphon). This structure is the most iconic extant monument of the Sasanian era and boasts the largest known unreinforced brick vault of antiquity. Rather than interpreting the structure primarily as a symbolic artefact or formal typology, this study approaches the Taq-e Kasra as a materially inscribed document one that encodes technical expertise, geometric reasoning, and layers of cultural memory. By closely analysing its structural proportions, vaulting techniques, material logic, and compositional geometry, the research investigates whether the monument reveals an embedded continuity of Achaemenid architectural knowledge, particularly in its measurement systems and harmonic design principles.

The central hypothesis advanced here is that architectural continuity on the Iranian plateau was not confined to the realm of stylistic citation or political allegory. Instead, it was materially embedded in the epistemologies of building evident in the proportional logics, construction methods, and geometric frameworks employed by master masons. If the Sasanians inherited a body of technical knowledge traceable to the Achaemenids, such transmission should be legible in the empirical features of their most ambitious structures. By leveraging interdisciplinary approaches, this research seeks to shed light on the often-overlooked yet profoundly revealing dimension of architectural continuity: the structural and mathematical intelligence inscribed in built forms.

This investigation thus contributes not only to the historiography of Iranian architecture but also to broader discourses in architectural theory and cultural memory. It invites a reconsideration of how empires construct their pasts, not solely through texts or images but through the enduring language of geometry, material, and space. In so doing, it positions the Taq-e Kasra as more than just a technical marvel; it becomes a palimpsest of architectural lineage where inherited knowledge of building and ideological aspirations converge in a single monumental expression.

2. Literature Review

The extent to which the Sasanians consciously engaged with their Achaemenid heritage remains a central debate in the historiography of ancient Iranian architecture. Scholars have generally approached this question through two opposing frameworks.

One school of thought maintains that a fundamental rupture separates the Achaemenid and Sasanian periods. Among the earliest advocates of this position was Ernst Herzfeld, who argued that Sasanian art and architecture were predominantly influenced by Hellenistic models from the West, exhibiting minimal continuity with native Achaemenid forms (Herzfeld 1935: 44–45). Ehsan Yarshater similarly emphasised a near-total erasure of Achaemenid cultural memory during the long interregnum of

Parthian rule (1971: 525–531). Michael Roaf later reinforced this thesis, expanding Herzfeld's initial claims into a more comprehensive archaeological narrative of rupture (1998: 1–7). Within a more ideological and textual framework, Rahim Shayegan reached comparable conclusions. He argued that during the *Arsacid and Sasanian Dynasties*, the Sasanians did not consciously see themselves as successors to the Achaemenid legacy. Rather, he attributed any apparent continuities to retrospective projections imposed by Greek and Roman historiography. Drawing on a broad spectrum of sources including Sasanian royal inscriptions, Greco-Roman accounts, and evidence from the Parthian period—Shayegan asserted that any semblance of Achaemenid awareness in later periods was filtered through Mesopotamian cultural traditions rather than constituting a direct lineage of historical memory (Shayegan 2011).

In contrast, a second body of scholarship contends that the Sasanians maintained a conscious and meaningful relationship with their Achaemenid past. Alireza Shapour Shahbazi argued that the Sasanians were not only aware of the Achaemenid Empire's achievements but also sought to appropriate that legacy, even if such awareness diminished over time (2001: 61–73). Building on this premise, Touraj Daryaee linked Sasanian genealogical narratives to the Kianid lineage, which was allegedly shared with the Achaemenids, as a way to establish dynastic legitimacy (2001: 11–12). This interpretation is further supported by archaeological evidence: Mousavi and Daryaee (2012: 78–79) highlighted the Sasanians' selection of Estakhr located near Persepolis as a royal centre, suggesting a strategic effort to invoke Achaemenid associations. Their commissioning of rock reliefs and inscriptions at Naqsh-e Rustam, directly beneath the tombs of Achaemenid kings, further reinforces the case for deliberate symbolic continuity. Expanding on these ideas, Matthew Canepa introduced the concept of a “technology of memory,” proposing that Sasanian rulers intentionally reactivated Achaemenid monuments (Fig. 1) as tools of dynastic legitimisation (2010: 590).

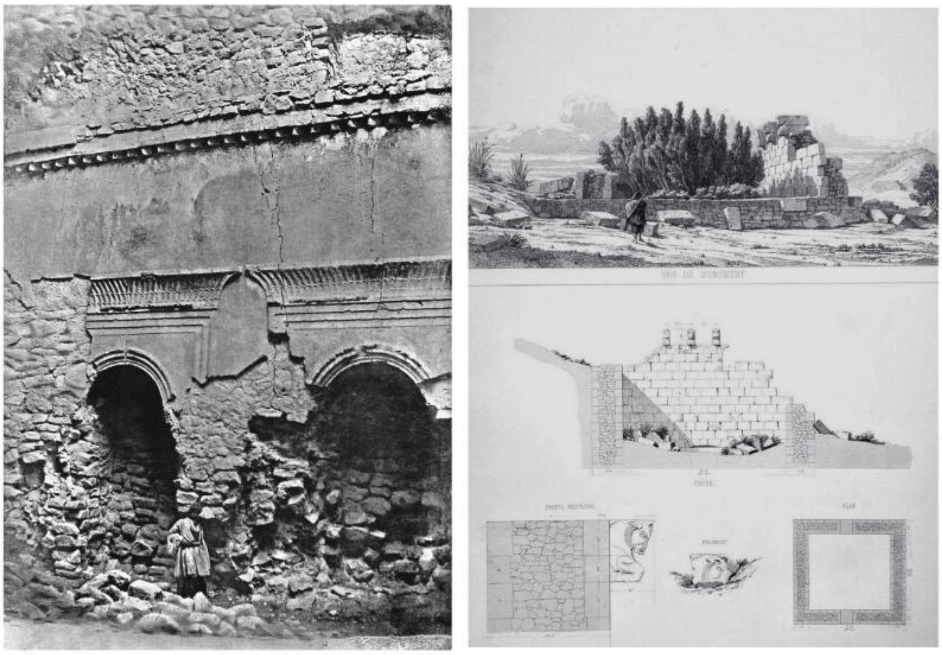

Figure 1: Right: The palace at Bishapur, featuring animal-shaped capitals similar to those found at Persepolis. Source*:* (After: Flandin and Coste 1851, tome 1: Plate 47). **Left:** The palace at Firuzabad, demonstrating the imitation of Persepolitan stone lintel inscriptions through the use of plaster and the incorporation of arches. Source*:* (After: Dieulafoy 1884, Pl. XV).

While the historiographical debate sheds light on important aspects of Iran’s cultural history, its inherently discursive nature limits the potential for analytical assessments based on measurable data derived from primary architectural evidence especially monumental structures. In fact, hypotheses concerning Sasanian awareness of Achaemenid architectural traditions cannot be sufficiently validated through textual sources or formal similarities alone; they require examination of empirical evidence preserved in historic buildings.

Among the notable monuments of the Sasanian Empire, Taq-e Kasra emerges prominently, distinguished not only as the most iconic surviving Sasanian structure but also as the largest unreinforced brick arch ever constructed. As with other monumental structures, its remarkable engineering sophistication underscores the Sasanian Empire's advanced capabilities in material management, construction techniques, geometric precision, and the coordination of large-scale labour forces (Trigger 1990). Thus, a rigorous analytical study of the structural and geometric logic embodied within Taq-e Kasra not only significantly advances our comprehension of Sasanian construction practices but also provides a critical analytical lens for evaluating deeper patterns of continuity and discontinuity within the broader architectural traditions of ancient Iran.

The historical engagement with Taq-e Kasra spans centuries. Medieval Arab observers and Byzantine chroniclers documented the arch extensively, and by the late 18th century, it had drawn significant interest from European Orientalists (Keall 1987: 155–159; Lacoste 1954: 6–9). Among the earliest and most detailed Western renderings of Taq-e Kasra are the mid-19th-century drawings by Eugène Flandin and Pascal Coste, published in their landmark study of Iranian monuments. While their illustrations surpassed earlier accounts in accuracy and detail (Motamedmanesh 2016: 12–13), their depiction of the arch's profile (Flandin and Coste 1851, tome 4: Plate 218) still deviated noticeably from its actual proportions (Fig. 2-1).

Subsequent attempts to reconstruct the arch's form often relied on speculative or culturally eclectic geometric models. Marcel Dieulafoy, for example, attributed its shape to a synthesis of Pythagorean triangles and Byzantine masonry principles (Dieulafoy 1884, vol. 4: 22; Fig. 2-3), although his theory does not withstand comparison with modern survey data. An early 20th-century expedition led by Ernst Herzfeld and Friedrich Sarre yielded invaluable documentation but also resulted in a geometric reconstruction that significantly deviates from the actual curvature (Sarre and Herzfeld 1911: Tafel XLI; Fig. 2-2). Later, mid-twentieth-century interpretations such as those by

Henry Lacoste proposed geometric models based on the Byzantine *zira*ʿ and triangle-derived centres. Although these reconstructions achieved partial alignment with specific segments of the arch, they ultimately failed to capture the full geometric complexity of the vault, especially at its springing point (Lacoste 1954: 11–13; Cejka 1978: Kap. 2. 49; Fig. 2-4).

Among Iranian scholars, Mohammad Karim Pirniya stands out for his contributions to understanding Iranian vaulting systems. He classified Taq-e Kasra*'s* arch as elliptical and cited the "gardener's method" for its construction (Pirniya 1994: 18; Fig. 2-5). However, contemporary precision surveys have disproven the elliptical hypothesis (c.f. Dahmen and Ochsendorf 2012: 438; Miccoli et al. 2023: 123). Pirniya's interpretation may reflect Islamic-era building practices, where elliptical geometry was more common and better documented. Similarly, Hossein Zomarshidi adopted an elliptical view, offering a detailed but ultimately inaccurate method for its derivation (Zomarshidi 2008: 172; Fig. 2-6). Even Oscar Reuther, in his foundational overview of Sasanian architecture, ambiguously characterised the arch's form as parabolic (Reuther 1977: 500), further illustrating the persistent uncertainty surrounding its geometry.

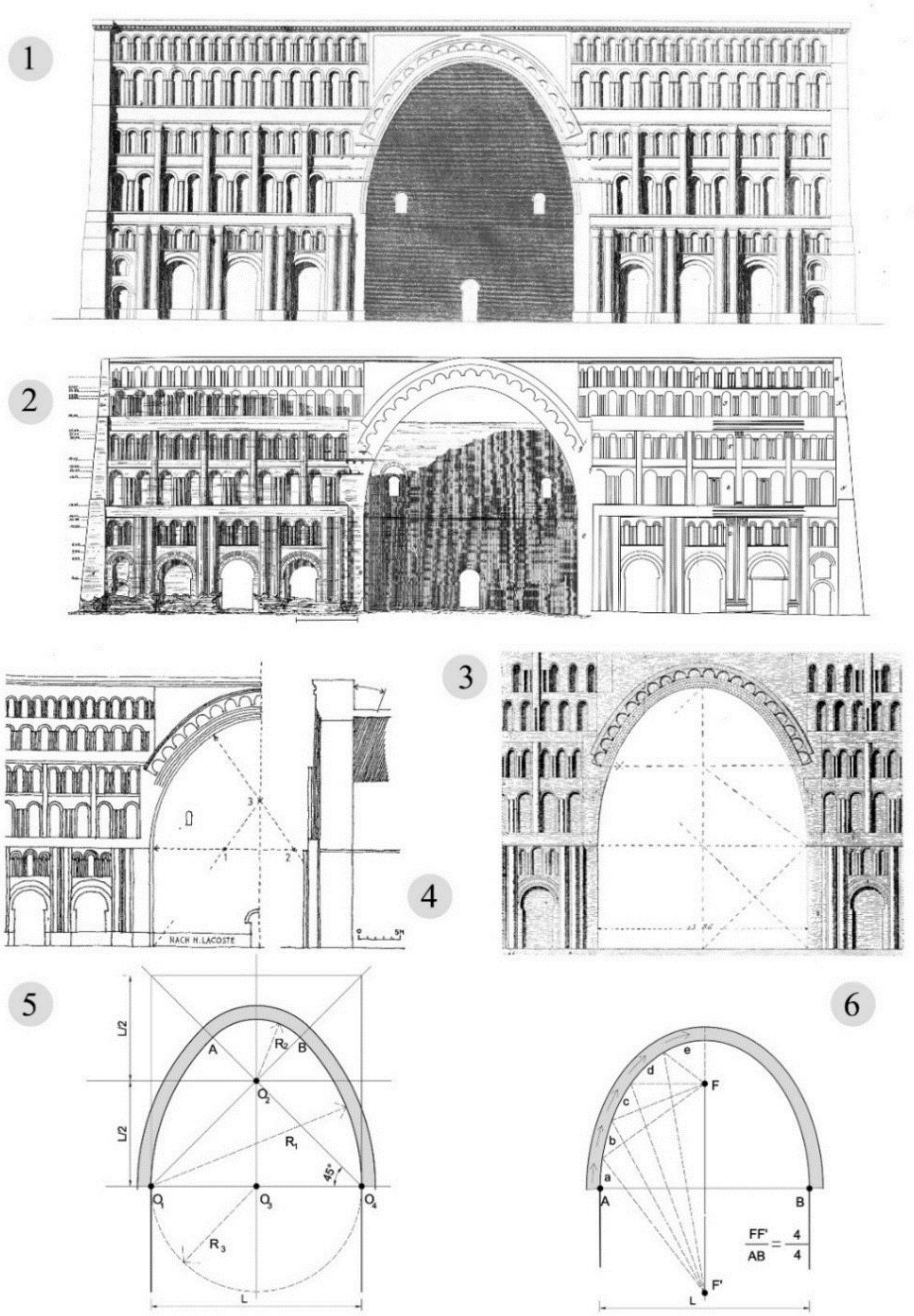

Figure 2. Various renderings of the Taq-e Kasra from the 19th century to the present. Source: (After: Flandin and Coste 1851, tome 4: Plate 218; Dieulafoy 1884, vol. 4: 22; Sarre and Herzfeld 1911: Tafel XLI; Cejka 1978: Kap. 2. 48; Pirniya 1994: 18; Zomarshidi 2008: 172)

The various interpretations of Taq-e Kasra over the past two centuries put forth by both Western explorers and Iranian historians underscore the enduring complexity of decoding the geometric rationale behind monumental structure. Each hypothesis, influenced by specific disciplinary paradigms, cultural contexts, and methodological tools, offers partial insights into the monument's design logic. However, none have fully succeeded in capturing the architectural intentionality and structural precision embedded in its original construction. These accumulated challenges emphasise the need for a rigorous, interdisciplinary reassessment that leverages contemporary digital modelling, geometric analysis, and architectural history to unravel the true mathematical and structural foundations of this emblematic Sasanian edifice.

It is important to note that the various geometric models through which the Taq-e Kasra arch has been interpreted including the ellipse, catenary, and parabola[1] may appear visually similar; however, each is governed by distinct mathematical definitions and exhibits fundamentally different structural behaviour (Fig. 3). In monumental architecture such as Taq-e Kasra, these differences, although subtle in form, carry significant material and structural implications. Precisely identifying the geometry employed in the design is therefore crucial not only for understanding the arch's mechanical performance but also for revealing the intellectual frameworks and construction strategies of its builders. Any reconstruction that fails to replicate the true curvature with accuracy risks misrepresenting both the original design intention and the underlying geometric logic of its construction

[1] **Ellipse**: The set of all points in a plane such that the sum of the distances to two fixed points (foci) is constant. **Catenary**: The curve formed by a uniform, flexible chain or cable hanging under its own weight when supported at its ends and acted on only by gravity. **Parabola:** The curve defined as the set of all points equidistant from a fixed point (focus) and a line (directrix).

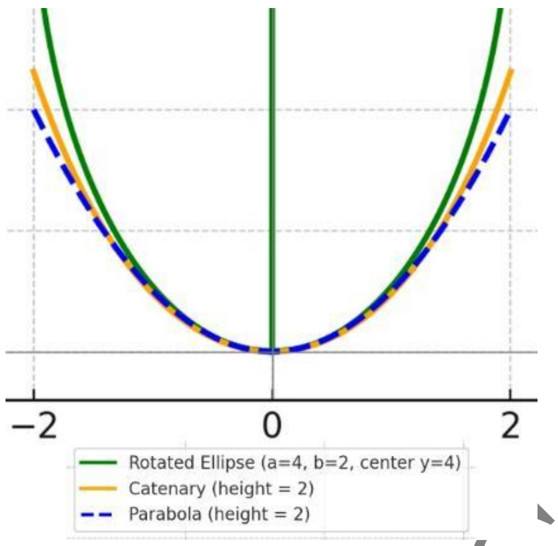

Figure 3: Geometric differences between the catenary (yellow), parabolic (blue), and elliptical (green) curves. Source: Author.

As noted by Reuther (1977: 499), construction techniques themselves play a significant role in shaping the formal outcomes of vaulted structures. Specifically, the employment of sophisticated masonry methods such as diagonal and staggered bricklaying (Fig. 4) can facilitate the realisation of geometrically complex profiles like catenaries and ovals by ensuring both formwork alignment and structural stability (Cejka 1978: Kap. 2. 50). However, attributing the adoption of the catenary form in the Taq-e Kasra solely to technical necessity proves insufficient. A comparative analysis of other monumental structures including Assyrian palatial architecture and early Islamic sites such as Qasr al-Hayr al-Sharqi, Mshatta, and Qasr al-Tuba demonstrates that comparable bricklaying techniques were employed alongside markedly different arch profiles, ranging from semicircular to pointed forms (Arce 2006: 201). This geometric variation in structures constructed using comparable methods challenges the reductionist view that the catenary form emerged solely from constructional pragmatism. Instead, it supports the interpretation that the form of the Taq-e Kasra was the result of a deliberate architectural choice reflecting not only advanced structural knowledge but also a sophisticated mental model of geometry held by Sasanian architects. The selection of the catenary, with its ideal load-bearing characteristics and intrinsic aesthetic harmony, signifies a purposeful engagement with mathematical design principles. Therefore, understanding why and how this specific geometric form was employed necessitates a systematic analytical framework that integrates empirical measurement, historical context, and computational modelling. The present study positions itself within this methodological intersection, aiming to reconstruct the rationale behind one of the most iconic architectural forms of the Sasanian era.

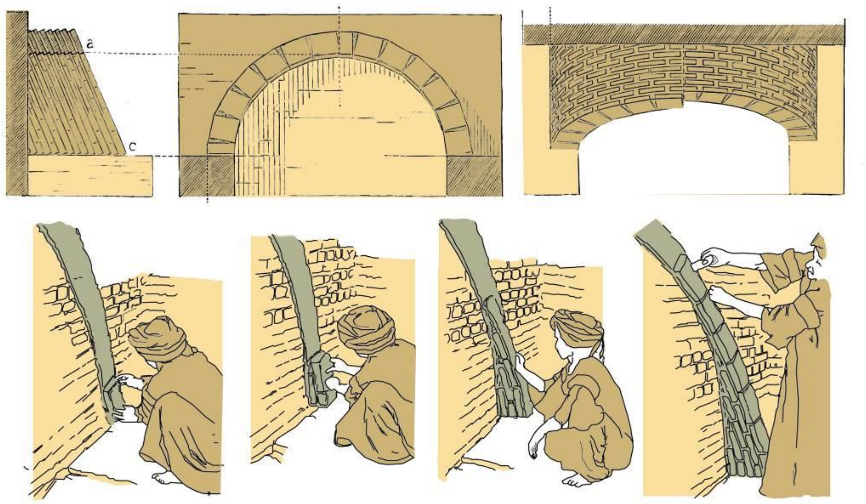

Figure 4: Oblique (diagonal) bricklaying technique. Source: Adapted and redrawn by the author, based on (After: Fathy 2010, Figure 9–16; Besenval 1984, Figure 30, following Choisy 1883).

3. Taq-e Kasra in Light of the Evidence: From Myth to Reality

3.1 Historical Analysis

Ctesiphon, located 35 km south of modern Baghdad, near Salman Pak, served as the winter capital of the Parthian and Sasanian empires. Its most prominent structure, Taq-e Kasra, features a monumental catenary arch that spans 25.5 m, reaches 48 m in depth, and exceeds 35 m in height (Bruno 1966: 99; Dahmen and Ochsendorf 2012: 437;

Madhloom 1978: 127). Italian excavations in the 1960s date its construction to the reign of Khosrow I Anushirvan (531–579 CE).

Taq-e Kasra holds a unique place in both Sasanian architecture and the broader cultural imagination of the Islamic world. Early Islamic historians such as al-Ya'qubi, Ibn al-Faqih, Ibn Khurdadbih, and al-Tabari referenced the monument in their works (Davaran 2010: 59–60). A widely circulated narrative claims that the arch cracked on the night of the Prophet Muhammad's birth, interpreted as a divine omen signalling the fall of the Sasanian Empire. Over time, the monument came to embody the transition from pre-Islamic to Islamic civilisation, symbolising both dynastic collapse and the rise of a new religious and political order.

Beyond these symbolic layers, historical accounts and archaeological findings provide substantial details regarding the monumental scale and opulent interior of the palace (Fig. 5). The central hall reportedly housed the Baharestan a legendary silk carpet embroidered with springtime motifs in precious stones. Byzantine-style glass mosaics illustrated military scenes, including Khosrow's victory at Antioch in 540 CE (Ali 2006: 56; Mousavi and Daryaee 2012: 1081; Reuther 1929: 445). This lavish decorative scheme also featured multicoloured marble panels, inlaid gems, intricate gypsum work, and metal sheeting. Early modern reports note that silver and bronze once adorned the palace façade, reflecting its imperial ambition (Dieulafoy 1884: 77).

Despite its enduring historical significance and the extraordinary craftsmanship and architectural sophistication evident in its construction, Taq-e Kasra has experienced long periods of destruction. Following the Arab conquest and the founding of Baghdad, Taq-e Kasra was gradually dismantled, with its materials repurposed for new construction. This process was not only pragmatic but also ideological, reflecting efforts to diminish pre-Islamic imperial legacies (Keall 1987: 156–157; Mousavi and Daryaee 2012: 1081). Natural degradation has also caused further damage to the structure most notably the collapse of the northern façade during a major Tigris flood in 1887 (Madhloom 1978: 122; cf. Lacoste 1954: 13).

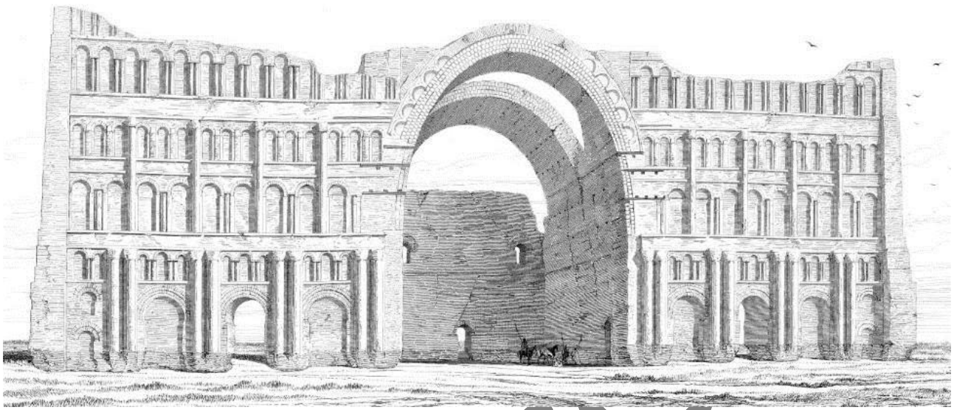

Figure 5: Taq-e Kasra in the early 1840s, before the collapse of its northern wall. Source*:* (After: Flandin and Coste 1851, tome 4: Plate 216).

Efforts to preserve the structure have been sporadic at best. Limited conservation measures were carried out in 1922 and 1942, followed by more ambitious but ultimately short-lived restoration initiatives in the 1960s and 1970s (Bruno 1966: 95-98; Madhloom 1978: 119-121). However, recent decades of instability in Iraq have stalled preservation, leaving many architectural details unexamined and the monument in a vulnerable state.

There is no scholarly consensus on the identity of the architect behind Taq-e Kasra. A widely cited view in modern architectural historiography attributes its design to Roman influence, a theory notably advanced by Auguste Choisy. Drawing on the writings of Isidore of Miletus co-architect of Hagia Sophia, who was active during Emperor Justinian's reign and roughly contemporaneous with the construction of the iwan Choisy linked the monument's design to theoretical principles of arch construction outlined by Heron of Alexandria (Choisy 1883: 31–43). Central to Isidore's teachings was the structural efficacy of the parabolic arch, a form praised for its ability to efficiently distribute weight. Building on this context, some scholars have argued that Justinian dispatched Roman engineers and masons to the court of Khosrow I, thereby facilitating a direct transmission of Roman construction knowledge to the Sasanian realm (Whitby and Whitby 1986: 140). This claim receives an additional, albeit more symbolic, layer of support in Ferdowsi's *Shahnameh*, which recounts the tale of a Roman architect named Farghan, who defeated his Iranian rival in a competitive selection process and was subsequently entrusted with the design of the arch (Behnam 1966: 12–14).

However, a structural examination of the surviving elements of Taq-e Kasra calls into question the attribution of its architectural style. The vault that spans the central hall departs significantly from the architectural principles and geometric conventions commonly found in Roman monumental construction. Roman imperial architecture, especially in large-scale public works, overwhelmingly favoured semicircular arches. While such arches appear in the flanking sidewalls recalling the arcaded tiers of the Roman Colosseum, which segmented elevation to mitigate lateral wind loads (Mark 1993: 83) the iwan's soaring, catenary form follows a fundamentally different spatial and structural logic.

What distinguishes Taq-e Kasra most clearly is its precise adherence to the catenary curve—a form that naturally arises from the physical behaviour of a suspended chain and is considered optimal for unreinforced masonry arches. Recent engineering analyses have shown that the vault's remarkably slender thickness at the apex measuring just 1.3 m closely aligns with the internal thrust lines generated by the self-weight of the structure. This demonstrates a sophisticated balance between geometry, material performance, and gravitational force (Dahmen and Ochsendorf 2012: 438; Miccoli et al. 2023: 132–133).

Although the formal codification of such structural principles is often attributed to Renaissance figures such as Christopher Wren and Robert Hooke who applied the inverted hanging chain method in designing the dome of St. Paul's Cathedral (Addis 1990: 144-145; Mainstone 2001: 321) evidence from Taq-e Kasra suggests that a similarly refined understanding of load paths and material behavior was already in use more than a millennium earlier. This points to not merely intuitive trial-and-error construction, but to an empirical body of architectural knowledge that enabled Sasanian architects to conceptualise and realise such a feat without access to formalised mathematics. In this light, Taq-e Kasra stands as a compelling counterpoint to prevailing Eurocentric narratives of architectural and structural innovation.

3.2 Technological Analysis

The original configuration of the Iwan of Khosrow exemplified the Sasanian Empire's architectural ambition and structural ingenuity. At its core stood an immense vaulted hall, symmetrically flanked by ten side chambers five on each side bringing the total longitudinal span of the two lateral walls enclosing these chambers to approximately 92 m (Mousavi and Daryaee 2012: 1081). These towering sidewalls, each rising to a height of 35.4 m, served both structural and compositional functions. The rhythm of their horizontally aligned arcades not only provided lateral reinforcement but also introduced a dynamic visual language that articulated the verticality and scale of the space.

What makes this edifice particularly remarkable is its material austerity: the entire structure was composed almost exclusively of fired bricks bound with gypsum mortar, a relatively weak adhesive compared to Roman concrete or lime-based mortars. This minimalist material palette required exceptional technical precision, as the structural integrity of the vault relied on meticulous load management and bricklaying techniques rather than on the cohesive strength of the mortar.

The construction of the central vault likely commenced with the preparation of robust load-bearing walls designed to absorb and redirect the lateral thrust exerted by the weight of the arch (Cejka 1978: Kap. 2. 44). These walls, with a formidable thickness of up to 7.2 m, were intentionally constructed with a slight inward tilt to further enhance their resistance to outward deformation. However, the designers did not rely solely on mass to stabilise the vault. On the outer face of each sidewall, five transverse arches projecting perpendicularly to the longitudinal axis of the iwan served as buttressing elements. These secondary arches functioned as a structural countermeasure, dissipating horizontal thrust and enhancing the vault’s resistance to collapse under asymmetric or dynamic loading conditions (Fig. 6).

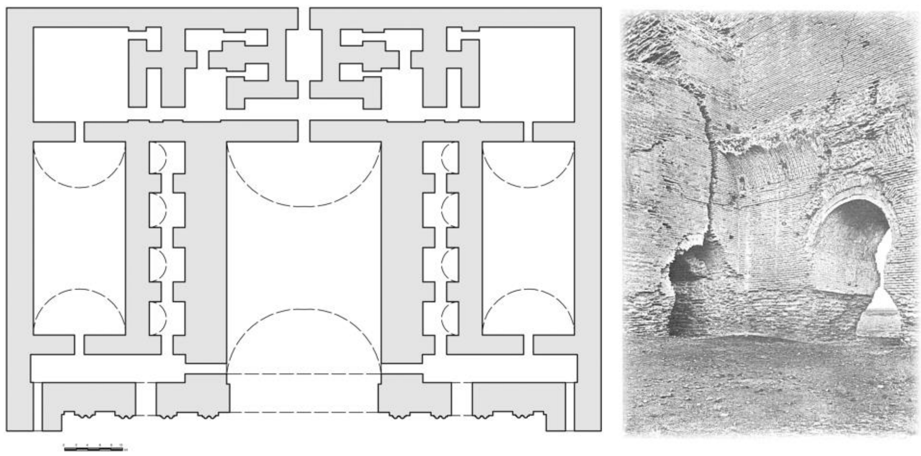

Figure 6: Left: Plan of the Kasra Palace and its adjoining spaces. Source: Drawn by the author based on (After: Bruno ١٩٦٦: PL. XXV). **Right:** The chamber situated at the rear side of the flanking walls. Source: (Sarre and Herzfeld 1911: Tafel XLIV).

Throughout the height of the buttressing system and sidewalls, Sasanian builders strategically integrated timber elements at various vertical intervals within the masonry, reflecting a sophisticated approach to structural reinforcement. Wooden beams, measuring between 25 and 30 cm in width and extending up to 4.5 m in length, were inserted into sealed, ventilated cavities embedded within the mass of the walls. These beams were secured with iron clamps and protected from moisture infiltration, allowing them to function as tensile components within the broader architectural framework (Dieulafoy 1884: 70–71). In addition to structurally linking the lateral façades to the central vaulted hall, the wooden reinforcements enhanced the building's resilience against seismic forces and differential foundation settlement. By harnessing the tensile strength of wood in conjunction with the compressive capacity of masonry, the builders introduced a counterbalancing system that increased the overall structural adaptability and durability of the monument. This sophisticated deployment of timber in a monumental context reflects a continuity of construction practices traceable to the Achaemenid period. The most prominent precedent can be observed in the roofing system of the Apadana at Persepolis, where large timber beams were employed not only to span expansive interior spaces but also to absorb seismic forces (Motamedmanesh 2022: 308–309; Motamedmanesh 2025: 24–28).

At approximately 12 m above ground level, the lower section of the vault consists of 74 horizontal courses of corbelled bricks, each slightly inclined inward (Cejka 1978: Kap. 2. 44). This stepped arrangement serves to reduce the effective span of the final arch by roughly two metres. The number of corbelled layers appears to have been calibrated with careful consideration of structural limits, balancing the need for incremental narrowing with the risk of lateral instability. The final phase of construction involved the erection of the vault proper, composed of bricks laid obliquely at an angle of approximately 18 degrees from the vertical axis (Lacoste 1954: 11). These bricks were set directly against the massive rear wall of the throne hall (Fig. 4, top), which functioned as a permanent abutment to absorb initial thrust forces during the construction phase (Fig. 7).

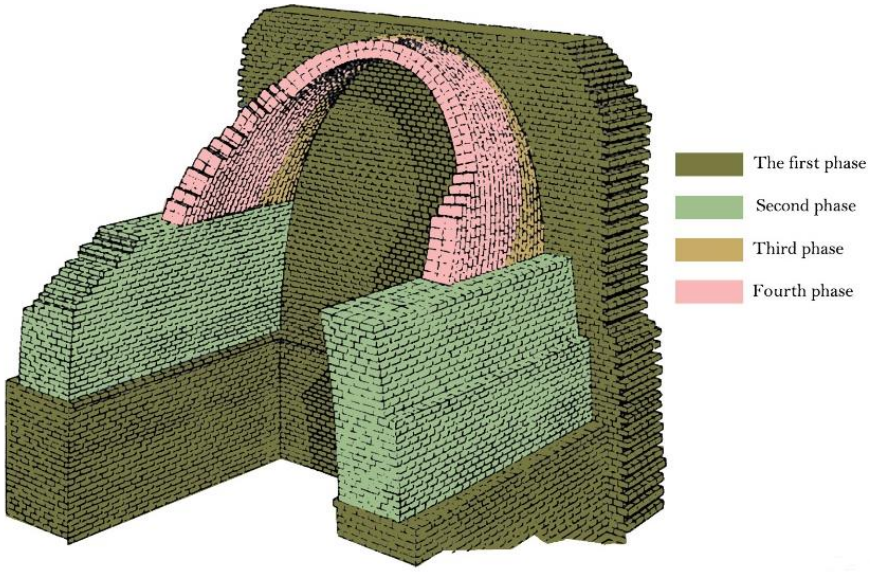

Figure 7: Construction phases of the Taq-e Kasra vault. Drawing and colouration by the author, based on (After: Reuther 1977: 500)

This construction method is rooted in antiquity, with its earliest known applications traceable to the New Kingdom period in Egypt. It later spread across Mesopotamia during the 8th century BCE, appearing at sites such as Ur and Tell al-Rihaneh, and subsequently to Elamite Iran, most notably at Haft Tappeh (Besenval 1984: 223–224). As a technique, it represents a transformative innovation in ancient vaulting technology, significantly reducing reliance on temporary centring or elaborate scaffolding (Arce 2006: 201). The method exploits the fast-setting adhesive properties of gypsum mortar: once the first row of oblique bricks is placed directly against a vertical or slightly inclined backing wall (Fig. 4, bottom), successive courses can be built with minimal external support. This technique was employed extensively by the Parthians in the palace of Ashur and later by the Sasanians at architectural sites such as Kuh-e Khwajeh, Sarvestan, and Firuzabad. Remarkably, despite the immense scale of the Iwan of Khosrow, the builders continued to rely on the same construction logic and principles used in these earlier, more modest structures (Motamedmanesh and Rückert 2015: 35).

The length of newly laid brick courses plays a critical role in assessing the feasibility of constructing vaults without temporary centring. If the individual courses extend too far across the span, they become prone to buckling or collapsing during construction, especially before the full ring has been completed and stabilised. This structural vulnerability led ancient master builders to devise strategies to reduce the effective span of each curved course, thereby maintaining control over incremental loads throughout the building process (Wendland 2007: 315–316).

Upon the completion of the Taq-e Kasra, approximately 150 regularly spaced holes each measuring 12 to 15 cm in diameter and lined internally with ceramic pipes were integrated along the structure (Fig. 8). Multiple functions have been proposed for these openings. Positioned just above a subtle brick projection located directly beneath the springing point of the arch, the most plausible interpretation is that they supported a lightweight scaffolding system or possibly a mobile wooden centring frame. Such a system may have served dual purposes: acting as a guide for controlling the curvature of the vault and providing temporary support to hold the bricks of each ring in place until the ring was structurally complete (Karydis, 2012: 7; Cejka, 1978: Kap. 2. 47).

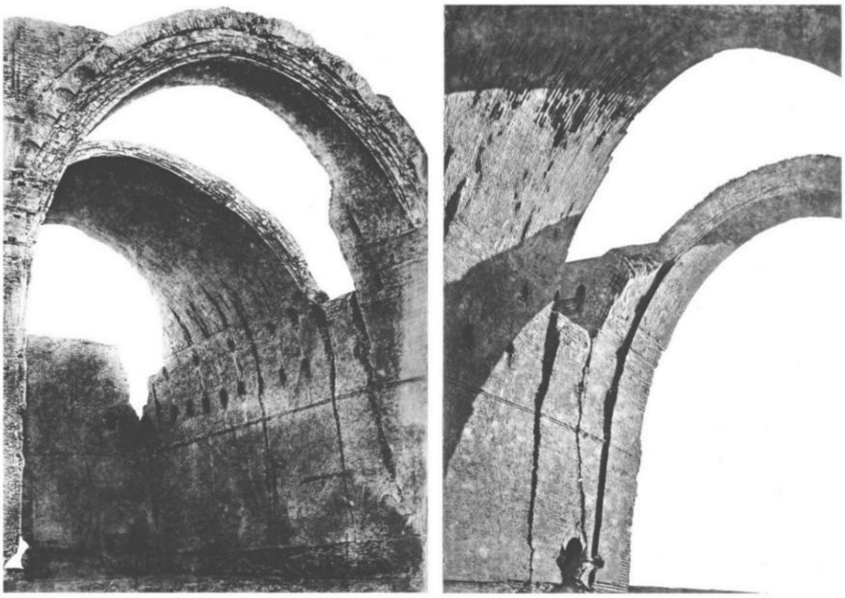

Figure 8: The earliest known photographs of Taq-e Kasra, taken by Dieulafoy before the devastating flood of the late 19th century. Source: (After: Dieulafoy 1884: PL. V, VI).

4. Discussion: **Tracing the Evolution of the Taq-e Kasra Vault Form**

As previously noted, despite the extensive scholarship dedicated to Taq-e Kasra, the origins of its distinctive vault geometry remain the subject of considerable debate. While some interpretations attribute the arch's form to structural imperatives or constructional pragmatism, others suggest that cultural symbolism or the adoption of foreign architectural models played a role. What has been largely overlooked, however, is a systematic and analytically grounded investigation into the historical evolution of this specific geometric form one that accounts for the cumulative development of construction techniques, the empirical understanding of structural behaviour by ancient builders, and the continuity of indigenous architectural traditions.

This section adopts a comparative and diachronic framework, situating Taq-e Kasra within the broader continuum of Iranian building culture. It examines early vaulting technologies and modes of knowledge transmission to uncover both the theoretical logic and practical methodologies that may have informed the emergence of the catenary profile. By integrating historical, technical, and symbolic dimensions, the following subsections aim to reconstruct the design trajectory that culminated in the form realised at Taq-e Kasra thus testing the central hypothesis of this study regarding the architectural continuity embedded in Sasanian construction.

4.1 Early Construction Technologies and the Emergence of Architectural Forms

The evolution of architectural form in antiquity was significantly influenced by empirical experimentation. In the absence of formalised structural theory or advanced knowledge of material mechanics, early builders relied on observation, repetition, and incremental refinement to determine which configurations were both feasible and durable (Mark 1990: 169-170). This pragmatic approach led to the intuitive discovery of geometries that enhanced structural performance and effectively responded to environmental and material constraints. One of the earliest vaulting techniques developed in Mesopotamia was corbelling the horizontal staggering of brick or stone courses to create a gradually narrowing span. Although not a true arch in the structural sense, the resulting profile often steep and parabolic in appearance allowed for the spanning of interior spaces without fast-setting mortar (Besenval 1984: PL. 126–127). Variations of this technique were eventually adapted for dome construction, with enduring examples such as the Treasury of Atreus in Mycenae and vaulted enclosures at Tell Erbajiyah.

The development of true curved forms, particularly elliptical arches, marked a significant turning point in architectural innovation. In Egypt, some of the earliest elliptical vaults of appreciable scale were constructed using geometries that, while initially undefined, were gradually refined through practice to closely approximate the ellipse (Huerta 2007: 214). This evolutionary process underscores a construction logic grounded not in abstract mathematics, but in embodied knowledge and tactile engagement with materials (Mainstone 2001: 75–77). As a result, egg-shaped and elliptical profiles became recurring formal strategies in the architecture of early civilisations, especially within the Mesopotamian cultural sphere.

High-rise arches, in particular, conferred a series of technical and logistical advantages. Their steep curvature reduced lateral thrusts, thereby minimising the need for massive buttressing, while simultaneously reducing reliance on timber centring, which was often scarce in arid environments. These pragmatic considerations contributed to the widespread adoption of tall arch profiles in the Middle East and early Byzantine architecture, even though they diverged from the semicircular ideal that characterised Roman construction (Karydis 2012: 10). The introduction of gypsum-based mortar further enhanced construction flexibility, allowing builders to lay bricks or stones in stable courses without the needing continuous wooden formwork (Safaeipour and Pour-Ahmad 2024: 790–791). This innovation enables builders to experiment with increasingly ambitious curved geometries.

The structural intelligence embedded in these early construction practices laid the groundwork for a distinct architectural tradition in Mesopotamia and Iran, which sharply contrasted with the Roman predilection for semicircular forms (Mark 1993: 138). A rare exception within the Roman context is the Temple of Diana at Baiae (3rd century CE), which features a parabolic arch capable of spanning a remarkable 29.8-meter-wide dome (Sinopoli and Aita 2021: 1152, 1157). In his pioneering study of this building, De Angelis argued that it was likely during the Parthian period (2nd–3rd centuries CE) that Roman engineering practices began to be influenced by knowledge of elliptical and parabolic vault construction, offering further evidence of technological transfer flowing from east to west, rather than the reverse (De Angelis d'Ossat 1977: 227–272).

Sasanian architects inherited this long trajectory of empirical knowledge and extended it with unprecedented scale and precision. In response to increasingly complex spatial and ceremonial demands, they developed a diverse range of vaulting techniques (Fig. 9) tailored to different functional and symbolic needs (Mazhari Motlagh 2010: 56). Despite this formal diversity, one geometric principle recurs consistently: the use of high-rise vaults whose profiles closely approximate the catenary curve. This recurring formal strategy suggests not only a continuation of Near Eastern vaulting practices but also a deliberate pursuit of optimal structural form. The catenary, long before being codified in post-Renaissance theory, appears to have emerged in Sasanian architecture as the result of accumulated experience, refined material logic, and a profound, if implicit, understanding of construction physics. The exact pathways by which this geometric knowledge was transmitted or abstracted, however, remain an open area for future interdisciplinary research.

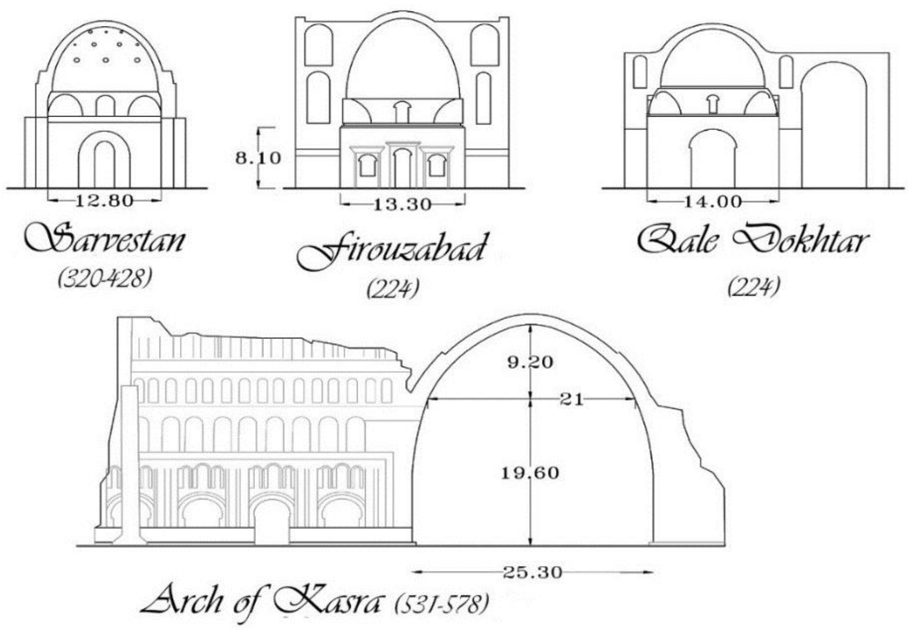

Figure 9: Comparative analysis of the main halls in Sasanian palaces and the Taq-e Kasra. Source: Author.

4.2 The Construction Culture of the Sasanian Empire

Alongside the Roman Empire, the Sasanians constituted one of the two dominant geopolitical forces of Late Antiquity. Steeped in the memory of Achaemenid grandeur, the Sasanians consciously positioned themselves as the rightful successors of that earlier imperial lineage. This aspiration is clearly articulated in their rock reliefs at Naqsh-e Rustam, inscribed beneath the tombs of Achaemenid kings a deliberate act of spatial and symbolic alignment. Their imperial vision extended beyond military expansion to encompass a civilisational project aimed at recreating the sociopolitical order of the Achaemenid past (Farrokh 2007: 177). In architecture, this revivalist ethos manifested in efforts to replace or reinterpret the Hellenised Parthian idiom with a distinctly Iranian style rooted in indigenous traditions (Reuther 1977: 497, 515; Mousavi and Daryaee 2012: 1076).

Material and environmental constraints across the Iranian plateau played a decisive role in shaping this architectural response. The scarcity of high-quality timber, coupled with the labour-intensive nature of stone construction, led Sasanian builders to rely primarily on earthen materials most notably baked brick and gypsum mortar. Fortunately, this shift did not entail a loss of technical sophistication. Rather, it activated a deep reservoir of regional knowledge accumulated over millennia of experimentation with vaults and domes. Even as material choices evolved, key architectural elements were retained to evoke Achaemenid antecedents. Decorative motifs originally carved in stone above lintels were now reproduced in gypsum above arches; such elements can be found in the ruins of Qalʿeh Dokhtar and Firuzabad (Fig. 1). Similarly, the presence of animal-headed capitals closely resembling those from Persepolis at Tomb-e Bot in Lamerd and within the temple precinct at Bishapur attests to the intentional appropriation of Achaemenid visual vocabulary.

This fidelity to earlier forms may be interpreted not merely as aesthetic homage but as a deliberate commemorative strategy through which the Sasanians sought to legitimise their authority by inscribing their rule into a continuum of Iranian imperial greatness (Canepa 2010: 590). This raises a critical question: were such formal citations limited to surface symbolism, or did they reflect a more profound continuity in construction knowledge embedded within the built fabric itself?

As previously discussed, scholarly attempts to reconstruct the geometric logic of the most renowned Sassanid monument, Taq-e Kasra, by referencing Roman architectural paradigms have thus far proven inadequate in providing a convincing explanation for the genesis of its distinctive catenary profile. In light of this, the present study advances an alternative hypothesis rooted in the continuity of Iranian construction culture a tradition that, as Tadjvidi (1971) argued, exhibits an uninterrupted lineage throughout the history of Iranian art and architecture. Despite centuries of Hellenistic presence following the conquests of Alexander and the establishment of Seleucid rule, scholars widely acknowledge that the project of cultural Hellenisation in Iran ultimately failed to penetrate deeply into native practices (Davaran 2010: 4; Farrokh 2007: 117; Ghirshman 1965: 242). Even when aesthetic imitation occurred, it often remained superficial, leaving the structural and conceptual core of Iranian architecture largely intact.

Within this continuous tradition of Iranian architectural practice, the Achaemenid period emerges as particularly influential (Motamedmanesh 2022: 299). The construction of Persepolis the most sophisticated Achaemenid architectural site offers substantial evidence for further scholarly exploration, especially regarding its systematic and modular approach to design. At Persepolis, the monumental complex was meticulously planned according to a standardised measurement system that featured a fundamental unit (the foot) measuring 0.3424 m, complemented by a larger modular dimension known as the Arash (cubit),[1] equivalent to 1.5 feet or approximately 0.5136 m (Krefter 1971: 30). If one assumes that this system persisted into the Sasanian period, its traces should be detectable in the built dimensions of Taq-e Kasra. Indeed, the bricks used in its construction typically ranging from 30 to 33 cm in length (Madhloom 1978: 126) closely correspond to this modular logic when accounting for the thick gypsum mortar layers typical of traditional adobe-based construction. When the minimum mortar thickness is included, the effective unit length aligns precisely with the Achaemenid foot. Moreover, a broader examination of the monument's primary dimensions its span, height, and depth reveals a consistent adherence to this ancient system of Arash (Fig. 10C). These proportional relationships suggest not only a theoretical knowledge of modular planning but also the transmission of specific measurement standards across centuries. Such evidence supports the interpretation of Taq-e Kasra not as a technical anomaly or a product of Roman intervention, but as the architectural culmination of a native Iranian tradition one that synthesised symbolic revivalism with enduring structural intelligence. The critical question remains whether this measurement system can effectively serve as a key to deciphering the distinctive geometry of the Arch.

4.3 Geometry, Structural Analysis, and the Emergence of Form in Iranian Architecture

Throughout history, nature has served as a profound and enduring source of inspiration for human creativity, shaping not only the physical techniques of building but also the

[1] **Arash:** A traditional Persian unit of length, roughly equivalent to the distance from the elbow to the tip of the middle finger. Commonly used in Achaemenid architecture and earlier Mesopotamian civilisations, the Arash functioned as a standard modular unit in construction, facilitating proportional design and spatial planning.

conceptual frameworks of scientific and aesthetic thought. The earliest principles of architectural design particularly those rooted in harmony and proportion were derived from observations of natural order. Beauty, in this context, was regarded not as subjective or contingent, but as a universal and eternal quality grounded in objective and intelligible structures. The inherent regularity of the natural world was perceived as a manifestation of cosmic laws, accessible through geometry, mathematics, and harmonious proportion (Ardalan and Bakhtiar 1973: 25; Hildebrandt and Tromba 1996: 41-42). In this tradition, Iranian architecture across millennia has reflected a consistent commitment to these principles. As Arthur Upham Pope (1965) noted, the defining features of Iranian cultural expression vitality, precision, symmetry, proportional coherence, and a unified design sensibility are evident at every stage of its architectural development. Iranian builders, from antiquity onward, consistently demonstrated a mathematical mode of reasoning, embedding abstract geometrical logic within the physical realities of architectural production (Pope, 1977: 8).

While structural stability and strength were not always the explicit drivers of architectural form in historical Iranian practice, master builders held a profound, intuitive understanding of the forces at play within a structure (Hejazi 2005: 1424). Rather than privileging engineering calculations as a starting point, they approached form as an integrated system, where geometry inherently dictated structural performance. As Engel (1997: 30) points out, regardless of the stylistic or cultural context, a building’s behaviour under external forces is ultimately determined by its geometric configuration. In essence, sound geometry ensures structural stability even in the absence of formal theoretical knowledge.

Among the harmonic proportions employed historically across civilisations, the golden ratio (φ) occupies a particularly esteemed position. Revered in both the aesthetic and building traditions of Egypt and Greece, it also found deep resonance in the architectural canon of Iran, including the Achaemenids (Hejazi 1997: 20; Veisi et al. 2014: 204). Traditional Iranian builders frequently employed golden-ratio-based principles sometimes explicitly, more often through inherited rules of proportion as part of a broader tradition of "sacred geometry" that unified mathematical reasoning with spiritual symbolism (Hejazi 2005: 1424–1427). Importantly, the Sasanian period witnessed a flourishing of mathematical and scientific inquiry, encompassing geometry, astronomy, and natural philosophy (Farrokh 2007: 240–243). As such, the use of harmonic proportions in Sasanian architecture may be interpreted not merely as a continuation of Achaemenid precedent, but as a reflection of a broader intellectual engagement with the underlying principles of natural order.

From a structural engineering perspective, natural forms evolved through millennia to optimise energy and material use represent a model of unparalleled efficiency (Hildebrandt and Tromba 1996: 213–266). It is thus unsurprising that human constructions emulating such geometries exhibit high degrees of performance and economy. As previously discussed, the catenary form of the Taq-e Kasra vault represents one of the most efficient configurations for distributing compressive stress in unreinforced masonry. This curve minimises tensile forces and concentrates load paths along stable, vertically resolved vectors.

Figures 10A and 10C illustrate that the geometry of the Taq-e Kasra vault from its foundation to its apex can be inscribed within a geometric framework (a rhombus) structured by golden-ratio-based triangles. The internal angles of this framework correspond precisely to those of a regular pentagon (36° and 108°), establishing a direct link between the structural profile and idealised geometric proportions (Fig. 10B). This alignment is not incidental; rather, it suggests a deliberate compositional logic that integrates mathematical optimisation with symbolic expression. Within Iranian architectural cosmology, the pentagon transcends its geometric utility to embody deeper metaphysical concepts, signifying spiritual renewal, cosmic harmony, and the cyclical nature of time (Hejazi 2005: 1422). In this context, Taq-e Kasra serves as a powerful exemplar of the Iranian tradition, where structure and symbolism reinforce each other rather than oppose.

The application of this design framework uncovers a nested system of proportional relationships rooted in the Achaemenid architectural Arash. The principal bounding rhombus formed using golden-ratio-based triangles can be subdivided into a series of smaller rhombuses, all congruent in internal angles and aligned along the vault's central vertical axis (Fig. 10C). The key geometric figure, triangle ABB′, derived from the central triad of rhombuses, defines the primary vault contour. The apex of this triangle (point A) rests upon the initial construction line (cd), which also appears as a projected line along the lateral walls (see Fig. 8), demarcating the upper limit of the corbelled brickwork. From this apex, an arc (R_1) is drawn with a radius equal to the vault's rise (AN), establishing the highest point of the vault profile (arc NO). The intersection of this arc with the extended side of triangle AB determines the upper curvature limit of the structure.

The construction of the next segment of the vault begins at point B′, which serves as the base of triangle ABB′. A second arc (R_2), with a radius equal to B′O, is projected to intersect the angle subdivision line ef, which represents the division of the original 54° angle into 36° and 18° segments (referred to as golden degrees). The point of intersection, P, defines the termination of the second segment of the vault. Below this point, the lowest portion of the vault segment PQ is primarily composed of horizontally laid bricks, constructed using the corbelled technique (Fig. 7, Stage II). The baseline extension (ab), when intersected by the continuation of line ef, defines point C′. A final arc (R_3), drawn from C′ with radius C′P, completes the lower vault curvature, ending precisely where arc R_3 intersects the vault's horizontal baseline, thus defining point Q.

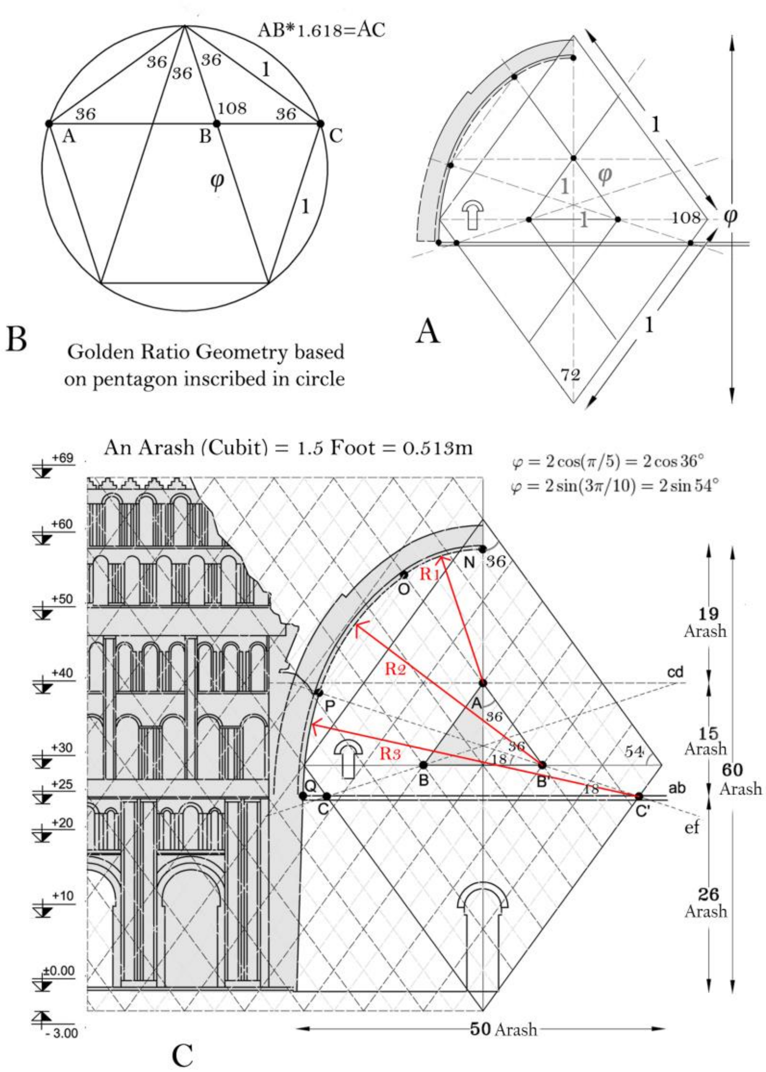

Figure 10: Identification of the vault's underlying geometry based on the golden ratio and Achaemenid construction modules. The primary dimensions of the vault, shown at bottom right, are expressed in Achaemenid units of measurement. Source: Adapted and redrawn by the author, based on (After: Hejazi 2005: 1417; Motamedmanesh and Rückert 2015: 38; Dahmen and Ochsendorf 2012: 438; Bruno 1966: PL. XVIII, PL. XX).

This geometric method yields a profile that closely approximates the observed catenary curve of Taq-e Kasra. As shown, the emergence of this specific structural form was not arbitrary; it resulted from a sophisticated interplay among three interlocking systems: the golden ratio, the Achaemenid module of measurement, and the builder's experiential understanding of structural stability.

5. Findings

The findings of this study derived from an interdisciplinary analytical framework and supported by high-resolution field data indicate that Taq-e Kasra should not be viewed as a rupture from antecedent traditions, but rather as a culmination of the enduring architectural practices that evolved across millennia in ancient Iran. Geometric analyses, based on meticulous on-site measurements and digital modelling via AutoCAD, confirm that the arch profile conforms with remarkable precision to a catenary curve. This curve is celebrated for its optimal capacity to distribute compressive forces across wide spans, while simultaneously adhering to compositional principles grounded in the golden ratio, pentagonal geometries, and the modular measuring system characteristic of Achaemenid architecture. This formal correspondence not only attests to structural efficiency but also reflects a mathematically guided design sensibility rooted in sacred geometry a dimension that has remained underexplored in previous scholarly accounts. The synthesis of empirical evidence and symbolic logic points toward an architectural conception that integrates engineering rationality with metaphysical and cosmological significance.

Complementing this geometric and structural assessment, historical and archaeological sources reveal a deliberate Sasanian agenda to reclaim and reinterpret the architectural vocabulary of the Achaemenid past. The recurrence of visual motifs, such as animal-headed capitals, monumental gateways, and decorative friezes adapted to gypsum and brick media suggests a programmatic revival of imperial symbolism aimed at reinforcing dynastic legitimacy through built form (Fig. 1). Rather than engaging in passive imitation, Sasanian architects recontextualised these elements within new spatial and material frameworks.

The analysis of building methods employed at Taq-e Kasra further confirms the systematic application of long-established Near Eastern techniques, particularly oblique brick-laying without reliance on centring. This approach, rooted in empirical knowledge transmitted over centuries, enabled the realisation of vast, uncentred vaults using only modest resources. The refinement of such techniques already evident in Parthian and Elamite precedents reaches its architectural zenith in the execution of the Kasra vault.

Crucially, the comparative evaluation of the vault's dimensional logic against Achaemenid modular systems particularly the Arash unit provides compelling evidence for a sustained engagement with inherited knowledge systems. The alignment of the vault's principal dimensions with multiples of the 0.5136 m unit reflects a conceptual continuity that is both symbolic and functional, suggesting that Sasanian architects were not merely aware of Achaemenid practices but actively employed their principles within a framework of measured architectural intentionality.

Overall, through historical, structural, and geometric dimensions, the evidence suggests that Taq-e Kasra represents the culmination of an evolutionary trajectory in the architectural knowledge of the Iranian plateau. This trajectory was formed not just by intuitive reasoning or technical constraints but also through a deep and deliberate engagement with structural, aesthetic, and symbolic traditions. Thus, the study's central hypothesis that there existed a meaningful continuity between Achaemenid and Sasanian construction culture is convincingly supported through a synthesis of documented data, quantitative analysis, and comparative evaluation.

6. Conclusion

This study has demonstrated that the Arch of Ctesiphon embodies a profound continuity in Persian architectural knowledge, going beyond stylistic or symbolic imitation. By integrating a catenary form and harmonic ratios anchored in Achaemenid metrology, the monument reflects a systemic transmission of architectural epistemology from the Achaemenid to the Sasanian period this is materially embedded in construction logic rather than ideologically gestured. These findings refine prevailing narratives of rupture and signal a structural resilience within the architectural heritage of Iran, where proportional systems acted as instruments of both technical precision and cultural identity.

From the standpoint of cultural memory studies, this monument offers an instructive case of how architecture acts as a durable medium for transmitting identity and knowledge across dynastic, political, and temporal boundaries. The vault of Taq-e Kasra is not merely a formal echo of earlier traditions; it embodies what might be termed a tectonic memory a mode of historical consciousness that survives in materials, construction techniques, and geometric systems rather than solely in iconography or text. This continuity reinforces the idea that memory in the built environment operates through embodied craftsmanship and architectural logic, not just symbolism. In this respect, the monument reorients the discourse from semiotic readings of imperial architecture to one grounded in epistemic and technological transmission.

In terms of structural engineering, the findings prompt a reevaluation of long-held assumptions about ancient architectural rationality and regional innovation. The unreinforced brick vault of Taq-e Kasra executed without centring, and using empirically derived load paths and embedded reinforcement strategies reflects a level of structural intelligence that rivals, and in some respects exceeds, contemporaneous Roman and Byzantine methods. The use of the catenary curve, in particular, reveals an intuitive grasp of statics and load distribution, achieved long before these principles were formally codified in post-Renaissance Europe. This challenges Eurocentric narratives in the historiography of engineering and underscores the necessity of more fully integrating Middle Eastern contributions into global accounts of structural innovation.

Looking ahead, the interdisciplinary methodology employed in this study merging geometric reconstruction, digital modelling, archaeological evidence, and historical interpretation provides a replicable framework for future research into ancient architecture. To deepen our understanding of structural behaviour and design intent, future investigations must incorporate advanced diagnostic technologies, including high-resolution laser scanning, photogrammetry, and finite element analysis. These tools facilitate precise modelling of load paths, thrust-line behaviour, and geometric deviations factors critical to assessing both original construction logic and long-term stability.

In parallel, comprehensive materials analysis such as petrographic microscopy, X-ray diffraction, and microstructural imaging can yield quantitative data on the mechanical performance, compositional makeup, and durability of ancient bricks and mortars. Such data are crucial for reconstructing construction sequences, evaluating the technological sophistication of ancient builders, and validating claims of continuity between Achaemenid and Sasanian practices. Together, these methods not only enhance structural understanding but also strengthen the evidentiary basis for tracing epistemic lineages across historical regimes of construction.

Ultimately, the Arch of Ctesiphon serves as a unique convergence point between material intelligence and cultural continuity. It confirms that in the longue durée of Iranian architecture, construction techniques and structural forms are not merely responses to technical constraints, but also vehicles for preserving and projecting civilisational identity. Therefore, the vault is not simply an engineering marvel; it is a monument to the enduring dialogue between knowledge, memory, and form.

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References

Addis, William. 1990. *Structural Engineering: The Nature of Theory and Design*. New York: Ellis Horwood.

Ali, S. M. 2006. "Reinterpreting Al-Buhturī's Īwān Kisrā Ode: Tears of Affection for the Cycles of History," *Journal of Arabic Literature* 37(1): 46–67. https://doi.org/10.1163/157006406777070724

Arce, I. 2006. "Umayyad Arches, Vaults and Domes: Merging and Re-creation," In M. Dunkeld; J. Campbell; H. Louw; M. Tutton; B. Addis and R. Thorne, (eds.), *Proceedings of the Second International Congress on Construction History*. Exeter: The Construction History Society, 195-220.

Ardalan, N and L. Bakhtiar. 1973. *The Sense of Unity: The Sufi Tradition in Persian Architecture*. Chicago: University of Chicago Press.

Behnam, I. 1966. "Tisfun" (Ctesiphon), [In Persian], *Honar va Mardom* 44: 11–15.

Besenval, R. 1984. *Technologie de la Voûte dans l'Orient Ancien*. [Vault Technology in the Ancient East]. Paris: Editions Recherche sur les Civilisations.

Bruno, A. 1966. "The Preservation and Restoration of Taq-Kisra," *Mesopotamia: Rivista di archeologia, epigrafia e storia orientale antica* 1: 89–108.

Canepa, M. P. 2010. "Technologies of Memory in Early Sasanian Iran: Achaemenid Sites and Sasanian Identity," *American Journal of Archaeology* 114(4): 563–596. https://doi.org/10.3764/aja.114.4.563

Cejka, J. 1978. *Tonnengewölbe und Bögen Islamischer Architektur: Wölbungstechnik und Form*. [Barrel Vaults and Arches in Islamic Architecture: Vaulting Technique and Form], Ph.D. Thesis, Eigenverlag. München: Technical University of München,

Choisy, A. 1883. *L'art de Bâtir chez les Byzantins*. [The Art of Building among the Byzantines]. Paris: Librairie de la Societé Anonyme de Publications Périodiques.

Dahmen, J and J. Ochsendorf. 2012. "Earth Masonry Structures: Arches, Vaults and Domes," In M.R. Hall; R. Lindsay and M. Krayenhoff, (eds.), *Modern Earth Building*. Oxford: Woodhead Publishing, 427–460.

Daryaee, Touraj. 2001. "Memory and History: The Construction of the Past in Late Antique Persia," *Nāme-ye Irān-e Bāstan* 1(2): 1–14.

Davaran, Fereshteh. 2010. *Continuity in Iranian identity: Resilience of a Cultural Heritage*. London: Routledge.

Davtalab, J., A. Heidari, and Z. Sarabandi, Z. (2021). "A Study of the Architecture and Urban Planning of Dahaneh-ye Gholaman in Sistan, Iran," *Journal of Sistan and Baluchistan Studies* 1(1): 21–30. https://doi.org/10.22034/jsbs.2021.146217

De Angelis d'Ossat, G. 1977. "L'Architettura delle Terme di Baia," [The Architecture of the Baia Baths], In L. Marcucci and D. Imperi ,(eds.), *Realtà dell'Architettura*, Italy: Carocci, 227–74.

Dieulafoy, Marcel. 1884. *L'Art Antique de la Perse*, [Ancient Persian Art], Volume V. Paris: Librairie centrale d'architecture,

Engel, H. 1997. *Structure Systems*. Germany: Hatje Cantz Publisher.

Farrokh, K. 2007. *Shadows in the Desert: Ancient Persia at War*. New York: Osprey.

Fathy, H. 2010. *Architecture for the Poor: An Experiment in Rural Egypt*. Chicago: University of Chicago Press.

Flandin, E and P. Coste. 1851. *Voyage en Perse, Perse Ancienne: Planches*, [Travel in Persia, Ancient Persia: Plates], Volume 4. Paris: J. Baudry.

Ghirshman, R. 1965. *Iran: From the Earliest Times to the Islamic Conquest*. London: Penguin Books.

Hejazi, M. 2005. "Geometry in Nature and Persian Architecture," *Building and Environment* 40(10): 1413–1427. https://doi.org/10.1016/j.buildenv.2004.11.007

Hejazi, M. 1997. *Historical Buildings of Iran: Their Architecture and Structure*. Southampton: Computational Mechanics.

Herzfeld, E. 1935. *Archaeological History of Iran*. London: H. Milford for the British Academy.

Hildebrandt, S and A. Tromba. 1996. *The Parsimonious Universe: Shape and Form in the Natural World*. New York: Springer-Verlag.

Huerta, Santiago. 2007. "Oval Domes: History, Geometry and Mechanics," *Nexus Network Journal* 9(2): 211–248. https://doi.org/10.1007/s00004-007-0040-3

Karydis, N. 2012. "Limiting the Use of Centering in Vaulted Construction: The Early Byzantine Churches of West Asia Minor," In R. Holod; R. Ousterhout and L.Haselberger, (eds.), *Center for Ancient Studies Symposium: Masons at Work*. Pennsylvania: University of Pennsylvania, 1-12. https://kar.kent.ac.uk/id/eprint/59648

Keall, E. J. 1987. "Ayvan-e Kesra," *Encyclopedia Iranica* 3(2): 155-159

Krefter, F. 1971. *Persepolis Rekonstruktionen*. Berlin: Gebr. Mann Verlag.

Lacoste, H. 1954. "L'Arc de Ctesiphon ou Taq Kesra," *Sumer* 10: 3–22.

Madhloom, T. 1978. "Restorations in Al-Mada'in 1975–77," [In Arabic], *Sumer* 34: 119–129.

Mainstone, R. J. 2001. *Developments in Structural Form*. Oxford: Architectural Press.

Mark, R. 1990. *Light, Wind, and Structure: The Mystery of the Master Builders*. Cambridge: MIT Press.

Mark, R. 1993. *Architectural Technology up to the Scientific Revolution: The Art and Structure of Large-scale Buildings*. Cambridge: MIT Press.

Mazhari Motlagh, M. 2010. "A Comparison between Sasanid Vaults and those of the Roman and Byzantine Periods." *Iran* 48.1: 43-58. https://www.jstor.org/stable/41431216

Miccoli, S; L. M. Gil-Martín, and E. Hernández-Montes. 2023. "New Historical Records about the Construction of the Arch of Ctesiphon and Their Impact on the History of Structural Engineering," *Notes and Records* 77(1): 113–134. https://doi.org/10.1098/rsnr.2021.0025

Motamedmanesh, M. 2025. "Zoomorphic Imposts and Dougong Brackets: A Cross-Cultural Examination of Intellectual Influences between Achaemenid Persia and Ancient China," *Journal of Sistan and Baluchistan Studies* 5(1): 21-36. https://doi.org/10.22034/jsbs.2025.514596.1079

Motamedmanesh, M. 2022. "Achaemenid Building Technology: The Key to a New Reading of Royal Achaemenid Architecture," *Journal of the Society of Architectural Historians* 81(3): 299-319. https://doi.org/10.1525/jsah.2022.81.3.299

Motamedmanesh, M. 2016. "Authenticity and Restoration: The Benefits of Historical Studies on Re-examining the Implemented Restorations in Persepolis," *Arts* 5(1). 1-19. https://doi.org/10.3390/arts5010002

Motamedmanesh, M. and K. Rückert. 2015. "Form Follows Construction: A Technical Analysis of the Arch of Ctesiphone, the Widest Ever built Adobe Vault," In B. Bowen, D. Friedman, T. Leslie and J. Ochsendorf, (eds.), *Proceedings of the 5th International Congress on Construction History*, Chicago: Palmer House Hilton Hotel, vol.3, 31-40.

Mousavi, A. and T. Daryaee. 2012. "The Sasanian Empire: An Archaeological Survey, c. 220–AD 640," In D. T. Potts, (ed.), *A Companion to the Archaeology of the Ancient Near East*. West Sussex: Wiley-Blackwell, 1076–1094. https://doi.org/10.1002/9781444360790.ch57

Pirniya, M. K. 1994. "Chafthā va Tāghhā" (Arches and Vaults), [In Persian], *Asar* 24: 5–192.

Pope, A. U. 1965. *Persian Architecture*. New York: G. Braziller.

Pope, A.U. 1977. "The Significance of Persian Art," In A. U. Pope and P. Ackerman, (eds.), *A Survey of Persian Art: From Prehistoric Times to the Present*, Volume. I. Tehran: Soroush Press, 1-41.

Reuther, O. 1929. "The German Excavations at Ctesiphon," *Antiquity* 3(12): 434–451. https://doi.org/10.1017/S0003598X00003781

Reuther, Oscar. 1977. "Sasanian Architecture," In A. U. Pope and P. Ackerman, (eds.), *A Survey of Persian Art: From Prehistoric Times to the Present*, Volume. II . Tehran: Soroush Press. 493-578.

Roaf, M. 1998. "Persepolitan Echoes in Sasanian Architecture: Did the Sasanians Attempt to Re-create the Achaemenid Empire," In V. S. Curtis; R. Hillenbrand and J. M. Rogers, (eds.), *The Art and Archaeology of Ancient Persia: New Light on the Parthian and Sasanian Empires*. London: IB Tauris, 1–7.

Safaeipour, H and M. Pour-Ahmad. 2024. "Transformation of a Temporary Mold to a Permanent Structural Member: A Strategy for Without-Centering Vaulting in the Iranian Traditional Architecture," In S. Holzer; S. Langenberg, C. Knobling and O. Kasap (eds.), *Proceedings of the 8th International Congress on Construction History*, Zurich: ETH, 788-795.

Sarre, F. and E. Herzfeld. 1911. *Archäologische Reise im Euphrat-und Tigris-Gebiet*. Band III. [Archaeological Journey in the Euphrates and Tigris Region, vol. 3]. Berlin: D. Reimer.

Shapour Shahbazi, A. 2001. "Early Sasanians' Claim to Achaemenid Heritage," [In Persian], *Journal of Ancient Persian History* 1(1): 61–73.

Shayegan, M. R. 2011. *Arsacids and Sasanians: Political Ideology in Post-Hellenistic and Late Antique Persia*. Cambridge: Cambridge University Press.

Tadjvidi, A. 1971. "Tadavom dar Memari-e Iran" [Continuity in Iranian Architecture], [In Persian], *Honar va Mardom* 111(1): 2–17.

Sinopoli, A and D. Aita. 2021. "The Dome of the Temple of Diana in Baiae: Opus Caementicium, Geometry and Mechanics," *International Journal of Architectural Heritage* 16(8): 1152-1183. https://doi.org/10.1080/15583058.2020.1870777

Trigger, B. G. 1990. "Monumental Architecture: A Thermodynamic Explanation of Symbolic Behaviour," *World Archaeology* 22(2): 119–132. http://www.jstor.org/stable/124871

Veisi, M; A. Hejebri Nobari; S. Mousavi Koohpar and J. Neyestani, 2014. "An Investigation of the Geometric Proportions of Bell-Shaped Column Bases and Bull Capitals at Persepolis and in Caucasian Achaemenid Sites," *Ancient Civilizations from Scythia to Siberia* 20(2): 195–211. https://doi.org/10.1163/15700577-12341268

Wachtsmuth, F. 1977. "Achaemenid Architecture," In A. U. Pope and P. Ackerman, (eds.), *A Survey of Persian Art: From Prehistoric Times to the Present*, Volume. I. Tehran: Soroush Press, 309-320.

Wendland, D. 2007. "Traditional Vault Construction without Formwork," *International Journal of Architectural Heritage* 1(4): 311–365. https://doi.org/10.1080/15583050701373803

Whitby, M. and M. Whitby. 1986. *The History of Theophylact Simocatta: An English Translation with Introduction and Notes*. Oxford: Clarendon Press.

Yarshater, E. 1971. "Were the Sasanians Heirs to the Achaemenids?," In *La Persia nel Medioevo*. Rome: Accademia Nazionale dei Lincei, 517–531.

Zomarshidi, H. 2008. *Tagh va Ghos dar Memari-e Iran* [Vaults and Arches in Iranian Architecture]. [In Persian]. Tehran: Iranian Urban Regeneration and Improvement Company.