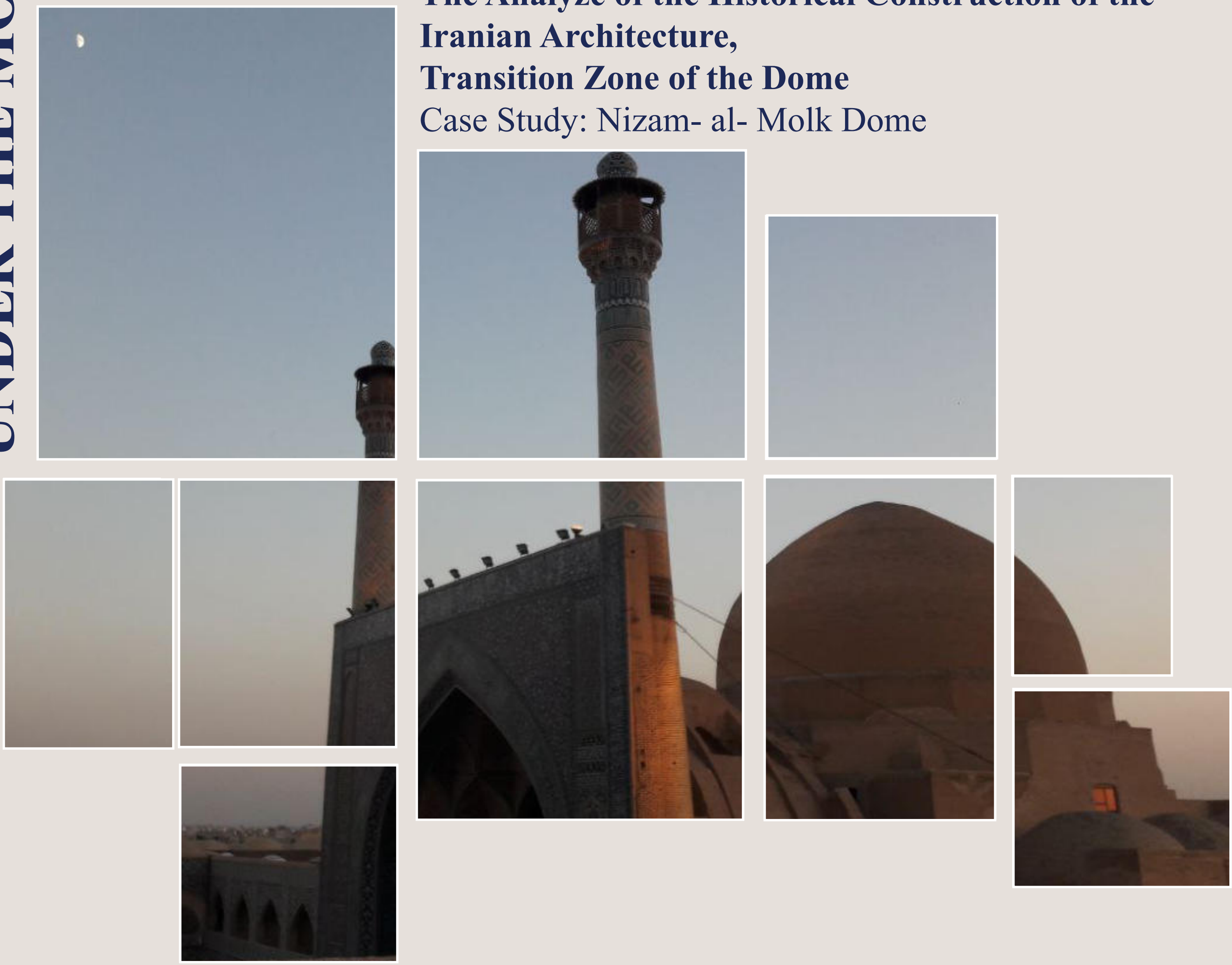
UNDER THE MOON

The Analyze of the Historical Construction of the Iranian Architecture, Transition Zone of the Dome

Case Study: Nizam- al- Molk Dome



Politecnico di Torino

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The Analyze of the Historical Construction System of the Iranian Architecture, Transition Zone of the Dome

Case Study: Nizam-al- Molk dome in Iran.

Supervisor:
Edoardo Piccoli

Co- Supervisor:
Cesare Tocci

Candidate:
Roya Homayooni

ABSTRACT

This thesis investigates the historical construction system and structural logic of Iranian architecture. then, by analyzing dome transition systems in Iranian architecture through a detailed case study of the Nizam al-Mulk Dome in the Jameh Mosque of Isfahan. It explores how Iranian builders achieved stability and enormous spaces without centering frameworks, relying instead on geometric precision, material intelligence, and modular construction principles. The research begins with a historiography of construction history in Iran, from the ancient civilizations in Iran through the contemporary era highlighting key figures, historical descriptions, institutions, and international collaborations. in the next step, the study examines the characteristics and evolution of Iranian architecture in different eras especially typologies of arches, vaults, and domes, analyzing their geometric configurations and structural performance across time. Particular attention is given to the squinch system, which played a crucial role in transitioning from square bases to circular domes and later evolved into complex compositions. The Nizam al-Mulk Dome serves as a pivotal example, represents the technical and symbolic culmination of Iranian architecture, where mathematical reasoning and craftsmanship converge to produce a stable, enormous and enduring structure. This dome was selected as the central case study of the thesis because its construction technique particularly in the transition zone is complicated, innovative and rich in different especial Iranian styles in the construction and structure solutions. Combining architectural analysis, structural behavior and historical sources, this research aims to reconstruct the underlying logic of Iranian dome construction, contributing to a deeper understanding of Iran architectural heritage within global construction history.

Keywords: Iranian architecture, dome transition system, Nizam al-Mulk Dome, Construction History, Structural behavior, Geometry, squinch, Seljuk architecture.

Table of Contents

Introduction

The architectural heritage and its construction system of Iran represents one of the rich traditions in the world which is distinguished by its geometry, material logic, and spatial innovation. Among the many structural achievements of this tradition, the development of dome construction and more specifically, the invention of transition systems that convert a square plan into a circular dome and the dome construction without centering and load transmitting by this transition system is one of the identities of Iranian architecture which use successive refinement of squinch-based transition systems, rib-like structural logic, and diverse arch typologies. These innovations are the outcomes of centuries of experimentation, empirical knowledge, and the transmission of craft-based expertise from one master builder to another. Yet despite the importance of this knowledge, much of the structural and geometric intelligence embedded in traditional Iranian architecture has remained understudied because this knowledge was preserved not through academic institutions, but through the tacit experience of traditional master builders, whose understanding of geometry, material behavior, and construction sequencing was transmitted orally or through practice. As these master builders age and their numbers diminish, this knowledge is increasingly at risk of being lost. Today, many of the techniques that once defined Iranian architectural identity survive primarily in historical buildings, scattered manuscripts, and rare archival sources. This growing gap between traditional knowledge holders and contemporary architectural research underscores an urgent need for systematic analysis and documentation to ensure the continuity and preservation of this intellectual heritage. because the preserving this knowledge can be beneficial in the sustainability of architecture around the world as a adopted architecture with environment and climate. moreover, by improving this historical knowledge with modern technics, new solutions for architectural problems are introduced. The Jameh Mosque of Isfahan as a museum of Iranian architecture, embodying transformations from the pre-Islamic period to the culminating achievements of the Seljuks and later. in other words, it includes architectural inventions and additions of every period of Iran history and era, analyzing that it's like analyzing the whole Iranian architecture. Within this complex, the Nizam al-Mulk Dome stands as one of the most important structural innovations in the history of Iranian architecture. Its transition zone demonstrates an extraordinary combination of geometric creativity, constructive intelligence, and symbolic intentionality for having the enormous building. For this reason, the Nizam al-Mulk Dome offers an unparalleled case study for understanding the larger epistemology of Iranian construction. This thesis therefore situates the dome within a broader historical and technical context. Ultimately, this research aims not only to provide a detailed structural and historical analysis of the Nizam al-Mulk Dome but also to contribute to the preservation of endangered traditional knowledge for using in contemporary world for having the sustainability. By situating the dome within both its local tradition and the broader narrative of global architectural development, the thesis demonstrates how Iranian builders synthesized craftsmanship, scientific thought, and cultural meaning to produce one of the most enduring architectural achievements.

Translation and Research Methodology

The methodology of this research is grounded in a multidisciplinary approach combining historical inquiry, field-based observation, architectural analysis, and structural interpretation. The research began with an extensive examination of historical Persian sources, including architectural treatises, classical historiographies, archaeological reports, and modern studies on Iranian construction traditions. A significant portion of these Persian references was available to the author in digital (PDF) format, while many others were part of the author's personal architectural library in Iran. During a research trip to Iran undertaken in the course of this thesis, additional primary materials were consulted directly in physical form. This included visits to the National Library and Archives of Iran, where rare manuscripts, printed historical documents, and architectural reference works were examined firsthand. In parallel, English-language sources accessed through the Polytechnic of Turin library, academic journal databases, and previously collected scholarly materials were systematically reviewed and integrated. Because many foundational references were in Persian, the main body of the thesis was first developed in Persian and subsequently translated into English under the author's supervision, using ChatGPT with the architectural and academic language. Specialized terminology particularly technical vocabulary related to domes, squinches, arches, vaults, construction sequences, and structural behavior was carefully verified using authoritative lexicons, including the Cyclopedia of Iranian Professional Architecture, to ensure consistent and academically precise usage across the thesis.

TIMELINE

IRAN

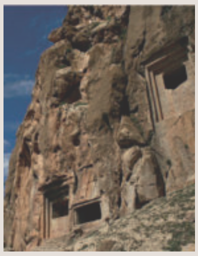
Prehistoric and Protohistoric

10000–4000 BCE

Elamite Civilization

2700–539BCE

Elamite Civilization



728–550 BCE

WORLD

Early settlements, Natufian Culture, Neolithic Revolution in

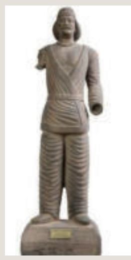
Old and New Kingdoms of Egypt, Mesopotamian city-states, Ur, Babylon

Neo-Assyria n Empire, Greek

Achaemenid Empire

550–330 BCE

Parthian Empire



247–224 CE

Sasanian Empire

224–651 CE

Classical Greece, Peloponnesian War, Macedonian

Roman Republic, early Roman Empire

Late Roman Empire, Byzantine Empire

Early Islamic period

651–1055 CE

Early Middle Ages, Carolingian Empire, Islamic Spain (Al-Andalus)

Seljuk Dynasty

1055–1230 CE

High Middle Ages, Romanesque & Gothic architecture, First Crusades)

Mongol/Ilkhanid Period

1220–1353 CE

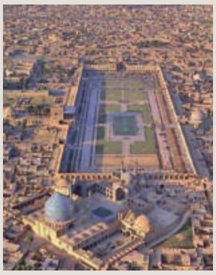
Late Medieval period, Gothic architecture, Black Death in Europe

Timurid Dynasty

1370–1507 CE

Early Renaissance in Italy (Brunelleschi, Alberti)

Safavid Empire



1501-1706 CE

High Renaissance, Baroque Period

Qajar Dynasty

1794-1925 CE

Enlightenment, Industrial Revolution, Neoclassicism

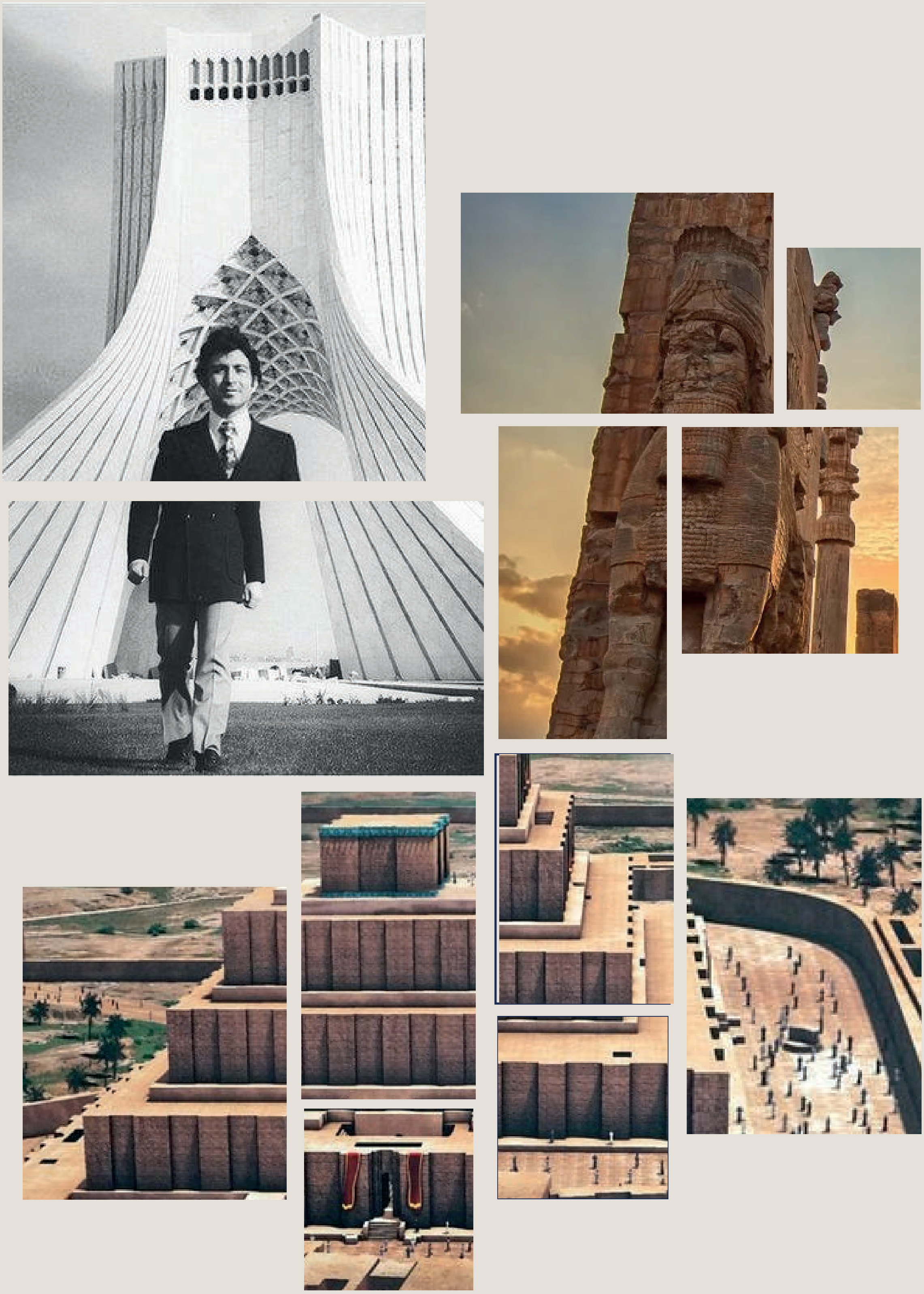
Pahlavi Dynasty and Contemporary Iran

1925 CE-Present

Enlightenment, Industrial Revolution, Neoclassicism

The History of Construction History of Iran
(State of the Art)

1



Iran, as one of the oldest civilizations in the world, is rich in construction and structural heritage from the ancient periods till now and it holds a wide array of natural and architectural heritage. however, to the reason of lacking traditions of writing, there are not vast array of documents about the details, structures and etc., the most references are including tablets, inscriptions, seals, and architectural structures that offer valuable insight into ancient building techniques. the oldest documents are discovered in ancient archaeological sites such as Tappe Yahya, Godin Tappe from the Elamite which they are historical tablets which contain administrative and economic records indirectly linked to construction practices like structure and context imply systematic documentation of labor, resource allocation, and construction materials [1]. moreover, In the ancient site of Chogha Zanbil, a major Elamite complex, thousands of inscribed bricks in Elamite cuneiform have been unearthed, directly referencing architectural details. A prominent inscription by the Elamite king Untash-Napirisha reads: “I built this ziggurat with glazed bricks in silver and gold colors, with marble and white obsidian, and dedicated it to the gods Humban and Inshushinak.” This inscription reveals a sophisticated understanding of materials and architectural aesthetics (Fig.1). From the Achaemenid period, monumental inscriptions emerge as the earliest formal documentation of construction history in Iran [2]. The Bisotun Inscription (c. 520 BCE), commissioned by Darius the Great near present-day Kermanshah, is widely regarded as the earliest known Iranian text (Fig.2).

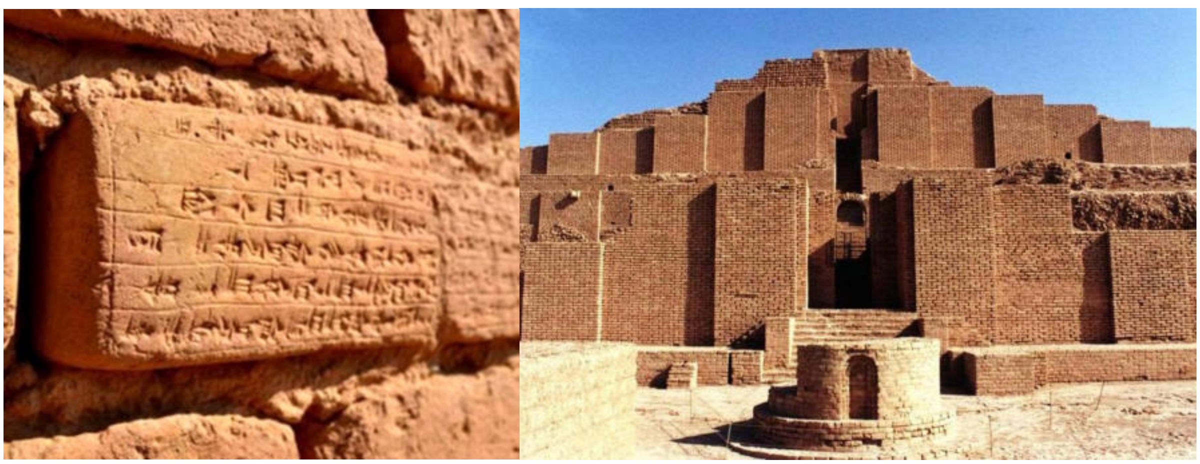


Fig.1 Chogha Zanbil and inscribed bricks, Reference: [1].

Fig. 2 The Bisotun Inscription, Reference: [2].

The Persepolis complex further exemplifies Achaemenid construction, featuring both architectural grandeur and administrative records [3]. there plenty of tablets were discovered there about the the process of constructing and sources of materials. In one of Persepolis' foundation inscriptions, Darius declares: "As it has been seen above, this fortress was built; before, there was no fortress here. By the will of Ahuramazda (the historical Iranian God), I built it, made it secure and beautiful, just as I desired." This underscores the royal intent to immortalize construction achievements. The Fortification Tablets from Persepolis are about construction materials such as bitumen for waterproofing and timber for doors and frameworks, and the sources of stones from Egypt and also, they are demonstrating detailed project management [4]. During the Sasanian period, several inscriptions provide evidence of architectural and construction activity. The inscription of Ibnun at Barme Delak near Shiraz commemorates the construction of a fire temple. Inscriptions at Naqsh-e Rustam from Ardashir I and Shapur I, written in Middle Persian, Parthian, and Greek, contain references to public works and architectural patronage [5]. With the advent of Islam, the recording of technical and construction knowledge in Iran entered a new phase. In addition to architectural inscriptions on religious buildings and caravanserais, scientific and technical texts emerged. In the 10th century CE, Abu al-Vafa al-Buzjani authored a treatise titled "Ma Yahtaj Ilayh al-Sani Amal al-Hendeseh", widely regarded as the first manual directly addressing the needs of architects and builders. His work bridged theoretical mathematics and practical architectural applications, covering geometric drawing techniques, calculations, and structural design [6]. In later centuries, other scholars contributed significantly to the scientific discourse on architecture. In the 15th century, Jamshid al-Kashi composed one of the most detailed mathematical-architectural works of the Iranian architecture. His book, "Miftah al-Hisab", contains chapters on measuring architectural volumes and surfaces, including domes, arches, squinches, and muqarnas. A separate treatise attributed to him, "fi al-Taq va al-Azaj", delves deeper into the geometry of structural elements (Fig.3) [7]. this book yet is the most reliable references for the construction system of Iranian architecture.

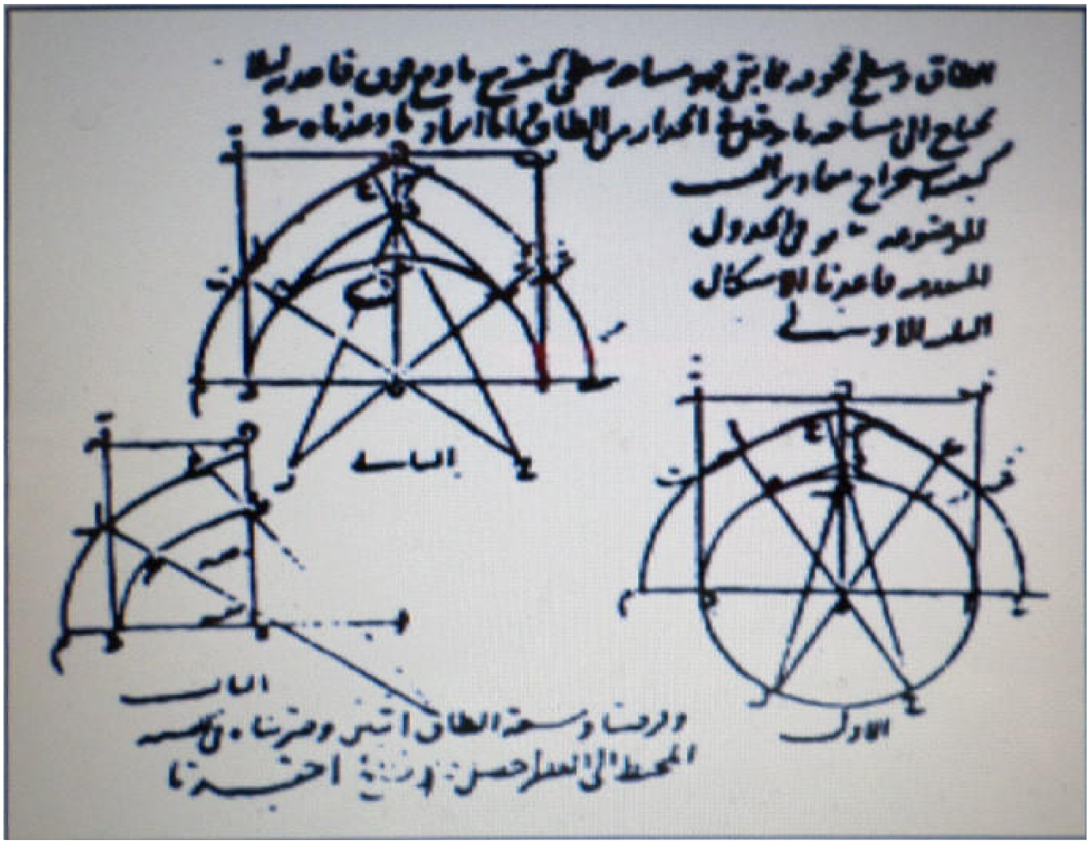


Fig.3 A page from *Miftaḥ al-Ḥisab* (*The Key to Arithmetic*) by Jamshid al-Kashani. In the section on arches and vaults, he presents a geometric typology of Iranian arches. Reference: [7].

moreover, other documents are written by another civilization writers such as Roman and Greek like Herodotus. in the later periods, European travelers, architects, and archaeologists who visited Iran from the 15th century through the 18th 19th century played a crucial role in shaping the historiography of Iranian architecture and construction history. Their observations, excavations, publications, and drawings continue to influence contemporary scholarship [8]. for example, Ruy Gonzalez de Clavijo, a Spanish envoy to Timur’s court in the early 15th century, provided observations of Timurid architectural policies, including monuments like Gur-e Amir and the Bibi Khanum Mosque (Fig.4).

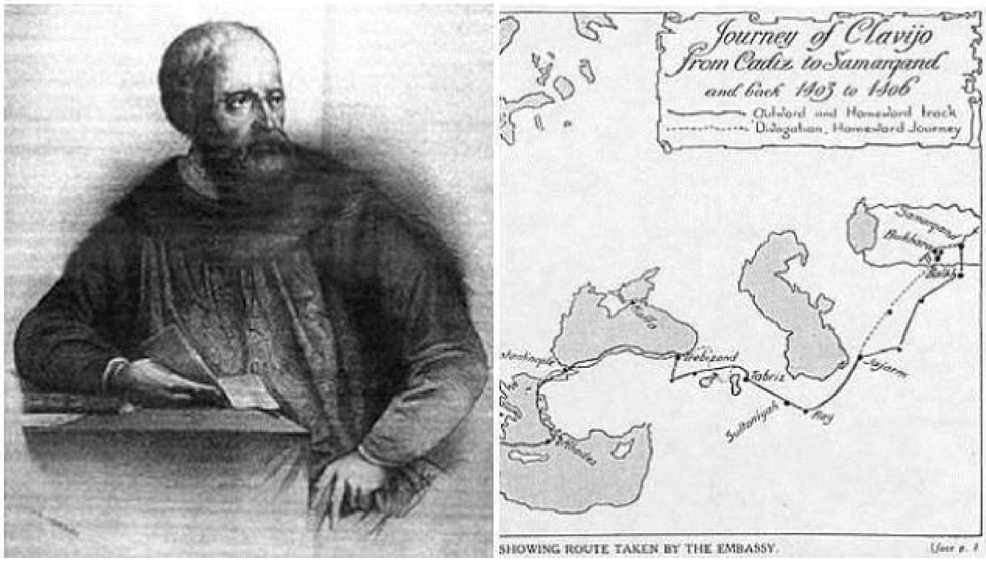


Fig.4 Ruy González de Clavijo, ambassador of King Henry III, and the route he took to Samarkand (Uzbekistan), Reference: www.elhistoriadores.com

Pietro della Valle, an Italian traveler in 17th, journeyed through Safavid Iran and documented his encounters in detailed letters. His writings offer some of the earliest European descriptions of urban life, architecture, and construction practices in cities such as Isfahan (Fig 5) [10]. Moreover, Jean-Baptiste Tavernier, a French gem merchant and Adam Olearius traveled to Iran multiple times and provided descriptions of bazaars, mosques, and public buildings. (Fig 6, 7) [11].

Fig.5 Della Valle's Persia, Reference:[10].

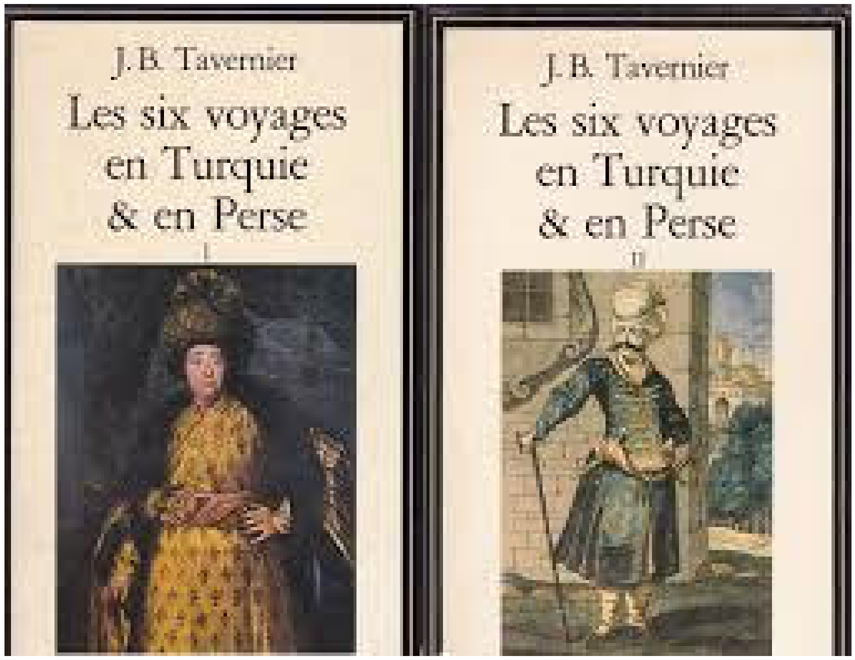


Fig.6 Cover of *The Six Voyages of John Baptista Tavernier* (London: 1678). Source: Internet Archive, https://archive.org/details/sixvoyagesofjohn00tave, accessed 26 September 2025.

Fig. 7 Isfahan (Isfahan) Capital of the Persian Kingdom, by Adam Olearius, published in Leiden by Pierre van der Aa, 1719, Reference:[11].

Another important traveler is Jean Chardin, a French traveler who spent over ten years in Iran, authored an extensive ten-volume travel account that remains a cornerstone in the study of Safavid architecture and urbanism. his paintings from the Iranian buildings such as palaces and gardens with details are the rich references of Iranian architectural knowledge. He painted the quality of construction and the integration of aesthetic and functional elements and also, he described different architectural characteristics of Iranian architecture like domes and minarets really close to reality (Fig 8). Chardin provided detailed descriptions of Safavid gardens, particularly the Chahar Bagh and the expansive gardens of Hezar Jarib which these gardens are full of especial Iranian technics in construction even the technics and buildings for supplying water are depicted in his paintings (Fig.9). He remarked on the relationship between water, geometry, and shade in Persian landscape design: " The great art of the Persians consists in arranging the water with such skill that it flows throughout the entire expanse of the gardens."[12].

Fig. 8 Chardin's depiction of Isfahan's urban layout and architecture, Reference:[12]

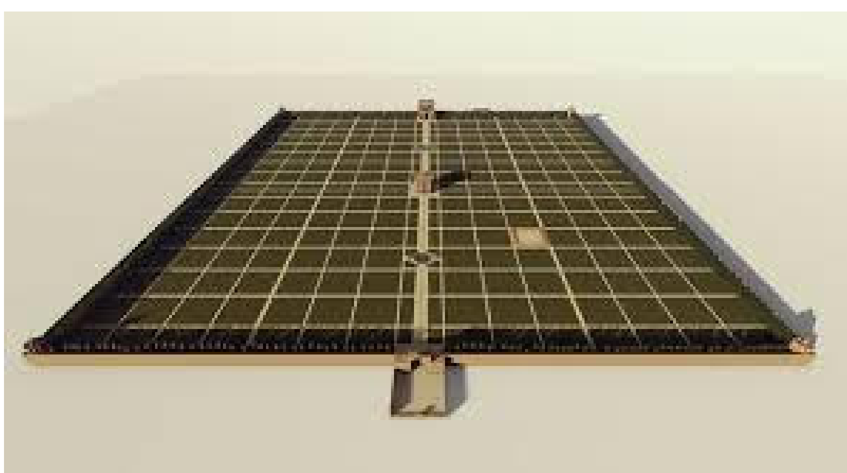


Fig. 9 Remodeling of Chardin's depiction of Hezar Jrib Garden, Reference:[13]

in Safavid era Engelbert Kempfer, a German traveler visited Iran also and offered valuable observations on Iranian architecture. He was deeply impressed by the scale and planning of urban landscapes in Safavid Isfahan. He was writing and painting many gardens and palaces in Iran with structural and architectural detailes and for this reason his paintings is a good reference for knowing the Iranian architecture better. (Fig 10) [14].

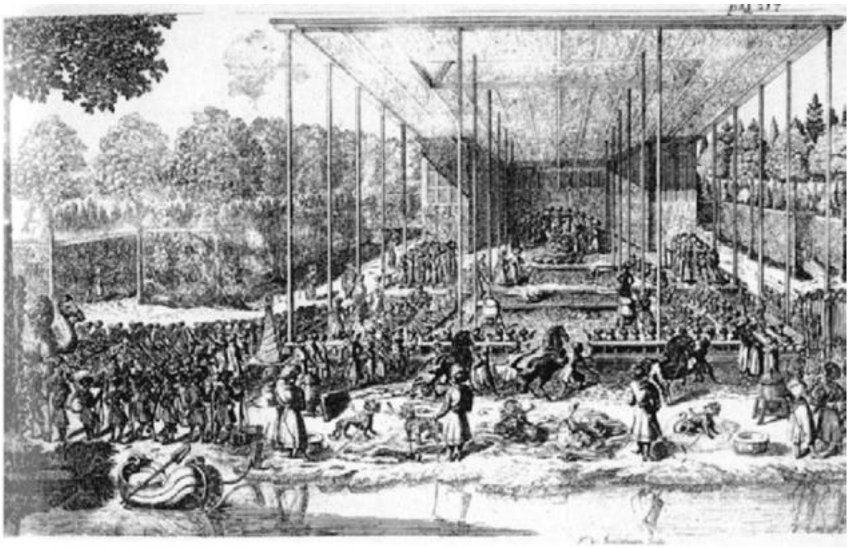


Fig. 10 Kemper's painting of Isfahan's Safavid Palace, Reference:[14].

James Morier, a British diplomat during the Qajar period, produced travelogues rich in descriptions of construction materials and spatial organization in cities like Tehran and Shiraz. He wrote in his book: "The bricks and mortar of Tehran may be crude, but they encase a society of vibrant ingenuity " (Fig 11) [15].

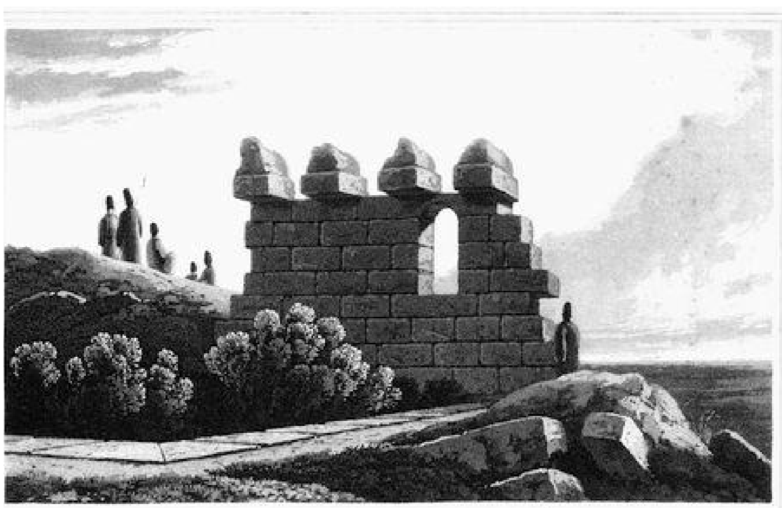


Fig. 11 Shapor Palace in Iran drown by James Morier, Reference:[15].

James Morier, a British diplomat during the Qajar period, produced travelogues rich in descriptions of construction materials and spatial organization in cities like Tehran and Shiraz. He wrote in his book: "The bricks and mortar of Tehran may be crude, but they encase a society of vibrant ingenuity " (Fig 11) [15]. in addition, Robert Ker Porter, a British traveler and artist, journeyed through Iran and produced panoramic drawings of Persepolis and other ancient sites. His visual documentation was among the earliest European efforts to accurately depict Achaemenid ruins. he wrote in his book: "These remains speak, with a voice that will not die, of the power and magnificence of ancient Persia. The proportions of the figure are not in the least defective, nor can any fault be found with its taste, being perfectly free from the dry wooden appearance we generally find in Egyptian works of the kind; and, in fact, it reminded me so entirely of the graceful simplicity of design which characterizes the best Grecian friezes, that I considered it a duty to the history of the art, to copy the forms before me, exactly as I saw; without allowing my pencil to add, or diminish, or to alter a line" (Fig 12) [16]. from this script we can understand that his depicts were close to reality as a copy and in this way, they are rich references for analyzing especially the construction systems and historical buildings which they are ruined and vanished in the Modern days.

Fig. 12 Painting Persepolis by Robert Ker Porter, Reference:[16].

in the 18th and 19th century and in the Age of Enlightenment in Europe the plenty of archeologist travelled to Iran for discovering the history. therefore, William Kennett Loftus, a pioneering British archaeologist and explorer, conducted some of the earliest systematic excavations at Susa during the 1850s. His discoveries, notably the identification of the Apadana palace complex, were foundational in shaping the 19th-century understanding of Iranian palace architecture. His contributions laid the groundwork for subsequent archaeological research and remain a cornerstone in the study of ancient Iranian construction history (Fig 13) [17]. in addition, Jane Dieulafoy, a French explorer and archaeologist, conducted significant excavations in Susa alongside her husband Marcel. Her illustrated travelogue, La Perse, la Chaldae et la Susiane, contains some of the earliest analytical representations of Achaemenid architecture, including brickwork and reliefs. Marcel-Auguste Dieulafoy collaborated in excavating the Darius palace complex and was instrumental in reconstructing Achaemenid architectural elements in European museums. “According to Dieulafoy, all valuable artefacts were carried away, and those that could not be transported were chopped with axes” (Fig 14) [18].”

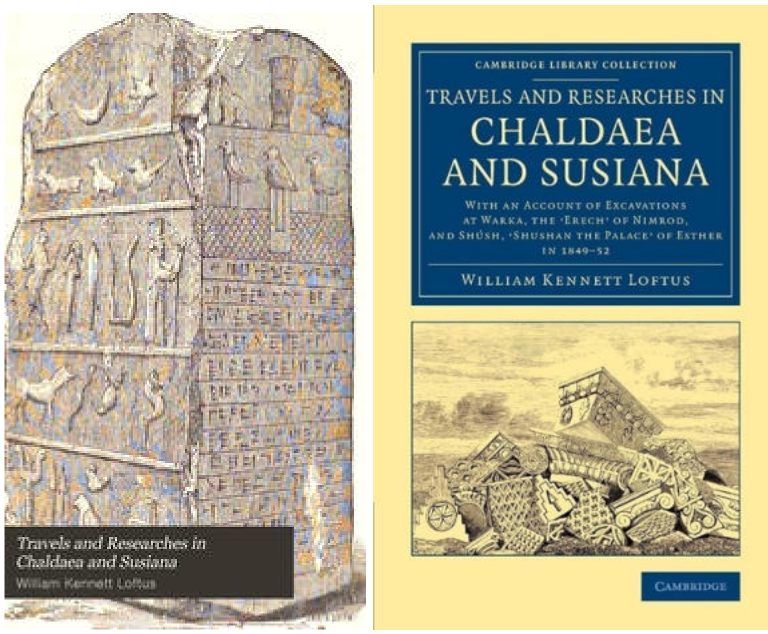


Fig. 13 front cover of Chaldae and Susiana by Robert Ker Porter, Reference: Internet archive.

Fig. 14 Sarvestan Palace drowned by Jane Dieulafoy, Reference:[18].

Roman Ghirshman, a French archaeologist, improved the study of pre-Islamic Iranian architecture through his extensive excavations at ancient sites such as Tappe Sialk. He combined archaeological findings with architectural analysis to reconstruct the evolution of Iran's built environment from the earliest civilizations through the Sassanian period. (Fig 15) [18, 19]. in this time, Ernst Herzfeld who was German archaeologist and orientalist, excaviated and studied at Persepolis and Pasargadae profoundly advanced the study of Achaemenid architecture and construction techniques. His comprehensive architectural drawings, photographs, and detailed site plans remain fundamental references for scholars of ancient Iranian architecture. He famously stated, "Iranian architecture is not just an art, it is the material embodiment of imperial ideology" [20]. Herzfeld's bridged archaeological evidence with architectural analysis, highlighting the sophisticated engineering and symbolic language embedded within Achaemenid and Iranian construction (Fig 16) [20].

Fig. 15 Roman Ghirshman on the site of the Apadana Palace, Reference: https://granger.com/.

Fig. 16 Ernst Herzfeld on the site of Persepolis, Ernst Herzfeld at Persepolis. Photograph, ca. 1930-1935. Arthur M. Sackler Gallery Archives.

In the 20th century Friedrich Krefter, a scholar and architectural historian, significantly advanced the visual and analytical understanding of Persepolis and ancient Persian architecture. His pioneering work involved meticulous visual reconstructions of the Persepolis ruins, combining archaeological evidence, historical texts, and comparative architectural analysis to recreate the site's original grandeur. Krefter's reconstructions were not mere artistic interpretations but grounded in rigorous research, allowing scholars to better comprehend the spatial organization, structural systems, and symbolic meanings embedded in Iranian architecture. His detailed drawings and measured plans were instrumental in documenting fragile architectural elements threatened by natural erosion and human interference (Fig17) [21]. in this field, Erich Friedrich Schmidt, an American archaeologist with the use of aerial photography for archaeological surveys, conducted excavations at key Iranian sites including Persepolis, Naqsh-e Rustam. Schmidt's innovative application of aerial surveys allowed for the precise mapping and documentation of large archaeological complexes, greatly enhancing the understanding of spatial organization and construction techniques used in Achaemenid and earlier civilizations (Fig 18) [22].

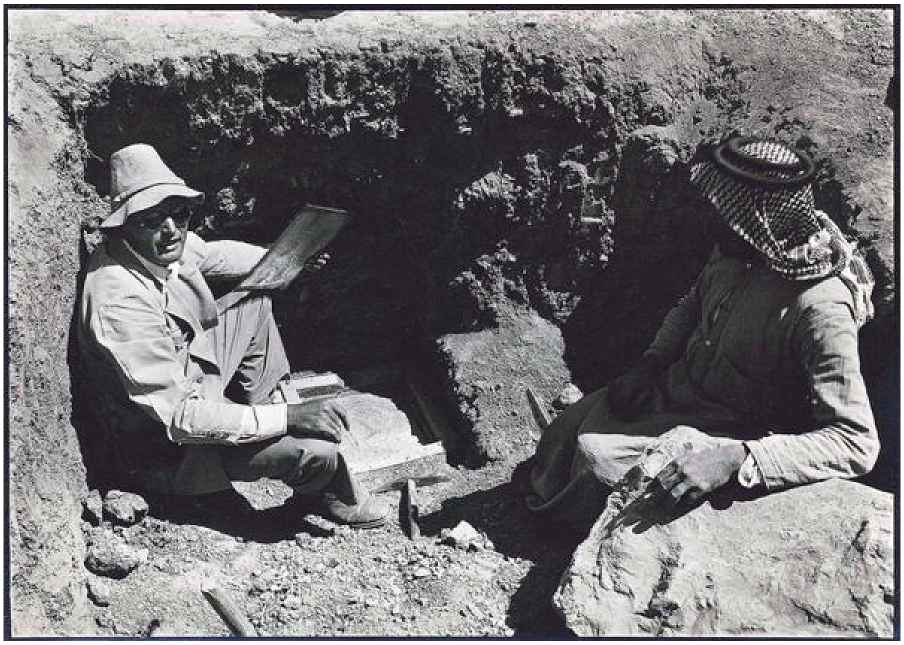


Fig. 17 Site architect Friedrich Krefter separates the gold and the silver tablets that were discovered at the excavation of Persepolis. Hans-Wichart von Busse, "Excavation of tablets." Gelatin silver print. Collection of Azita Bina and Elmar W. Seibel, TL41708.51., Reference: https://harvardartmuseums.org/

Fig. 18 Eighteen aerial photographs and views of Persepolis and Iranian archaeology by Erich Friedrich Schmidt

after 19th century and in the 20th century Iran has changed in different aspects and these changes started the fundamental and new approaches in Historiography and knowledge of architecture and construction. in this period one of the effective characters was Andre Godard. he was a French architect, archaeologist, and art historian, who Appointed as the director of the Iranian General Administration of Antiquities in 1928, he oversaw numerous conservation projects, including the restoration of key monuments such as the Friday Mosque of Isfahan and the Tomb of Hafez in Shiraz. Godard also played a central role in founding the National Museum of Iran in Tehran, which he designed and directed, promoting a vision of museology rooted in scientific classification and cultural authenticity. Godard emphasized the continuity and originality of Iranian architecture, asserting that “Architecture in Iran is neither Eastern nor Western, it is distinctly Iranian.” His approach combined archaeological precision with architectural sensibility, setting a model for future interdisciplinary research in Iran. his researches in Iranian architecture and historical construction in Iran for designing the National Museum and central library become key roles for further architecture and researchers. For example, for designing national museum he studied the diversity of Iranian structure and construction systems such as Arcs and with the inspiring of the structural behaviors of Iranian arches he designed the entrance of museum (Fig 19).

Fig. 19 the National Museum of Iran in Tehran designed by André Godard, Reference: https://irannationalmuseum.ir/

Among the most influential foreign scholars during the Pahlavi period was Arthur Upham Pope, an American historian of art and architecture. his works established Iranian architecture as a central field within global art historical discourse [24]. Pope was not only a scholar but also a cultural ambassador for Iran and his book culminated in the monumental multi-volume series A Survey of Persian Art from Prehistoric Times to the Present [36]. Pope scholars yet are the most important and rich of the construction and structural architecture of Iran [24]. He organized major photographic and architectural documentation campaigns across Iran, producing one of the earliest comprehensive visual records of architecture in the country (Fig 20) [25]. These documents these days are the references for rebuilding the historical cities with their buildings in Iran. it should be noticed that one of important early contribution to the historiography of Iranian construction is The Architecture of Iran: The Ilkhanid Period, written by American scholar Donald Newton Wilber as his doctoral dissertation which is affected by Pop scholars [26]. moreover, another important document is written by Josef Strzygowski which has profound influence on the study of Iranian art and architecture through his extensive writings. Strzygowski's comparative approach, which sought to trace the diffusion of artistic forms across Eurasia, brought renewed scholarly attention to the architecture of Iran, situating it within broader transregional currents [27].

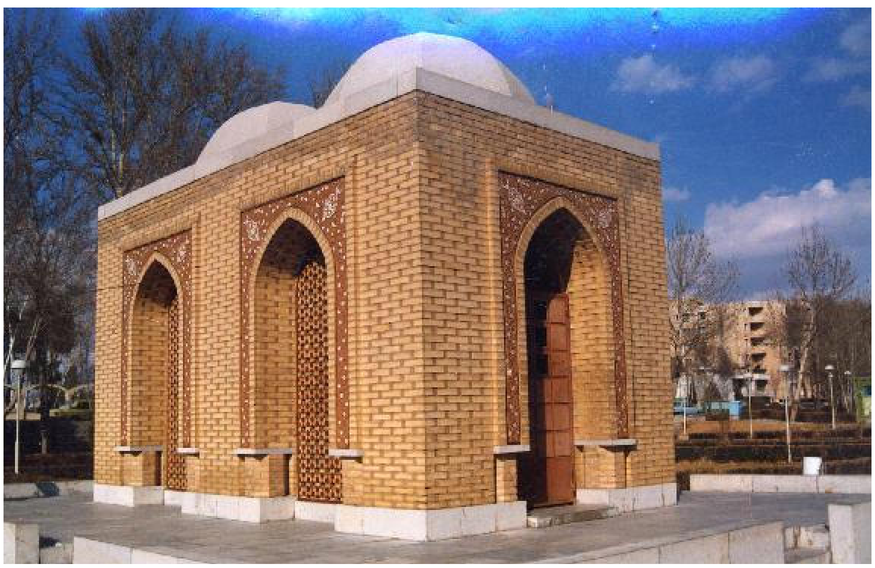


Fig. 20 Tomb of Arthur Upham Pope in Isfahan, Iran, Reference: [25].

However, the Pahlavi era marked a decisive turning point in the institutionalization and systematic study of Iranian architectural history. The establishment of the Society for National Heritage of Iran (Asar-e Melli) catalyzed efforts towards the documentation, preservation, and restoration of Iran's architectural patrimony [25]. The Society undertook major restoration projects, including the Tomb of Hafez in Shiraz, the Tomb of Ferdowsi in Tus, and the historic Jameh Mosque of Isfahan, thereby fostering a national architectural consciousness grounded in cultural identity and historical continuity (Fig. 21) [25]. and also, under support of this organization researching and studding about the architectural heritages and origins were done with more detailes and more academic approaches. in this period architects helped to knowledge of historical construction of Iran by analyzing them and using them in their designing in the contemporary styles. for instance, Mohesn Foroughi and Hosein Lorzadeh, were key figure, contributed extensively to the architectural and history of construction of Iranian architecture. Hosein Lorzadeh contributed to drawing and analyzing different historical construction systems like Iranian arcs. This era (Pahlavi era) also witnessed the establishment of formal academic institutions dedicated to architecture. The Faculty of Fine Arts at the University of Tehran, founded in 1940, became the epicenter of architectural education and research. Faculty members such as Maxime Siroux and Andre Godard integrated Western academic standards with deep respect for Iranian architectural heritage (Fig 22) [28]. These institutions fostered a new generation of architects and historians who began rigorous documentation and theoretical studies of Iranian construction history.

Fig. 21 Tomb of Ferdowsi, designed by Hosein Lorzadeh under the commission of Anjoman-e Asar-e Melli, Reference: [28].

Fig. 22 The Faculty of Fine Arts at the University of Tehran, Iran, Reference: [28].

one of these architectures who played an important role in Iraninan architecture adn construction knowledge was Houshang Seyhoun. As both a practicing architect and a scholar, Seyhoun emphasized the continuity of Iranian architectural identity through a modernist lens. His works such as the tombs of Ferdowsi, and Nader Shah embody a reinterpretation of historical motifs, aiming to synthesize national heritage with modern expression (Fig. 23). Seyhoun's public lectures and writings also contributed significantly to a national narrative of architecture that located Iranian identity [29]. he also used different historical Iranian architecture in his designing to preserve them from the forgetting. The history of Iran's architectural profession in the second half of the twentieth century cannot be understood without considering the profound role of transnational engagements.

Fig. 23 the tomb of Nader Shah by Houshang Seyhoun, Mashhad, Iran, Reference: [28].

Fig. 24 Tehran Museum of Contemporary Art by Kamran Diba, Tehran, Iran, Reference: [28].

in the further time especially after Revolution in Iran in 1979 Key figures such as Mohammad Karim Pirnia and Mohammad Ayatollah-Zadeh Shirazi sought to document and preserve traditional Iranian architecture in the face of rapid urban transformation and Westernization. Pirnia, widely regarded as the father of the field, worked on the indigenous architectural principles such as hierarchy, modularity, and climatic responsiveness [30]. in his framework, he introduced "five principles" of Iranian architecture (human scale, structural clarity, avoidance of waste, harmony with nature, and symbolic geometry), became foundational for subsequent generations [30]. he relieved most of the heritages of Iran from the ancient time and documented them with plan, sections, designing details and photos in his books. his books have become the most important references for knowing about the structural architecture and their behaviors. moreover, Among the most influential figures in the historiography of contemporary Iranian architecture, Amir Bani-Masoud has played a pivotal role in shaping academic discourse through both scholarship and pedagogy. Trained as an architect and architectural historian, Bani-Masoud is best known for his extensive research on the evolution of architectural thought and practice in Iran from the Qajar period to the present [28, 31]. In the especial field of construction history other architectures and researchers like Ayat-allah-zade Shirazi were effective. They tried to record the geometrical and historical designs of Iranian structures and components in their researches such as two articles about arches, vaults and domes which are the one reference for new researches.

Fig. 25 Naghsh-e- Jahan square, Isfahan, Iran, Reference: [52].

The History of Construction of Iran

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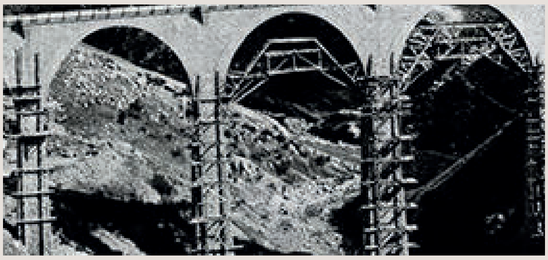
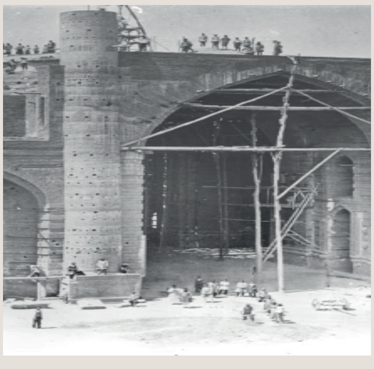




by starting civilizations human came out of caves and tried to make one safe place for himself, this a start points of history of architecture. in Iran from the Neolithic period, with the formation of the first permanent settlements, significant architectural heritages were constructed. During this time, people used mud bricks, wattle and daub, and natural materials to build early dwellings and organize their living spaces based on basic architectural principles. Gradually, with advancements in construction techniques, social and religious spaces also began to emerge in architecture. Neolithic architecture in Iran witnessed the creation of structures such as mud-brick houses in archaeological sites like Nushi jan Tappe, Tappe Chogha Mish, Tappe Cheshmeh Ali, and Tappe Sialk. These sites indicate the beginning of urbanization and the development of public spaces and diverse functional areas in the architecture of that era.

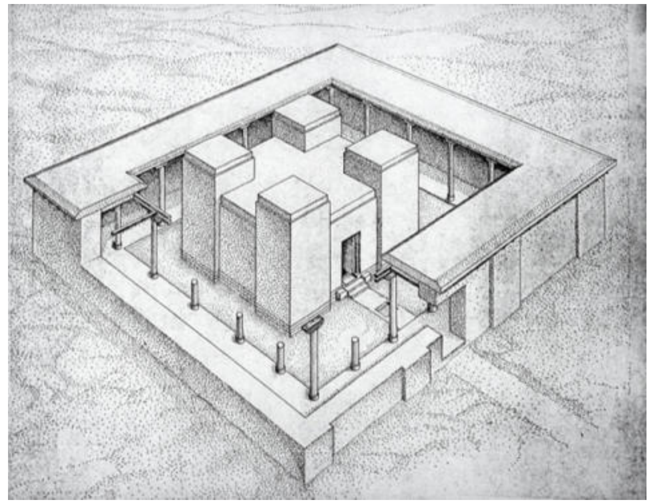
2.1 Pre-Islamic Architecture

-The Urartian and Elamite

the study of the history of construction in Iran tracing back to the Urartian and Elamite civilization, and their pivotal role in shaping architectural traditions in the region. The Urartian established a powerful kingdom in the 9th century BCE, spanning present-day eastern Turkey, northwestern Iran, and Armenia [36]. Their architectural advancements encompassed fortifications, urban planning, religious structures, and sophisticated water management systems such as Extensive canal networks, and aqueducts were meticulously constructed to distribute water efficiently, which were integral to their socio-political stability and economic growth. Urartian cities were strategically constructed on elevated terrains to maximize defense and control over surrounding landscapes. Their fortifications, composed of meticulously cut and fitted stone blocks, exemplified advanced masonry techniques (Fig.26) [37]. Religious architecture in Urartu was deeply intertwined with state ideology, as temples often occupied central positions within fortified settlements. Constructed on raised platforms, these temples adhered to a rectangular layout with a central sanctuary surrounded by auxiliary chambers for religious and administrative functions. this form of tempels in the later periods we repeated. Walls were adorned with inscriptions and intricate reliefs depicting divine figures and royal ceremonies, highlighting the theocratic nature of Urartian governance also on the historical tablets of this era the residential buildings in two floors are shown. One of the most important archeological sites of Urartian is Tappe Hasanlu which is rich in their architectural characters (Fig.27) [38-40].

Fig.26 Hasanlu Tappe, which features a circular form, Reference: [37].

Fig.27 Temples and Religious Architecture, Reference: [37].



on the other hand, The Elamite, centered in the southwestern region of modern-day Iran, particularly around Susa, developed a unique architectural style which was the start point of Iranian architecture, climatic architecture and sustainable. in Iran. in other words, their construction techniques, urban planning, and monumental architecture significantly influenced later Iranian architectural traditions, particularly those of the Achaemenid Empire like the use of glazed bricks, monumental platforms, and columned halls [41,19]. The Elamite constructed grand palaces, often with large courtyards, columned halls, and extensive storage rooms. Fortifications played a crucial role in Elamite urban planning, as seen in the massive walls surrounding their cities, which were built to protect against invasions from Mesopotamian and Iranian tribes [41]. Tappe Chogha zanbil is the most significant building a temple of Elamite which shows the skills of using uncooked bricks in the large scale.

- *The Architecture and Urban Planning of the Medes*

after big immigrations of Arians, the Medes, were the first empire and united ancient Iranian people who emerged and significantly contributed to the development of early Iranian architecture. One of the earliest references to Median architecture comes from Herodotus in the 5th century BCE. In his histories, he describes the Median capital, Ecbatana (modern Hamadan), noting its concentric walls and grandeur [42]. Tappe Nushi Jan, one of the most extensively studied Median sites, reveals a well-planned citadel with an advanced layout, including a fortified temple complex, storage facilities, and residential quarters (Fig.28) [42]. in this place the first symptoms of four- Iwan and making Patkane is defined. The construction of massive mudbrick walls and stone foundations in sites such as Godin Tappe further underscores their architectural prowess in fortification techniques. The layout of these settlements suggests hierarchical zoning, where religious, administrative, and residential buildings were distinctly segregated. Fortifications were a hallmark of Median architecture. and they built their fortifications using thick mudbrick walls reinforced with stone [37].

Fig.28 The citadel of Tappe Nushi Jan, Reference:[37].

Median architecture is characterized by the extensive use of mudbrick, timber, and stone, reflecting both local material availability and technological advancements. Structures were typically rectangular, featuring columned halls and large central spaces, foreshadowing the hypostyle halls of later Persian architecture. The remains of fire temples, particularly at Tappe Nushi Jan, indicate the emergence of Zoroastrian religious architecture, which became a defining feature of Persian sacred spaces [42]. Another remarkable feature of Median architecture is the presence of stepped terraces, possibly precursors to later Persian platforms and palatial designs [43].

- The Architecture and Urban Planning of the Achaemenid

Under the rule of Cyrus, the Great and his successors, the Achaemenids developed grand architectural complexes, road networks, and irrigation systems that transformed the empire into a highly structured and efficient entity and in this way, they were affected by the median and before median architectures.[44]. The urban planning of the Achaemenids was characterized by the development of vast imperial capitals such as Pasargadae, Susa, and Persepolis. Pasargadae, founded by Cyrus the Great, set the architectural precedent for future Achaemenid cities, with its organized layout of gardens, palaces, and defensive structures (Fig.29) [45]. The concept of royal gardens, known as paradise, was a significant innovation that influenced later Persian garden designs [46]. Persepolis, constructed under Darius I, epitomized the grandeur of Achaemenid architecture. The city was built on a massive terrace with palaces, audience halls, and ceremonial staircases, adorned with intricate bas-reliefs depicting subject nations of the empire [46]. other significant heritages of achimenes in Iran were discovered in Susa which were built in the Darius I era with the all characteristics of Iranian and Achaemenid architecture styles.

Fig.29 Pasargadae, organized layout of gardens, palaces, and defensive structures, Source: [37].

Achaemenid architecture was distinguished by its use of hypostyle halls, massive stone platforms, and grandiose columned structures. The Hall of Hundred Columns and the Apadana Palace at Persepolis are among the most remarkable examples of Achaemenid architecture (Fig.30) [48]. The columns, often topped with elaborate animal-shaped capitals, showcased the artistic synthesis of Persian, Greek, and Mesopotamian influences. One of the key architectural innovations of the Achaemenids was their advanced water management systems. The construction of qanats (underground irrigation channels) enabled the expansion of agriculture and urbanization in arid regions [49]. Additionally, the Royal Road, a sophisticated network of roads and relay stations, facilitated communication and administration across the vast empire [50].

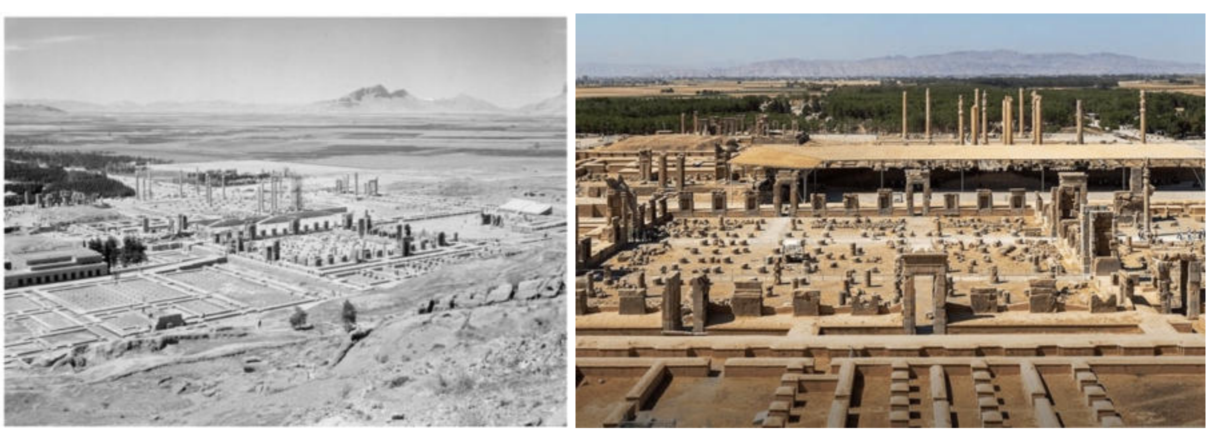


Fig.30 The Hall of Hundred Columns and the Apadana Palace at Persepolis, Source: [37].

-The Architecture and Urban Planning of the Parthian

With the attack of alexander, the great, the Achaemenid empire was vanished and for about two century the Greeks lived and were dominated on Iranian art, culture and architecture. after that Iranian history is witness of the Parthian Empire. the Parthian is known for its architectural innovations and urban planning strategies that reflected a synthesis of Persian, Hellenistic, and Mesopotamian influences [51]. The Parthians introduced new construction techniques, spatial organization, and decorative elements that significantly influenced later Iranian architecture, including the Sassanian and Islamic periods. One of the most significant contributions of Parthian architecture was the development of the Iwan, a large vaulted hall with an open front, which became a fundamental feature in later Persian and Islamic architecture. The Iwan first appeared in Parthian palatial and religious architecture and was constructed using advanced barrel vaulting techniques. Examples of this architectural form can be seen in the ruins of Hatra in modern-day Iraq and in the Temple of Mithra at Kangavar, Iran [30]. Cities like Nisa, the first capital of the Parthians, and Ctesiphon, their later capital, were designed with a blend of Persian and Mesopotamian spatial principles. These cities featured grand palaces, fortified walls, and ceremonial centers (Fig. 31) [51]. Parthian architecture was distinguished by its rich decorative details, which included stucco moldings, intricate brickwork, and vibrant frescoes. The use of stucco reliefs, often depicting royal figures, deities, and mythical creatures, became a hallmark of Parthian artistic expression. Parthian architects also developed innovative column styles that blended Hellenistic Corinthian designs with Persian motifs. The development of the iwan and large vaulted spaces laid the groundwork for monumental Sassanian structures, such as the Taq Kasra in Ctesiphon, and later Islamic mosques and schools [37].

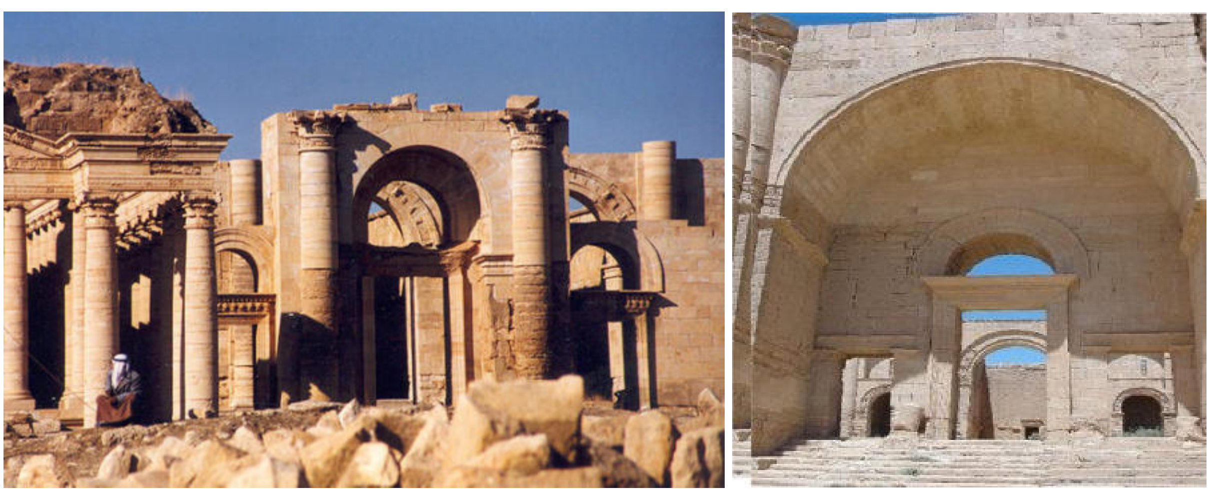


Fig.31 The ruins of Hatra, Iwan, Reference: [37].

- The Architecture and Urban Planning of the Sasanian

the ultimate empire of Iran before Arabs attack was The Sasanian Empire which is start with the Ardeshir I. Sasanian architecture was religious architecture and the most heritages of this period are temples. in Sasanian many new technics were invented for constructing grand palaces and fire temples, and urban centers that showcased their political power and religious beliefs. One of the most remarkable features of Sasanian architecture was the use of Arches and vaults techniques, Iwan and grand Domes with squinches. The Taq Kasra, or the Arch of Ctesiphon, is one of the most outstanding examples of such innovation, featuring a massive vaulted hall that remained the largest of its kind until the modern era (Fig.32) [52,53].

Fig.32 Taq Kasra, Reference: World History Encyclopedia.

The Sasanians established well-planned cities with circular layouts, a design inspired by earlier Persian and Mesopotamian traditions. The most famous example is Gundeshapur, which became a center of learning, engineering, and medicine, and Firozabad, designed with a radial layout and central administrative complex (Fig.33). The use of advanced water management systems, such as qanats and dams, make them as significant engineers and they inspired these skills of the Roman soldiers who they were arrested in the battles [53]. The Shushtar Hydraulic System, a UNESCO World Heritage site, is a testament to their advanced knowledge of water management, tunnels, and mills that optimized irrigation.

Fig.33 The city of Firozabad, Source: [37].

Sasanian religious architecture was deeply influenced by Zoroastrianism. Fire temples such as Takht-e Soleyman were built with a central domed chamber to house the sacred fire, a layout that influenced later Islamic mausoleums. Many temples were constructed on elevated platforms, reinforcing their spiritual significance. Royal palaces such as those in Bishapur and Sarvestan showcased elaborate stucco decorations, intricate mosaics, and large reception halls. The palaces often featured iwans opening onto courtyards, a feature that later became central in Islamic architectural design [56]. Sasanian architecture was richly decorated with carved stone reliefs, intricate stucco moldings, and colorful mosaics. these Palaces contained Roman-inspired mosaics depicting mythological and royal themes, reflecting the empire's interactions with other civilizations [54].

2.2 Islamic period

- *Early Islamic Architecture*

The Sasanian empire was vanished with the attack of Arabs and with the spread of Islam, many Sasanians architectural features, such as Iwans, domes, and squinches, were adapted into mosque architecture. Islam was a religion for poor people and invited people to simple life. therefore, in the first Islamic century which Arabs were dominated on Iranians the Iranian art and architecture was paused and the decorations and constructing grand buildings were forbidden. After centuries Iranian tried adopt their architecture in the Islamic rules and for this reason the Iranian architectural in the Islamic period was flourished. In other words, there is no Islamic architecture because Arabs didn't have any especial architecture, there is Iranian architecture in the Islamic era. in the Abbasid period constructing new builds but just mosque was started. but these buildings were simple and based on the prophet mosque without decorations and different spaces, in this period the Sasanian temples had changed to the mosque and the hypostyle mosques, characterized by rows of columns supporting wooden or brick roofs were constructed. An example is the early stages of the Jameh Mosque of Isfahan, which evolved over centuries [37].

- *The Seljuk Period*

The Seljuks introduced the four-Iwan mosque plan, which became a hallmark of Persian mosque architecture, emphasizing axial symmetry and spatial hierarchy. The Jameh Mosque of Isfahan exemplifies this design, with four large iwans surrounding a central courtyard, marking an evolution from the earlier hypostyle layout (Fig.34) [55]. This plan provided a sense of monumentality and grandeur, distinguishing Iranian mosques from their Arab predecessors. The formalization of this layout influenced later Persian and Central Asian mosques, establishing a template for architectural developments well into the Timurid and Safavid eras. Recent scholarly investigations into Seljuk domes in Isfahan have revealed a high level of structural and geometric sophistication and emphasizes the architectural rivalry between political figures, the integration of decorative calligraphy, and the influence of scientific and mathematical thought of the Seljuk period, notably inspired by the works of scholars like Omar Khayyam [56].

Fig.34 The four-Iwan plan in Iranian architecture, Reference: From "Architecture of the Islamic World" by George Michell (ed.), 1978.

Seljuk architects pioneered the double-shell dome, an innovation that allowed for larger, more stable domes with an elegant, lightweight outer shell which set a precedent for later Islamic and Ottoman domes. The double-shell technique enhanced the structural integrity of large domes while enabling a harmonious balance between weight and proportion [57]. Moreover, one of the defining features of Seljuk architecture was the refinement of arches, squinches, and muqarnas vaulting, which facilitated smoother transitions from square bases to circular domes [56].

- The Ilkhanid and Timurid Period

The Ilkhanid period marked a transformative era in Persian architecture, blending Mongol influences with established Iranian-Islamic design principles. The influx of Chinese and Central Asian motifs introduced new spatial concepts and ornamental techniques, resulting in a rich architectural heritage that laid the groundwork for subsequent developments in Timurid and Safavid architecture [58]. On the other hand, The Timurid dynasty brought about one of the greatest architectural flowerings in Persian history. Under Timur and his successors, architecture became grander, featuring larger domes, higher Iwans, and extensive tile decoration. A key architectural feature of this period was the ribbed and fluted domes, seen in Goharshad Mosque. Timurid architects also mastered glazed tilework, introducing haft-rang (seven-colored tiles), which allowed for intricate floral and geometric patterns [58].

- The Safavid Period

The Safavid era witnessed the consolidation of Persian architectural traditions into harmonious urban ensembles. Under Shah Abbas I, Isfahan was transformed into one of the most magnificent cities in the Islamic world. The construction of Naqsh-e Jahan Square, encompassing Shah Mosque, Sheikh Lotfollah Mosque, Ali Qapu Palace, and Qeysarieh Bazaar, established a new model of integrated urban planning (Fig 35). The Safavid architects developed sophisticated ribbed vaulting and double-shell domes, refining the techniques inherited from the Ilkhanid and Timurid periods. The dome of the Shah Mosque in Isfahan, rising to 53 meters in height and with an approximate external span of 25 meters and an internal clear span of 23 meters, is one of the finest examples of this innovation [59]. Sheikh Lotfollah Mosque presents another breakthrough in Safavid architectural ingenuity. Unlike the Shah Mosque, it lacks minarets and a courtyard, yet it features an extraordinary elliptical dome. This dome, with its delicate muqarnas transition, demonstrates a mastery of structural geometry and an unparalleled use of light and tilework to create a celestial atmosphere. The muqarnas system used in the Iwans of the mosque also displays a remarkable synthesis of mathematical precision and aesthetic elegance [60]. The Safavid period also saw the refinement of pointed arches which provided greater load distribution and allowed for larger spans in Iwans and gateways. The evolution of the four-Iwan plan in religious architecture reached its peak during this period, with larger and more elaborate Iwans featuring intricate tile mosaics and epigraphic decorations. These tiles, applied in complex arabesque and calligraphic compositions, reinforced the grandeur of the architecture and its celestial symbolism [30].

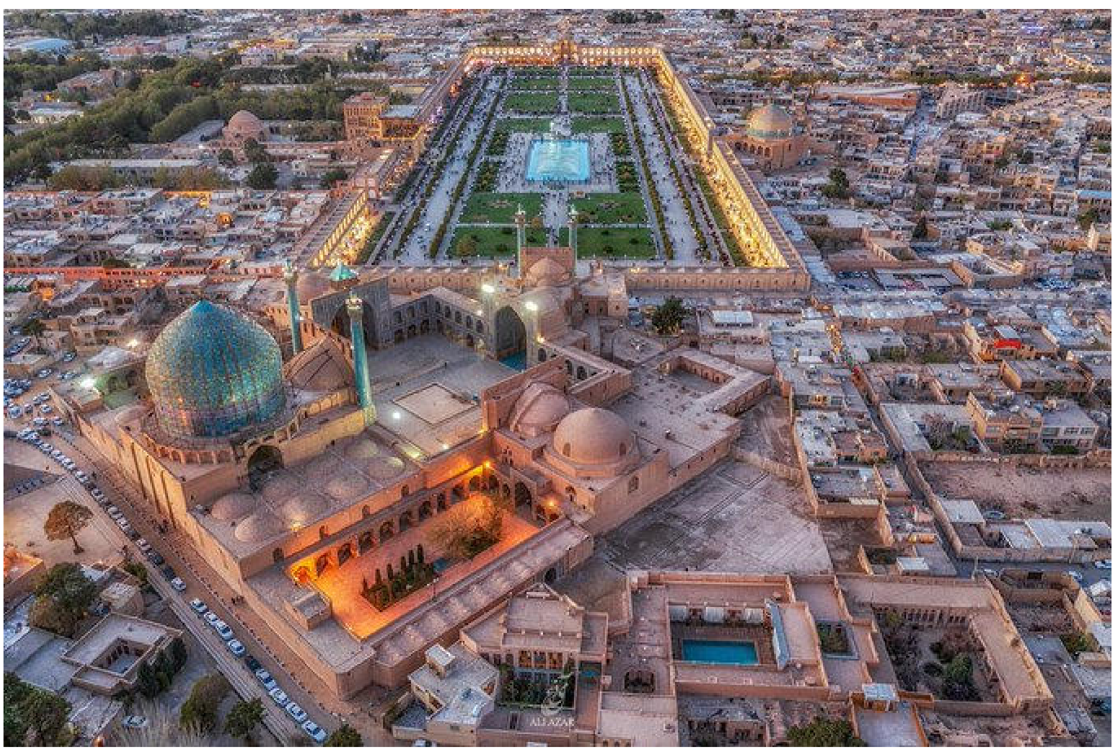


Fig.35 The Naqsh-e Jahan Square of Isfahan, Source: akharinkhabar.ir

- The Qajar and Pahlavid Period

The Qajar dynasty marked a transitional phase in Persian architecture, combining traditional Iranian forms with European neoclassical influences. The construction of Golestan Palace and Shams-ol-Emareh exemplifies the Qajars' fusion of Iranian, and European styles (Fig.36) [61]. In this period of time the western characteristics such as, western pavilions, theaters, semicircular arcs and etc., are determined in architecture. The western motifs and architectural identity in Iranian architecture in this time come from the easiest connection with Europe in 19^{th} century and also the new schools like Dar-al-fonon with European professors made different shapes of architecture in Iran. Moreover, Qajar kings was interested to travel to Europe and they were affected by modern countries.

Fig.36 The Golestan Palace and Shams-ol-Emareh, Reference: UNESCO World Heritage Centre. Golestan Palace. UNESCO; 2013

However, these western and modern effects in art and architecture in Iran were increased during the Pahlavid era. In this period, Iran underwent a profound transformation in architecture and urban development, characterized by assertive state-led modernization and a synthesis of modernist and nationalist influences. Under Reza Shah, rapid urban reforms reshaped city layouts, traditional districts were pierced by new grid-like boulevards to accommodate automobiles. and a wave of construction introduced railways, roads, and modern infrastructure as tangible symbols of progress. The regime actively enlisted European architects and Iranian architects trained in the West to drive these changes, fostering a "National" architectural style that blended modern materials and engineering with motifs from Iran's pre-Islamic and Islamic heritage [62]. Notable projects of Reza Shah's reign include Tehran's National Museum, designed by Andre Godard with a grand brick vault inspired by the Sasanian Taq Kasra arch. The Trans-Iranian Railway, a continent-spanning infrastructure feat meant to signal the nation's entry into the industrial age. Under Mohammad Reza Shah, these trends intensified amid oil-fueled development and rapid urbanization: new master plans (he 1968 Tehran Master Plan by Abdol-Aziz Farmanfarmaian and Victor Gruen) sought to manage Tehran's explosive growth and sprawl, modern highways and entire new districts were built, and Western-educated Iranian architects came to the fore of design and planning. By the 1960s–70s, International Modernist styles dominated many public and commercial buildings, while monumental projects like the Shahyad Tower of 1971 – an avant-garde concrete monument fusing contemporary design with traditional Iranian architectural motifs embodied the era's apex of national modernism (Fig.37) [34,62]. This monument was the combination of symbolic and structural features of Iranian architecture in every historical time like two different arches of pre-Islamic and after Islamic.

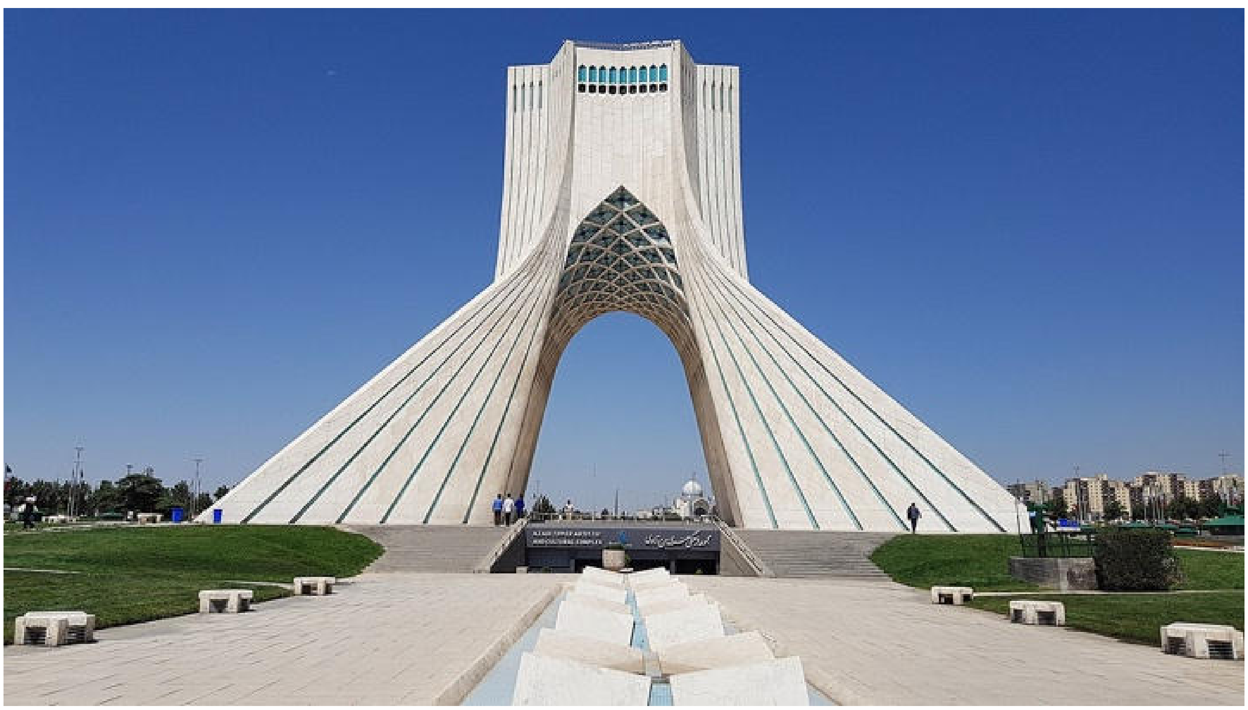
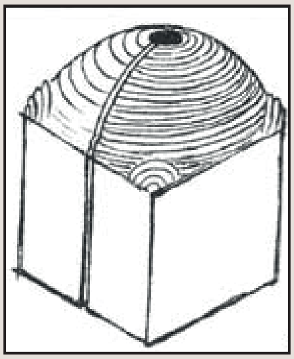
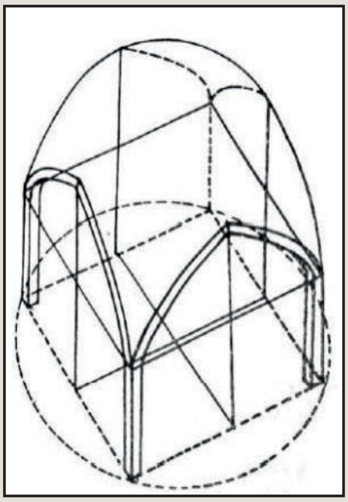


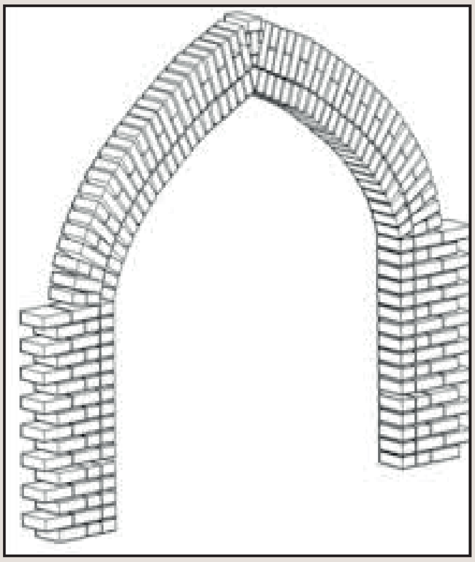
Fig.37 The Shahyad Tower in Tehran y Hushang Seyhun, Source: [62].

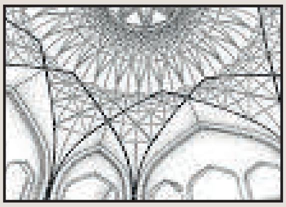
Historical and Structural Overview of Arches, Vaults, and Domes of Iranian Architecture

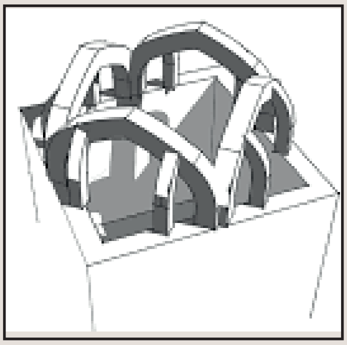
3

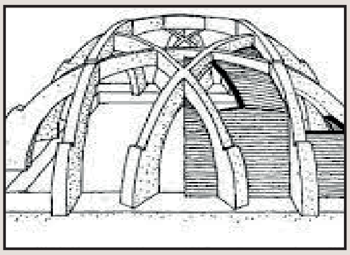


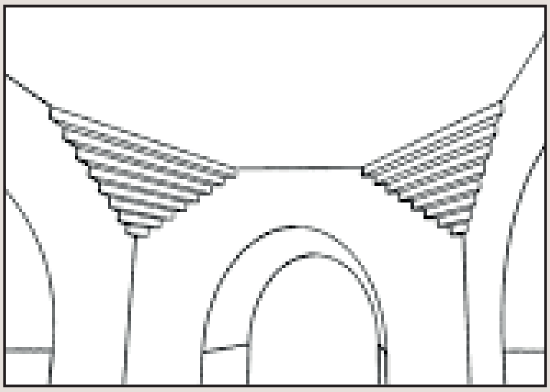


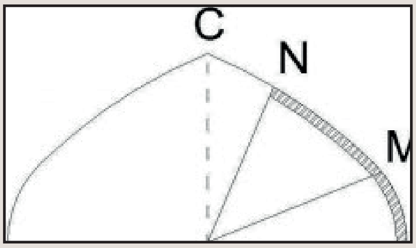


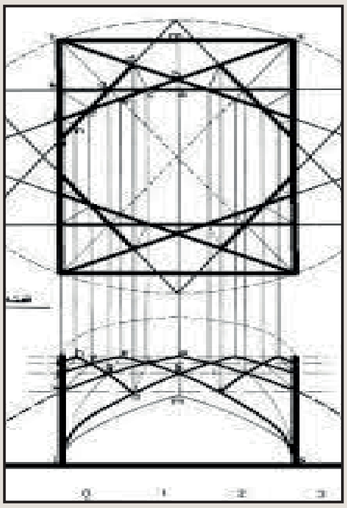


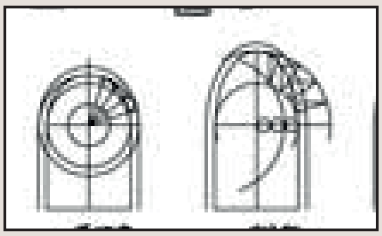












In Iranian architecture, two main types of roof structures are used: flat and curved. Curved structures, commonly referred to as ṭaq, rely on arches to span spaces and distribute loads efficiently. Arches in Iranian architecture appear in various forms, enabling the construction of diverse vaults and domes. The form of the arch determines the geometry and height of the covering, based on the load it must bear and its placement. This architectural logic ensures structural integrity [63].

3.1Types of Arches in Iranian Architecture

The oval[1] arch is derived from half of an ellipse, while the pointed arch results from the intersection of two ellipses. These geometrical principles reflect a deep understanding of statics and form in Iranian construction. Before classifying the various types of arches, it is essential to first understand their anatomical components. The highest point of an arch is referred to as the crown (d) or apex (afraz), while the horizontal span between the two springing points is known as the span (ab). The rise (khiz) of an arch is defined as the ratio between its height and its span $\frac{\mathrm{Cd}}{\mathrm{ab}}$ (Fig.38) [63]. Khiz and strength have the direct ratios with each other. In other words, higher khiz of the arches can have higher strength for bearing loads. Based on this fact before Islam in Iran (In Islamic philosophy, grandeur and excessive ornamentation as symbols of absolute power are discouraged. Instead, architecture is meant to be human-scaled and harmonious, reflecting humility and balance rather than dominance) for the construction of monumental buildings that symbolizes imperial power, arches with greater rise were employed, emphasizing verticality and grandeur as expressions of authority. Based on the rise, different types of arches can be categorized (Diagram.1).

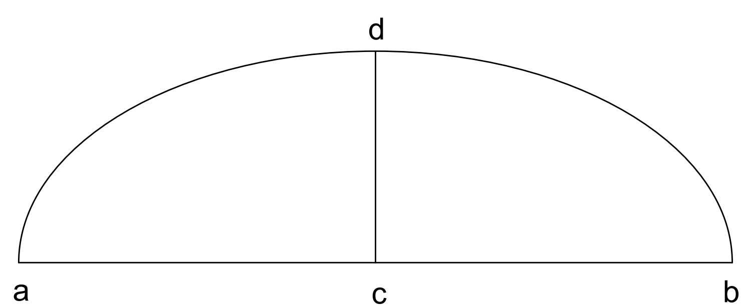


Fig.38 Anatomical Components of the Arch, Reference; Author based on [63].

[1] In Iranian architecture, the so-called "oval arch" (chafṭ-e tokhm-e morghi) is typically derived from half of an ellipse, representing a smooth, continuous curve. In contrast, the pointed arch is often the result of the intersection of two elliptical segments, creating a sharper apex and a different structural behavior. While the term "oval" may be used broadly, it does not always correspond precisely to a true mathematical ellipse.

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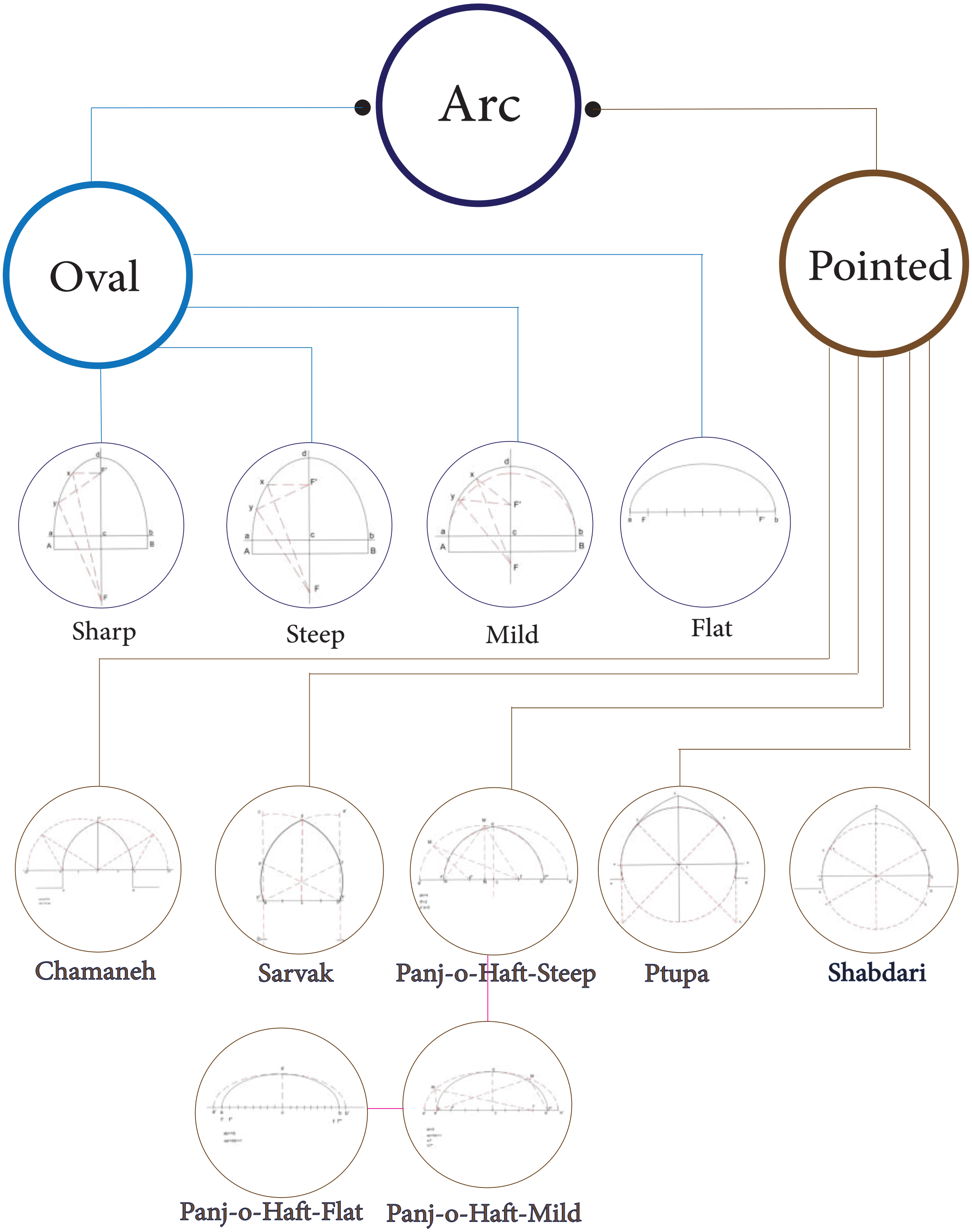


Diagram. 1 different types of Arcs of Iranian architecture.

3.1.1. Oval (Egg-Shaped) or Elliptical Arch

This type of arch is among the earliest used in Iranian construction. Unlike the semicircular arches of Western architecture, the elliptical arch offers superior resistance and distributes forces more effectively, making it ideal for heavy masonry.

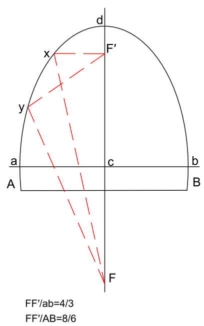
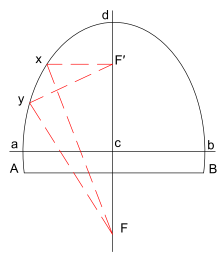
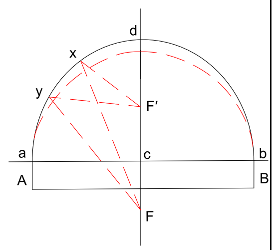
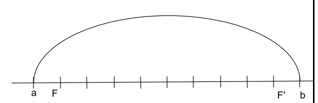
Sharp-Rise	Steep-Rise	Mild-Rise	Flat-Rise
			

Table.1 types of Arches in Iranian Architecture drawing Reference: Author based on [63,64].

-Sharp-Rise Elliptical Arch (Tiz)

In this type of arch, the rise is greater compared to other arch forms, such that the ratio of the focal distance to the span is 4 to 3 ($\frac{FF`}{ab} = \frac{4}{3}$). This arch type has the greatest rise relative to its span, which provides exceptional load-bearing capacity across wide openings. Due to its strength, it is frequently used in the inner shell of large domes, where considerable lateral and vertical forces are exerted. Additionally, this form is commonly found in the construction of historic ice houses, where structural integrity and thermal performance were critical (Fig.39,40) [63]. In traditional Iranian architecture, the term “Parasti” refers to the vertical part of masonry that rises above the supporting wall before the curvature of an arch begins. The distance between points A–B and a–b defines the height of the Parasti. its dimensions varied according to the stylistic preferences of each period. In most vault constructions, the arch does not begin directly from the springing line; instead, several courses of bricks (typically 40 to 50 centimeters) are laid vertically before the curve starts. This architectural element not only gives the arch a more complete and elegant appearance but also plays a crucial structural role in reducing lateral thrust [63].

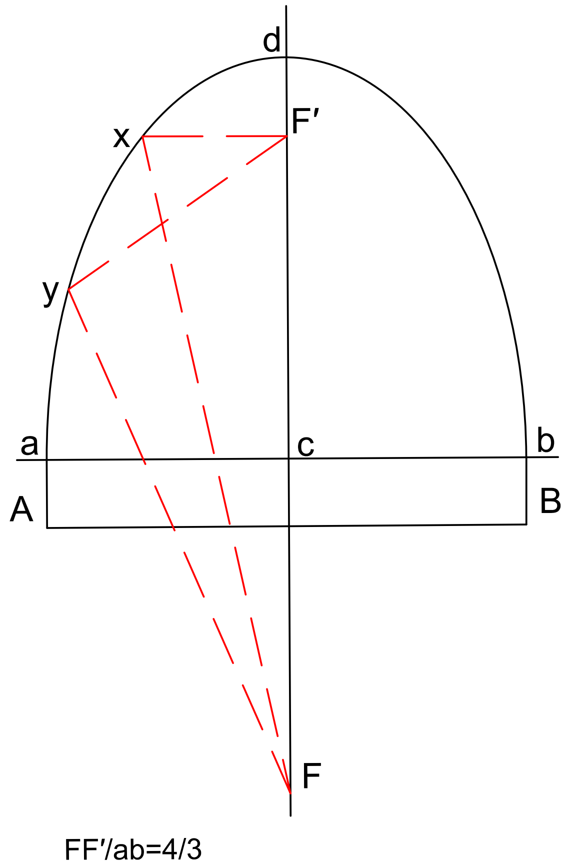


Fig.39 the sketch of Sharp-Rise Elliptical Arch (Tiz), Reference; Author based on [63].

Fig.40 ice house, Iran, Reference: [63].

-Steep-Rise Elliptical Arch (Tond)

This type of arch possesses a rise lower than that of the sharp-rise (tiz) arch, and is typically defined by a standing ellipse whose focal distance equals its span (ab=FF`). Despite its slightly reduced height, it retains considerable structural strength due to a sufficiently high rise. This form was widely used prior to the advent of Islam, reflecting its significance in early Iranian architectural traditions (Fig.41,42) [63,64].

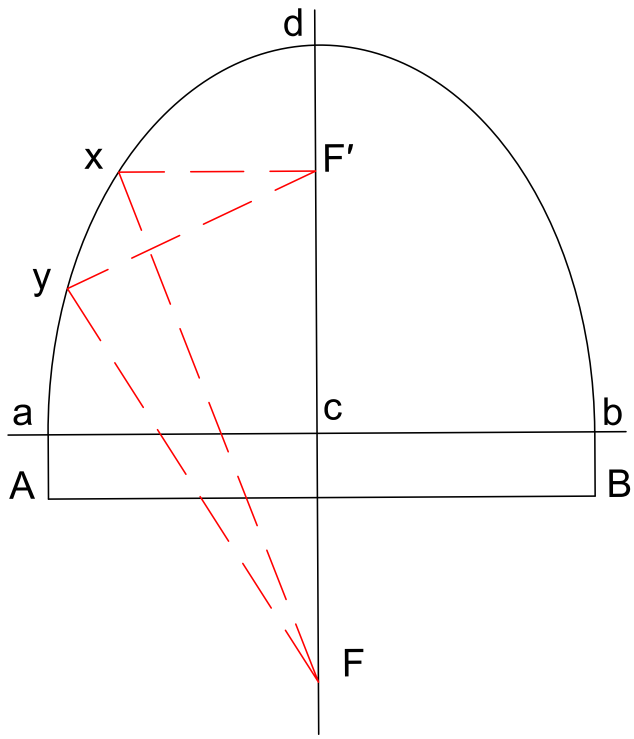


Fig.41 the sketch of Steep-Rise Elliptical Arch (Tond), Reference; Author based on [63].

Fig.42 Steep-Rise Elliptical Arch of Taq Kasra, reference:[63].

-Mild-Rise Elliptical Arch (Kond)

This arch is a vertically oriented ellipse whose focal distance is equal to half of its span ($\frac{FF`}{ab} = \frac{1}{2}$). For this reason, its shape closely resembles that of a circle, and many foreign scholars in Iran have mistakenly identified it as a semicircular arch. (In the diagram, the circle is shown with a dashed line (Fig.43).

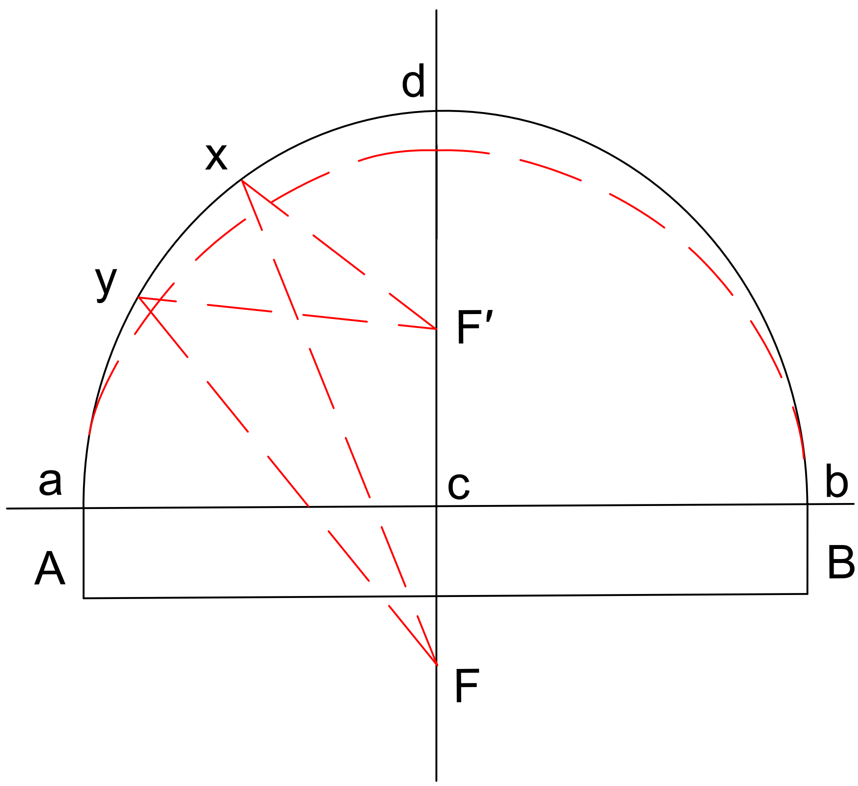
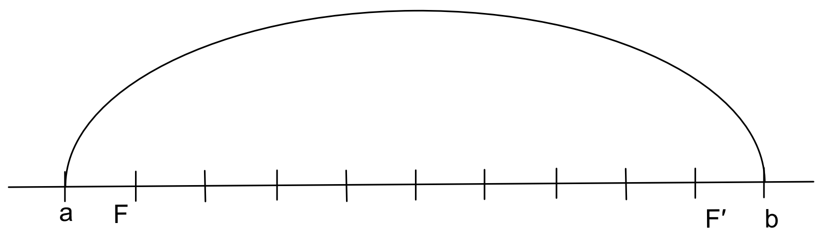


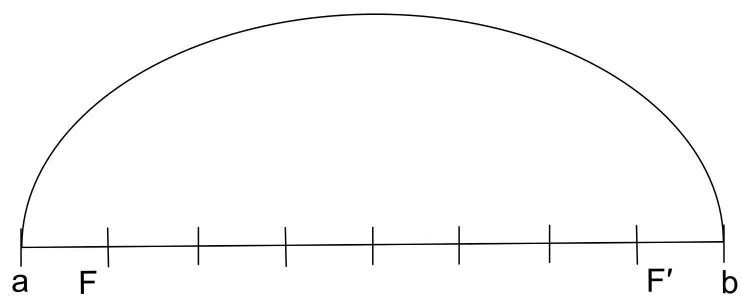
Fig.43 the sketch of Mid-Rise Elliptical Arch (Kond), Reference; Author based on [63,64].

-Flat-Rise Elliptical Arch (Kafteh)

This type includes flattened elliptical arches, which generally lack sufficient structural strength when used independently. As such, they are typically employed in the lower levels of towers or subterranean spaces, particularly where multiple stories are constructed above and the supporting piers or walls are sufficiently thick. A well-known example of this form is the Paniz arch, which closely resembles the basket-handle arch in Western architectural terminology. It is evident that in drawing the various forms of the Kafteh type Mazeh-i arches, the closer points F and F′ (located on the springing line) move toward the span's endpoints, the flatter the resulting ellipse becomes. Table 1 illustrates the details of different types of Arches in Iranian Architecture (Fig.44) [63,64].



$$aF = \frac{1}{10} ab$$

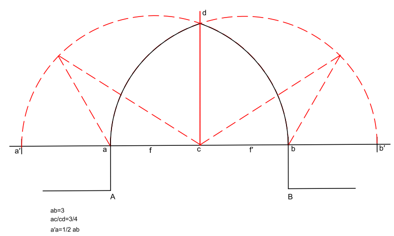
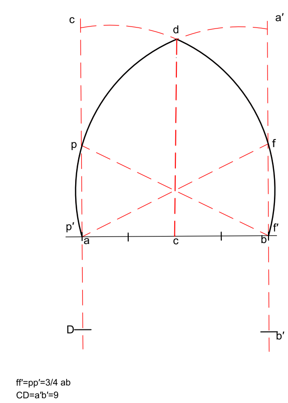
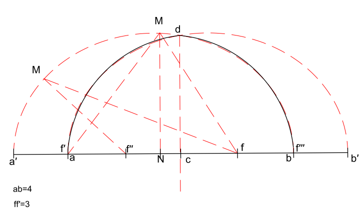


$$aF = \frac{1}{8} ab$$

Fig.44 the sketch of flat-Rise Elliptical Arch (Kond), Reference; Author based on:[63].

3.1.2-Pointed Arch, Chafd-e Tizeh-dar or Jenaqi

The pointed vault, known in Persian as tizeh-dar, is one of the most prominent structural elements in post-Islamic Iranian architecture. Its defining characteristic is the sharp apex created by the intersection of two symmetrical elliptical arcs. This vault type emerged as a response to both aesthetic refinement and structural efficiency, allowing for lower building heights while maintaining adequate load-bearing capacity [63,65].

Chamaneh	
Sarvak	
Panj- o- Haft Tond	

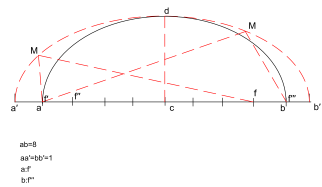
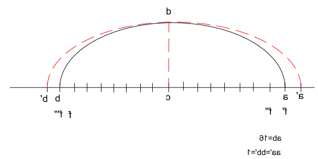
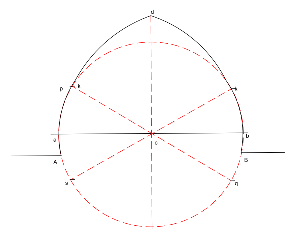
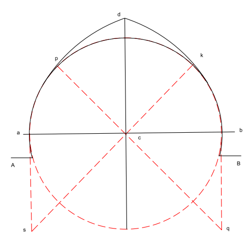
Panj-o-Haft Kond	
Panj-o-Haft Kafte	
Shabdari	
Patoupa	

Table. 2 different types of pointed arches.

-Advantages and Structural Features:

- Reduces the vertical height of buildings compared to elliptical vaults because when the rise is less than half the span, segmental and basket-handle arches are favored over semicircular or elliptical designs for their flatter form [65].

- Facilitates faster convergence of two spans at the apex because the configuration of consecutive circular arcs allows the arch to span quickly with minimal rise, enabling the crown to be reached rapidly [65].

- If the design requires a lower rise-to-span ratio, this arch type offers a more efficient distribution of thrust forces along the lateral walls, as its thrust line remains close to the geometric axis. As a result, the lateral thrust is more uniformly distributed, allowing for thinner and more efficient supporting walls without compromising structural stability. [65]. In other words, according to aforementioned paragraph, Following the advent of Islam in Iran, there emerged a growing emphasis on constructing buildings with more human-scaled proportions. This architectural shift required the use of arches with lower rise compared to the monumental pre-Islamic forms. However, as previously noted, reducing the rise of traditional oval arches weakened their load-bearing capacity. To address this structural limitation, builders increasingly adopted pointed arches (tizeh-dar), which allowed for lower overall height while maintaining structural efficiency. The geometry of the pointed arch ensured that the thrust line remained better aligned with the arch's form, thus preserving stability even at reduced heights. The oval arches with low rise act as semicircular arches, unlike semicircular arches, whose line of thrust tends to fall outside the intrados at lower rise-to-span ratios, the pointed arch allows the thrust line to remain within the masonry profile even at reduced heights, thereby increasing stability and minimizing the need for massive abutments [66]. This occurs because the two intersecting arcs forming the pointed arch produce a steeper central zone, redistributing horizontal thrust more efficiently toward the supports. Consequently, even with a lower rise, the structure maintains compressive integrity without excessive lateral forces (Fig.45) [77].

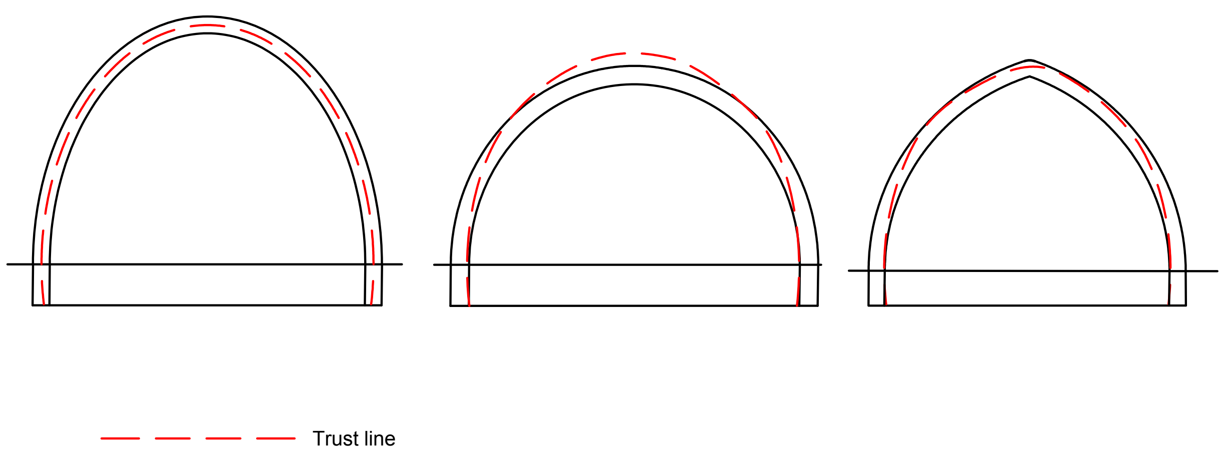


Fig.45 line of thrust in different type of Arch, Reference: Author based on: [66, 67].

- Well-suited to both monumental and modest architectural projects because of its balanced geometry and structural benefits, the basket-handle arch has been used both in grand bridges and smaller urban or rural buildings [67].

-Chamaneh Arch (Three-Fourths Arch)

Also known as the "3-and-4" arch, the chamaneh arch features a height-to-span ratio of 4:3. This proportion results in a well-balanced pointed form that was highly prevalent during the early Islamic periods in Iranian architecture. Its structural efficiency and elegant geometry made it a favorite for both religious and secular constructions [63-65]. In this arch, given that the ratio of rise to span is 4:3, constructing it using circular geometry would require dividing the span into three equal parts. However, by employing two ellipses drawn with pins and string—assuming the span to be three units—it is possible to achieve a rise equal to four units. The procedure is as follows:

Let the span ab=3. On the horizontal axis of the span, extend points a′ and b′ each at a distance equal to half the span beyond points. First, draw an ellipse with foci f and f′ and major axis a′ b then draws a second ellipse with the same foci but with the major axis ab′. The intersection point of these two ellipses defines the desired arch profile (adb), and the rise relative to half the span will be 4/3 (Fig.46,47) [63].

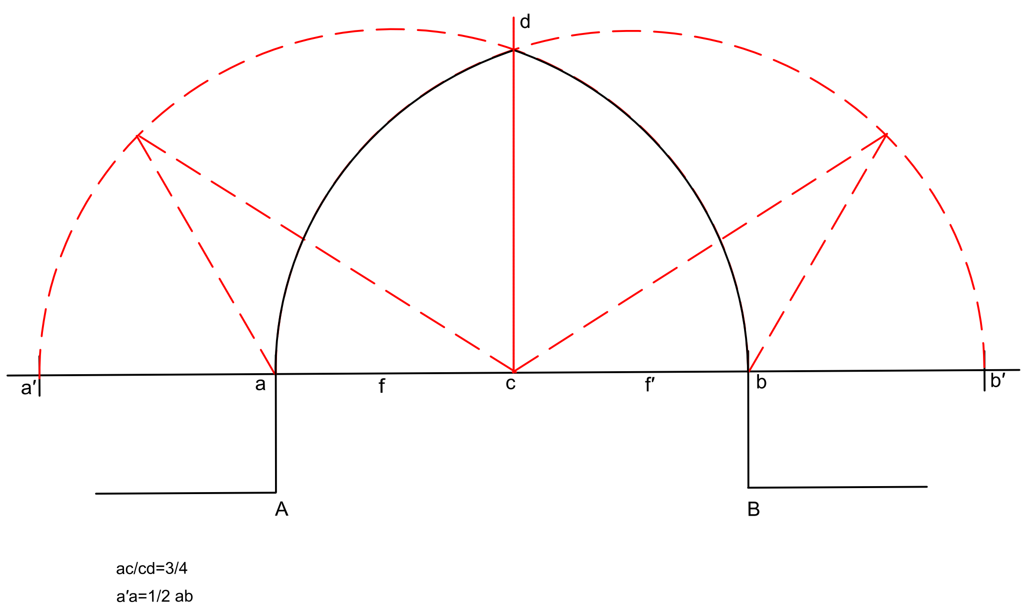


Fig.46 Chamaneh Arch, Reference: Author based on:[63].

Fig.47 Chamaneh Arch of Jameh Mosque of Yazd, reference: [63].

-Sarvak Arch

The sarvak arch is formed by the intersection of two standing ellipses, which gives it a very high load-bearing capacity. This type of pointed arch was in use even before the Islamic period, particularly in architectural structures that were subjected to substantial force and pressure. Notable examples include Achaemenid-era dams, where the sarvak arch's strength was essential for structural resilience. This type of arch became particularly prevalent after the advent of Islam, especially in the Fars region, where it was commonly used in the outer shell of domes with concave (avgoon) profiles [63].

The span ab is taken as the given base. From points a and b, two perpendiculars are drawn upward, each with a height equal to three-fourths of the span. Then, using the p-p′ as foci and the rise CD (CD=9) and passing through points f and f′, an ellipse is constructed. Then, a second ellipse is drawn using the focal points f and f′ (ff′ =3) and the span a′ b′ (a′ b′ =9), passing through points p and p′. The intersection of these two ellipses defines the desired arch (fig. 48,49) [63].

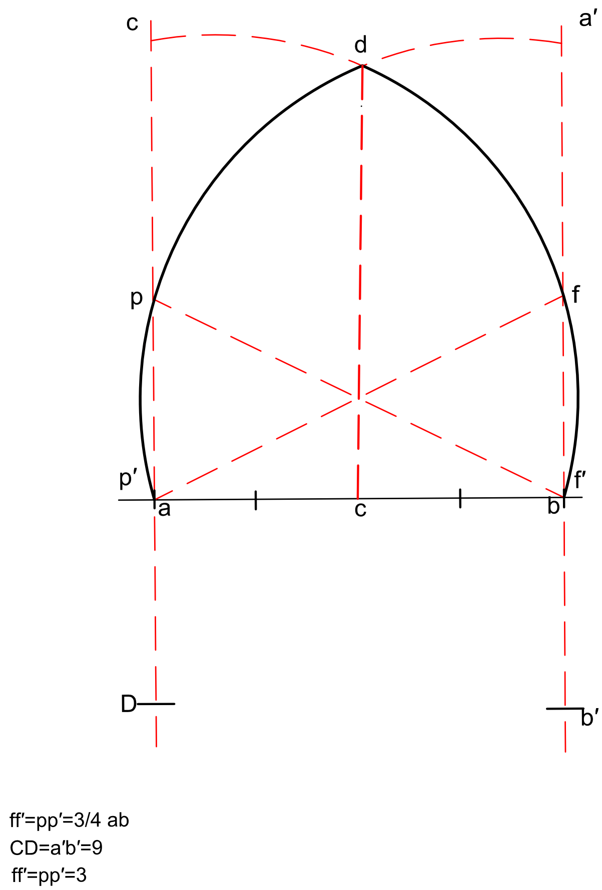


Fig.48 Sarvak Arch, Reference: Author based on [63,65]

Fig. 49 Sarvak Arch of Dorudzan Dam- Achaemenid period, reference: [63].

-The (Panj-o-Haft) and Its Variants

This arch has been represented in different ways across various sources. One of these methods is based directly on its name, The literal similarity of the term "Panj-o Haft" misled some architects into mistakenly constructing the arch using a 5:7 proportion. in Persian, panj means “five” and haft means “seven.” Accordingly, it has been assumed that the arch should be drawn using these two numerical divisions, with the proportions of “five” and “seven” serving as the guiding principles for its geometric construction Unfortunately, arches built based on this ratio were often structurally unsound and unable to bear the imposed loads, frequently resulting in failure or collapse (Fig.50) [63,64]. using a numerical ratio such as 5:7, when the vault thickness is insufficient, can lead to an increase in tensile stresses in the outer zones of the arch, resulting in a decrease in structural stability. The research revealed that when the thickness falls below a certain critical threshold, the vault becomes unable to properly distribute thrust forces, thereby increasing the likelihood of collapse. The primary reason for this instability in arches with a 5:7 ratio lies in the misalignment between the thrust line and the geometric profile of the arch. The curvature of such arches does not follow the natural path of compressive forces; consequently, the thrust line deviates outside the masonry thickness, especially near the midspan or the springing points. This deviation introduces tensile stresses in the masonry, even though materials such as brick and mortar are strong in compression but very weak in tension. Moreover, in low-rise proportions like 5:7, the arch shape becomes flatter, which increases the horizontal thrust at the supports. In traditional Iranian architecture, where vaults were typically supported by relatively slender walls, this high horizontal thrust often led to cracking of the supports and eventual collapse. Furthermore, the 5:7 form represents a geometric, not structural, curve—it does not follow a natural catenary form, and therefore fails to guide compressive forces efficiently along the intrados. As a result, stress concentrations appear in the upper parts of the vault, leading to diagonal cracking and failure. According to the numerical analyses of Valibeig when the vault thickness is below the critical limit[2], the thrust line shifts outside the arch section, causing the structure to behave more like a flexural beam rather than a purely compressive system. Since masonry lacks tensile strength, this leads to brittle and sudden failure [68].

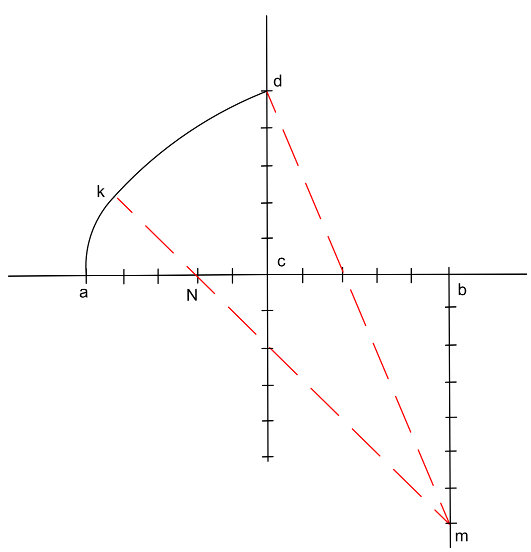


Fig. 50 Panj-o-Haft using a 5:7 proportion, Reference; Author based on [64].

[2] The term critical limit in Valibeig’s analysis refers to the minimum safe thickness of the vault; below this threshold the thrust line moves outside the arch section, the structural behavior becomes flexural rather than compressive, and the masonry acking tensile capacity fails in a brittle manner.

Another method of construction interprets the Panj-o Haft arch through advanced geometric principles. In its original form, the arch is generated by the intersection of two ellipses, a technique that provides both structural efficiency and a distinctive visual profile (Fig. 51). The elliptical form maintains a continuous curvature and allows the thrust line to remain within the thickness of the masonry throughout the span. This geometry naturally aligns with the flow of compressive forces and significantly reduces horizontal thrust at the supports. That is, the smoother the curvature and the greater the height distribution at the center (such as an elliptical), the thrust line remains within the thickness of the arch. In contrast, arches with abrupt curvature (such as a 5:7, which is essentially a geometric polygon) do not properly direct the compressive force [68].

Fig. 51 Regular Panj-o-Haft Arch of Kerman Bazar, reference:[63].

-Steep-Rise Panj-o-Haft Arch (Tond)

The most accurate method, which both derives from the intersection of two ellipses and provides the necessary structural resistance, is the double-ellipse method. In this approach, the span ab is taken as the given base and divided into four equal units. Two auxiliary points, a′ and b′, are then placed along the extension of the span, each located one unit beyond points a and b, respectively. The first ellipse is drawn with the major axis a′ b and focal points f and f′, followed by the construction of a second ellipse with the major axis ab′ and focal points f ″ and f ‴. The intersection of these two ellipses produces the final outline of the Panj-o Haft arch, ensuring both geometric precision and structural stability (Fig. 52, 53) [63].

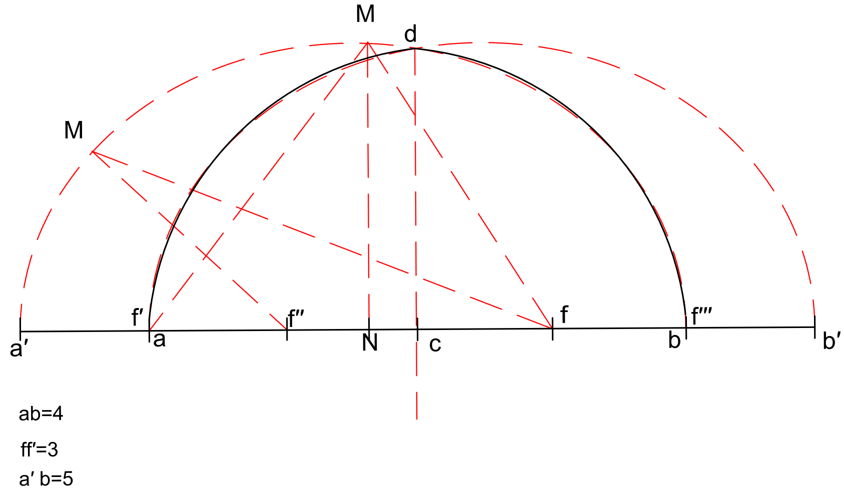


Fig. 52 Steep-Rise Panj-o-Haft Arch, Reference: Author based on:[63].

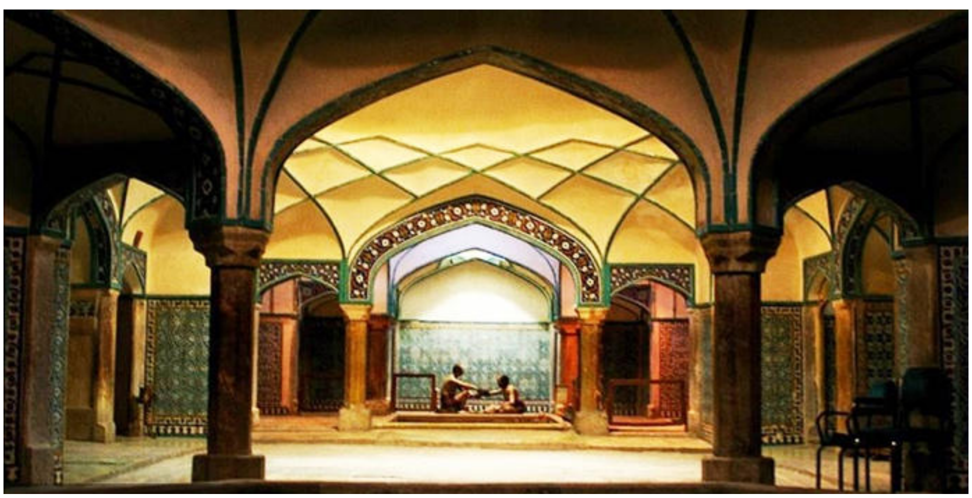


Fig. 53 Elongated Panj-o-Haft Arch of Kerman Bath reference: [63].

The point *M* serves as one of the controlling points of the ellipse, and its precise position plays a crucial role in defining the curvature and geometric profile of each elliptical segment.

-Mild Panj-o-Haft Arch (Kond)

The construction method of this arch with the intersection of two ellipse is based on the same geometric principles as the steeped-rise Panj-o Haft arch, with the only difference being that, in this case, the span is divided into eight equal parts instead of four (Fig.54). A subtly reduced version in terms of height, approaching a semi-pointed shape. Used in secondary spaces or corridors, where less vertical stress and more lateral stability are needed (Fig. 55) [63,64,65].

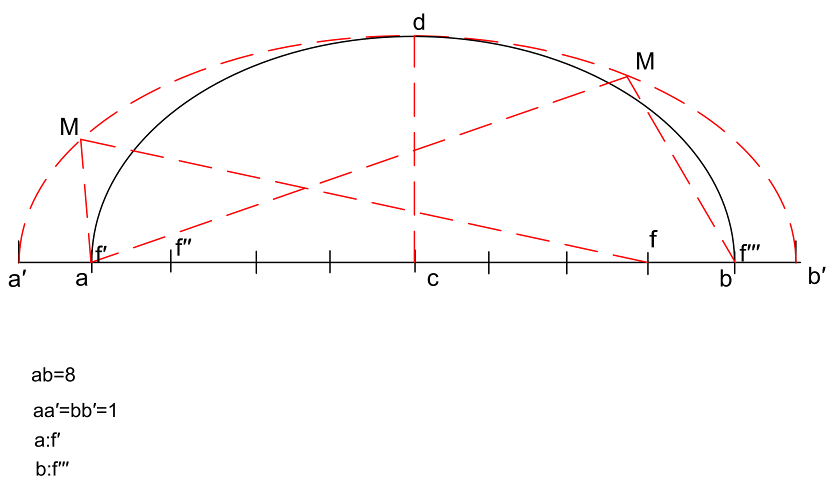


Fig. 54 Mild Panj-o-Haft Arch, Reference: Author based on:[63].

Fig. 55 Mild Panj-o-Haft Arch of Fin-Kashan-Garden

-Flatten Panj-o-Haft Arch (Kafte)

The construction of the depressed five-and-seven arch also follows the same geometric principles as the two previous types of arches, with the difference that, in this case, the span is divided into sixteen equal parts. This type of arch generally lacks significant load-bearing capacity due to its low rise and is therefore used only for spans up to approximately 1.5 meters. In any case, its execution requires considerable skill and the use of high-quality materials (Fig.56) [63].

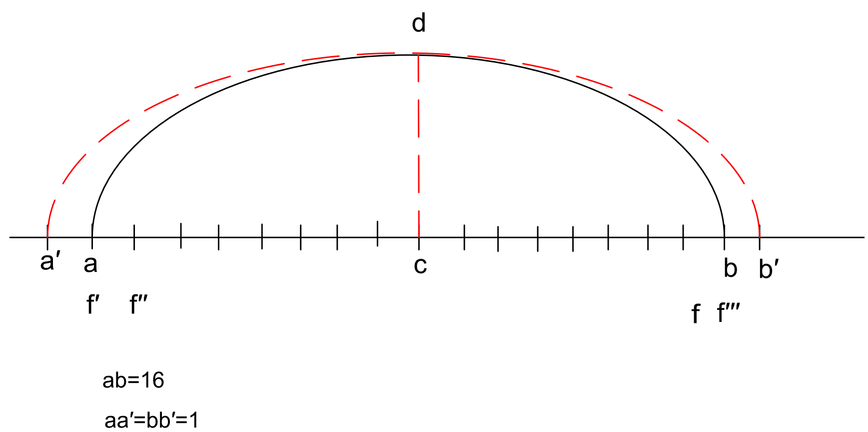


Fig. 56 Flat Panj-o-Haft Arch, Reference: Author based on [63].

-Shabdari Arch (Trefoil Arch)

The Shabdari arch, also known as the trefoil arch, is typically used in domes rather than in vaults. This is because its geometric design relies on circles, and finding the centers of these circles in three-dimensional space poses considerable difficulty, making it largely impractical for constructing vaults. However, in domes particularly in the outer shell this issue is resolved through the use of stencils and templates that guide accurate construction. Among the advantages of the Shabdari arch are its strong load-bearing capacity, aesthetically pleasing form, and its ability to seamlessly integrate with the curvature of concave (avgoon) domes. In the construction of this arch, the span ab is taken as the base. A circle is drawn with ab as its diameter, and this circle is divided into six equal segments from the apex point in order to determine points q and s. First, using point *c* as the center and radii *ca* and cb, the lower segments of the arch are drawn, generating points k and p. Then, using s and q as centers and radii sk and qp, the upper segments of the arch are constructed. The resulting arch profile is defined by the curve adb (Fig57,58) [33-65].

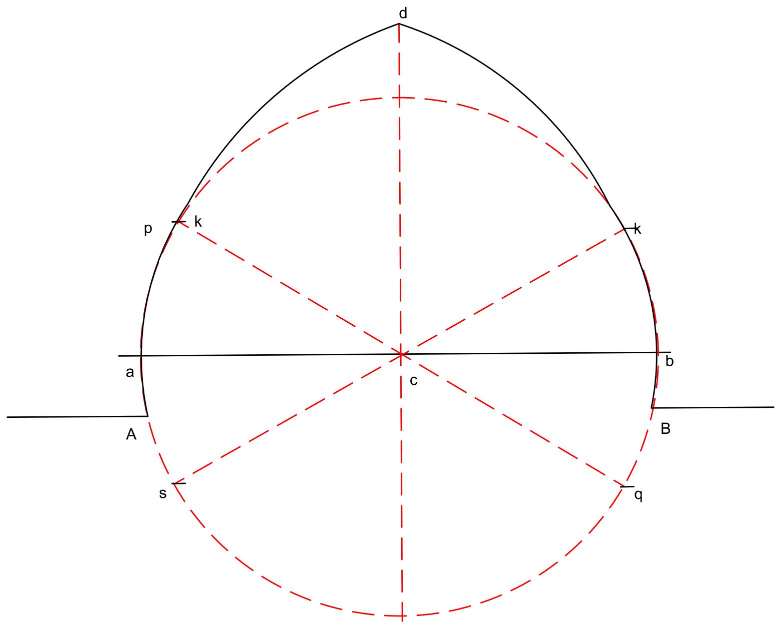


Fig. 57 Shabdari arc, Reference: Author based on:[63].

Fig.58 Shabdari Arc of the Dome of Jameh Mosque of Yazd

-Patoupa Arch (Patoupa)

This type of arch is also sometimes used for the outer shell of the dome. Assuming the span ab as the given base, a circle is drawn with ab as its diameter and then divided into four equal parts, yielding the key points k and p. The arcs kp and ap form the two lower segments of the arch. Points p and k are then connected to the center of the circle, and these lines are extended until they intersect the perpendiculars drawn from points a and b on the span at points s and q, respectively. Using s and q as centers and the radii sk and qp, the two upper segments of the arch are then drawn, completing the full profile. This type of arch is generally not used for large spans [63,64]. Table 2 depicts different kind of pointed arches (Fig.59,60).

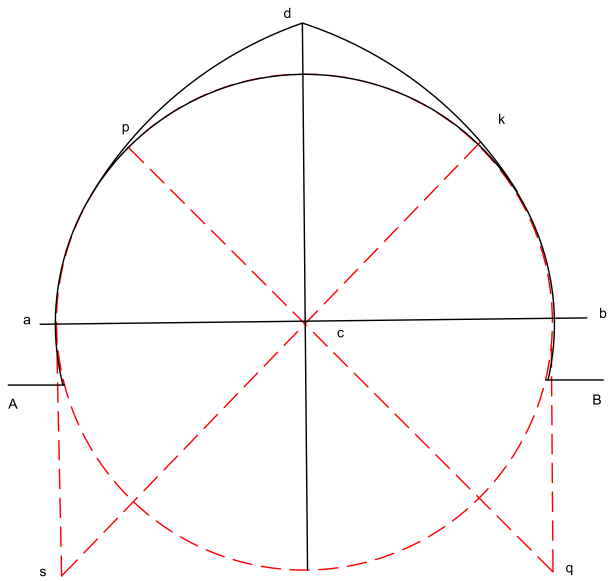


Fig.59 Patoupa Arch, Reference: Author based on: [63]

Fig.60 Patoupa Arch of Allah Allah Dome, [52].

There are many kinds of arcs in Persian architecture especially decorative arches but in this article, they are not mentioned.

3.2 Vault

The simplest definition of a vault (Taq) that can be presented using architectural terminology is the movement of one or more arches along one or several axes, forming a surface enclosed between two load-bearing walls or at least four load-bearing columns. In the study of vaults, two fundamental principles are of primary importance: (1) the design and function of different types of vaults, and (2) the method of construction.

3.2.1 Typology of Vaults

- *Barrel Vault (*Taq-e Ahang*)*

The simplest form of the Iranian vault is the Taq-e Ahang (barrel vault), which is essentially the continuation of a single type of arch along a defined axis. In French, this type of vault is referred to as a *berceau*. The Taq-e Ahang is considered the most suitable form of roofing for structures flanked by two continuous load-bearing walls (Fig. 61) [63].

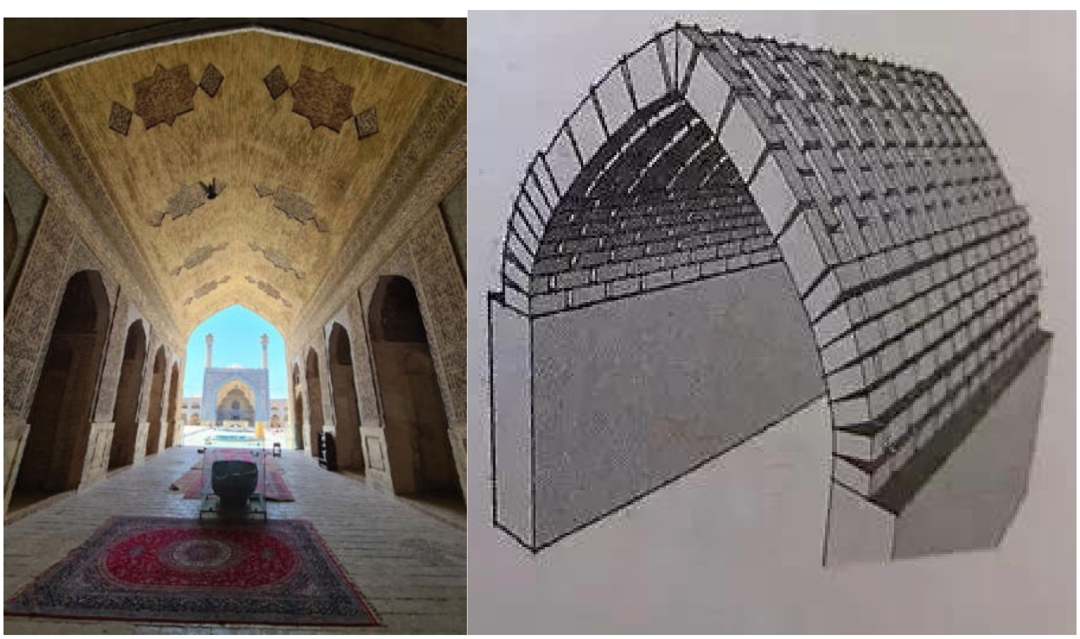
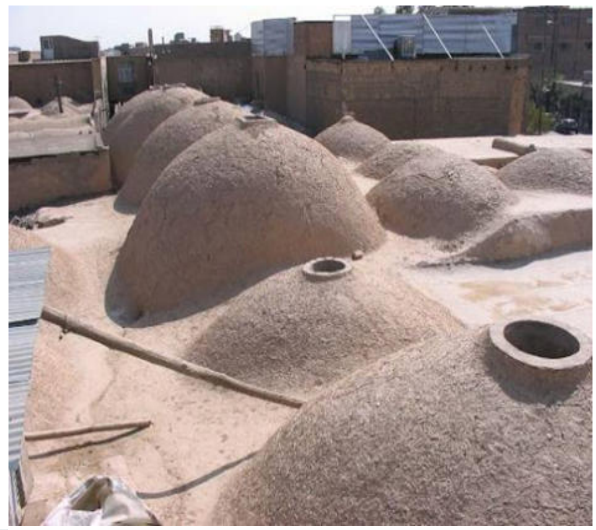


Fig. 61 Barrel Vault of Jameh Mosque of Isfahan, [63].

-Domical Vault (Kolonbo)

The *Kolonbo* vault is a small-scale domical structure commonly employed in Iranian architecture to cover square or rectangular spaces. the *Kolonbo* is particularly well-suited to the climatic conditions of Iran. Its curved surface effectively softens harsh sunlight, reduces solar gain during hot days, and limits heat loss during cold nights. Moreover, the compact and unified geometry enhances its seismic resilience—a critical factor in Iranian architecture, given the region's frequent earthquakes [65]. From a structural perspective, the *Kolonbo* vault distributes loads more evenly across its supporting elements, allowing for thinner walls and more efficient material use. This property not only enables lighter construction but also supports more refined architectural detailing in interior spaces. Traditional builders often favored this vault in private houses, small-scale domed rooms, baths, and mausoleums, particularly when transitional spaces or full domes were unnecessary. The construction technique typically involved laying concentric brick courses in horizontal or slightly inclined planes, often without elaborate centering. The self-supporting nature of the vault during construction made it economical and practical for builders working with limited resources or in rural contexts. In the context of sustainable architecture, the *Kolonbo* offers valuable lessons. Its thermal mass and passive solar performance align with contemporary energy-efficient design principles. Moreover, the vault's adaptability and compatibility with earth-based materials (such as adobe, mudbrick, and lime plaster) underscore its relevance to modern vernacular and eco-conscious architectural approaches (Fig. 62). Kolonbo is constructed in three ways: With Karbandi, with pendentives and with transvers arches (Tavize) [63,65] .



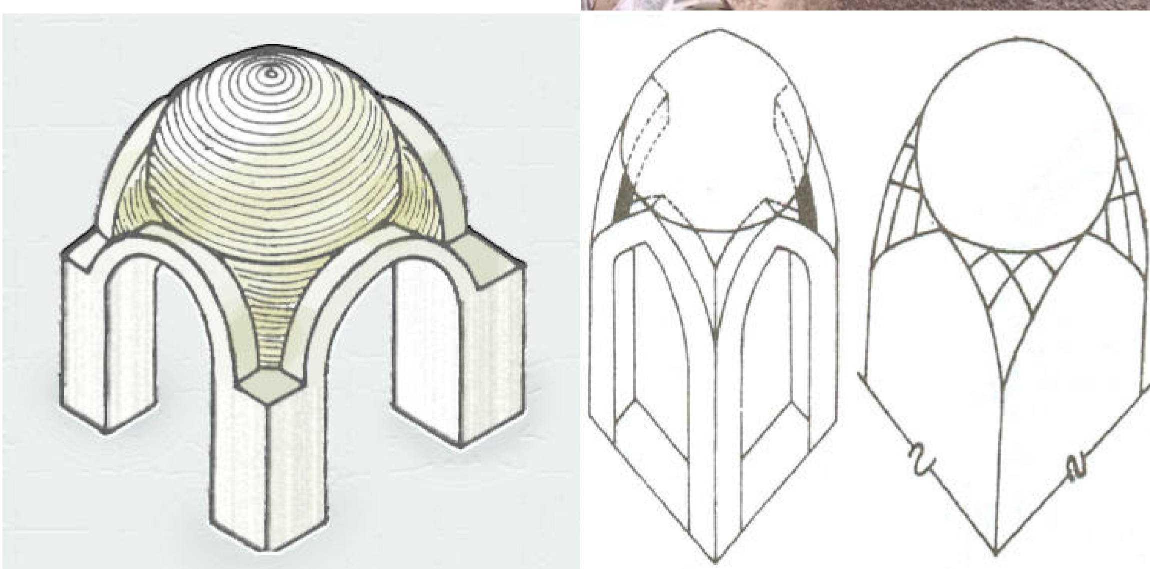


Fig. 62 the Kolonbo Vault in different construction methods, reference: [30,63].

-Groin Vault (Chaharbakhsh)

The Chaharbakhsh or groin vault results from the perpendicular intersection of two-barrel vaults, producing a complex load distribution system that directs forces toward the four corners. The notable example is the Shabestan (prayer hall) in (Fig. 64, 65) [63].

Fig. 63 The Chaharbakhsh vault, reference: [63,30].

-Vault and Transverse Arch (Taq and Tavizeh)

In traditional Iranian architecture, the structural system known as *Taq o Tavizeh* (vault and transverse arch) plays a foundational role in spanning enclosed spaces. The Tavizeh (transverse arch) functions as the primary load-bearing element, typically spanning the shorter side of a rectangular or square space. Once in place, a Taq (vault) is constructed by filling the space between successive Tavizeh units, creating a continuous surface or roof. This system allowed for the modular construction of elongated halls, porticos, and Iwans, enabling builders to extend spaces longitudinally without the need for large domes or complex structural transitions. The *tavizeh* effectively redirects vertical loads toward side walls or piers, and the vault that spans between them serves more as an infill, though it too contributes to the stability and integrity of the system. Traditional materials for both components included baked brick and Saruj (the traditional material-based lime) mortar, with construction techniques that required minimal centering. The Tavizeh was typically constructed first, using wooden centering frames, and once hardened, the vault was built between the arches using inclined brick courses. The Taq o Tavizeh system also provided great flexibility in design and there are different types of design such (Fig. 64,65) [63].

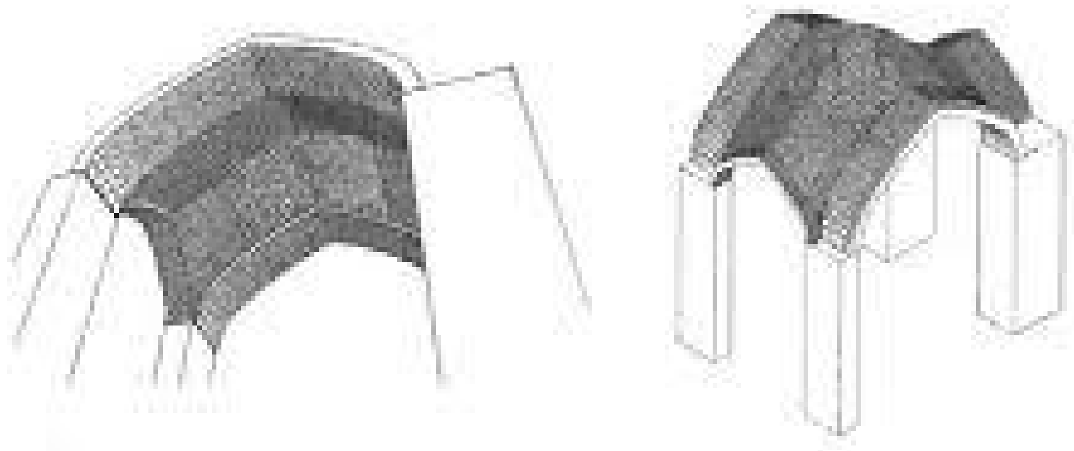


Fig. 64 Taq and Tavizeh, reference: [30].

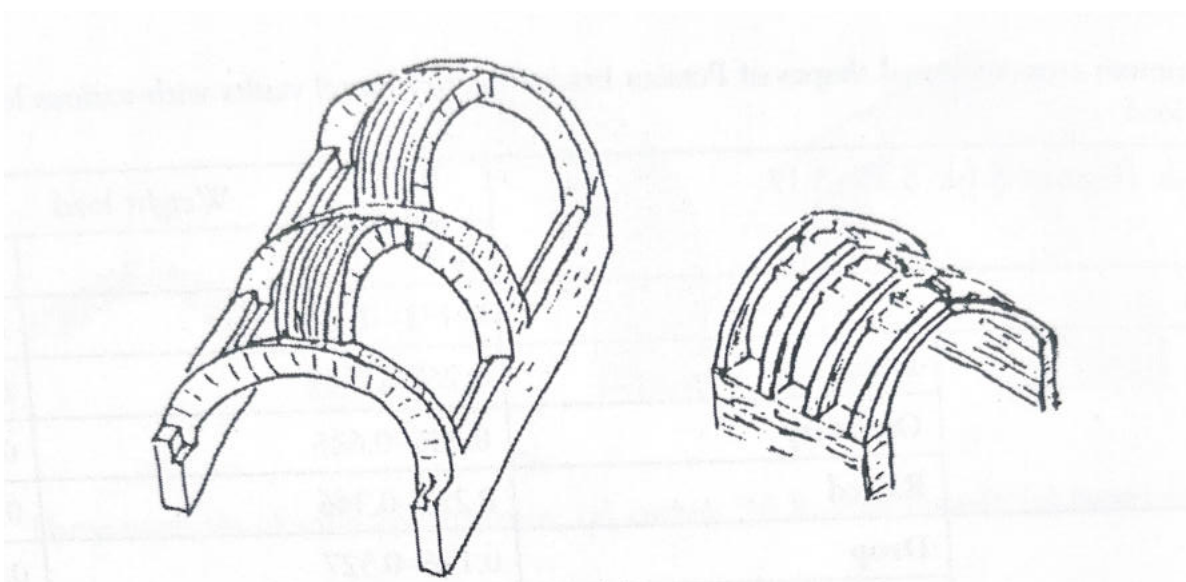


Fig. 65 the sketch of Taq and Tavize, reference: [69].

Recent scholarship on Iranian traditional architecture has shed light on a remarkable construction technique: vaulting without the use of load-bearing centering frameworks. In contrast to Roman architectural practices, where extensive wooden centering was necessary to support vaulted structures during construction, Iranian builders devised innovative strategies that significantly reduced or eliminated the need for such frameworks

the evolution of without-centering vaulting involved three primary strategies:

1.3.2.2 Complete Elimination of Centering:

Techniques such as pitched-brick barrel vaults allowed bricks to be laid at an angle or vertically without external support. Self-supporting geometries and interlocking brick patterns facilitated the construction of vaults without the need for formwork (Fig. 66).

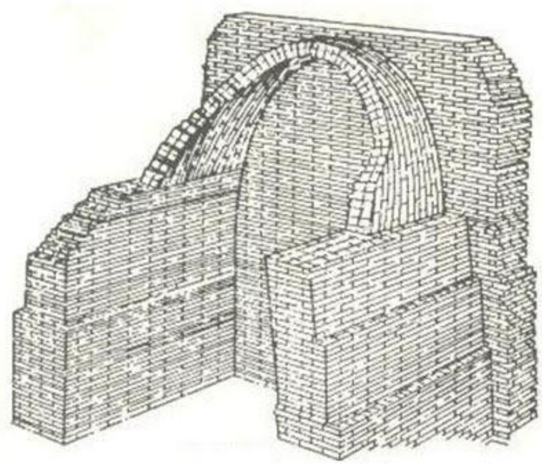


Fig 66 barrel vaults allowed bricks to be laid at an angle or vertically without external support reference:[63].

-Strengthening Temporary Molds:

Builders sometimes constructed a thin initial layer (e.g., a gypsum or wooden form) which would later be reinforced with bricks, transforming the mold into a semi-structural element. This method enabled the construction of larger spans while reducing risks associated with traditional heavy centering. These molds were constructed on the ground and then placed in their intended position during execution. In order to build a gypsum centering based on the traditional way, firstly, a full scale of the profile of the desired arch will be sketched on the ground. The front view of the of the sketch shall be two parallel curves with 15-20 cm space in between. Secondly, a mold will be shaped by placing the bricks on the borders of the lines on the ground. Then, gypsum mortar of medium consistency will be poured into the shaped mold. As a traditional solution to reinforce the fragile gypsum centering, reeds or date palm tree fibers will be placed inside the mold before the adulteration of the gypsum slurry. Finally, the gypsum/wooden centering will be in the shape of the profile of the vault to be built. (Fig. 67) [63].

Fig. 67 construction method of the mold, reference: author and [73].

-Transformation of Temporary Molds into Permanent Structural Members:

Particularly in large-scale vaults, initial lightweight frameworks were gradually thickened with radial and vertical brick bonds, ultimately forming robust structural ribs that remained integral to the finished vault. These techniques reflect not only an ingenious response to the scarcity of timber resources on the Iranian plateau but also demonstrate the highly evolved craftsmanship and material intelligence of Iranian master masons. The absence of heavy centering accelerated construction processes, economized materials, and contributed to the climatic adaptability and seismic resilience of vaulted spaces [69].

3.2.3 Ribs (Tavize or transvers arch) in Iranian architecture

In Iranian architectural heritage, the rib (known as tavizeh or transverse arch) plays a fundamental role in the structural and aesthetic composition of vaults and domes. Unlike Western traditions that rely heavily on wooden centering frameworks, Iranian builders developed ingenious methods to create ribbed structures using minimal formwork, relying instead on techniques such as centered ribs made of gypsum and reed, which acted both as guides and temporary support for brick layering [73]. The rib in Iranian architecture is more than a structural device; it is a form-generating element that facilitates the transition from a square base to a circular dome. In vaulted structures such as Karbandi, Patkaneh, and ribbed vaults, ribs serve as both the framework and ornament, marking intersections and dividing surfaces into geometrically organized sectors. This system provides a balance between load distribution and visual rhythm [70].

3.3 The Dome: Geometric Definition and Architectural Interpretation

In geometric terms, a dome is defined as the locus of points generated by the rotation of a specific arch around a vertical axis. However, in architectural terminology, a dome refers to a structural covering erected over a circular base.

A traditional Iranian dome typically consists of three main components (Fig.68) [71]:

1. Gonbad-khaneh (Dome Base Zone)

This refers to the ground level or base area on which the dome is constructed. It forms the circular or polygonal platform that defines the footprint of the dome.

2. Bashn or Heykal (Dome Drum or Body)

The drum or body of the dome rises above the base, typically in a cubic form, and serves as a transitional volume between the base and the dome itself. In post-Islamic domes, this body often features one or two open sides. In pre-Islamic domes, however, it was common for all four sides to be open, allowing full spatial connectivity.

3. Chapireh (Squinch)

The Chapireh is a structural device used to convert a square or rectangular base into a circular plan, enabling the dome to be seated atop the newly formed circle. This transitional zone also known as a squinch in Western terminology *is* crucial for distributing the dome's load onto the supporting walls or piers. Persian vaulted architecture, particularly in its domes and monumental Iwans, reflects a unique fusion of symbolic cosmology, material constraints, and ingenious structural adaptation. Persian architecture evolved original construction methods to meet both spiritual and technical imperatives, particularly under conditions of material scarcity (e.g., lack of timber for centering) and seismic vulnerability [71].

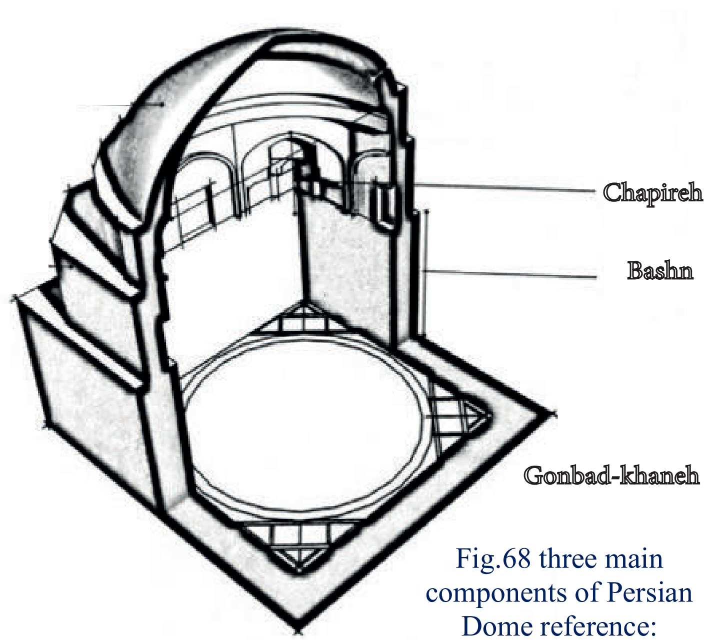


Fig.68 three main components of Persian Dome reference: [63,71].

One of the key innovations in Persian architecture was the development of dome construction without the use of beams or rigid centering, often using squinches to transition from square bases to circular domes, in this system, each transitional element functions structurally by transferring the loads of the dome toward its supporting piers. Due to their specific geometric and structural characteristics explained in the follow these elements play a crucial role in load-bearing performance and stability of the dome and most of the time they play structural role in Dome construction. The square symbolized the earthly realm, while the dome represented the celestial sphere. The resulting transition zone, often composed of four squinches reinforced by lateral masonry, was both symbolic and functional, providing continuity and support between vertical walls and the dome [71].

3.2.1 Squinch Construction in Domes:

Squinch construction in domes can be classified into two major categories: Gusheh-sazi and Shekanj [65, 71]. The types of squinches are shown in diagram 2.

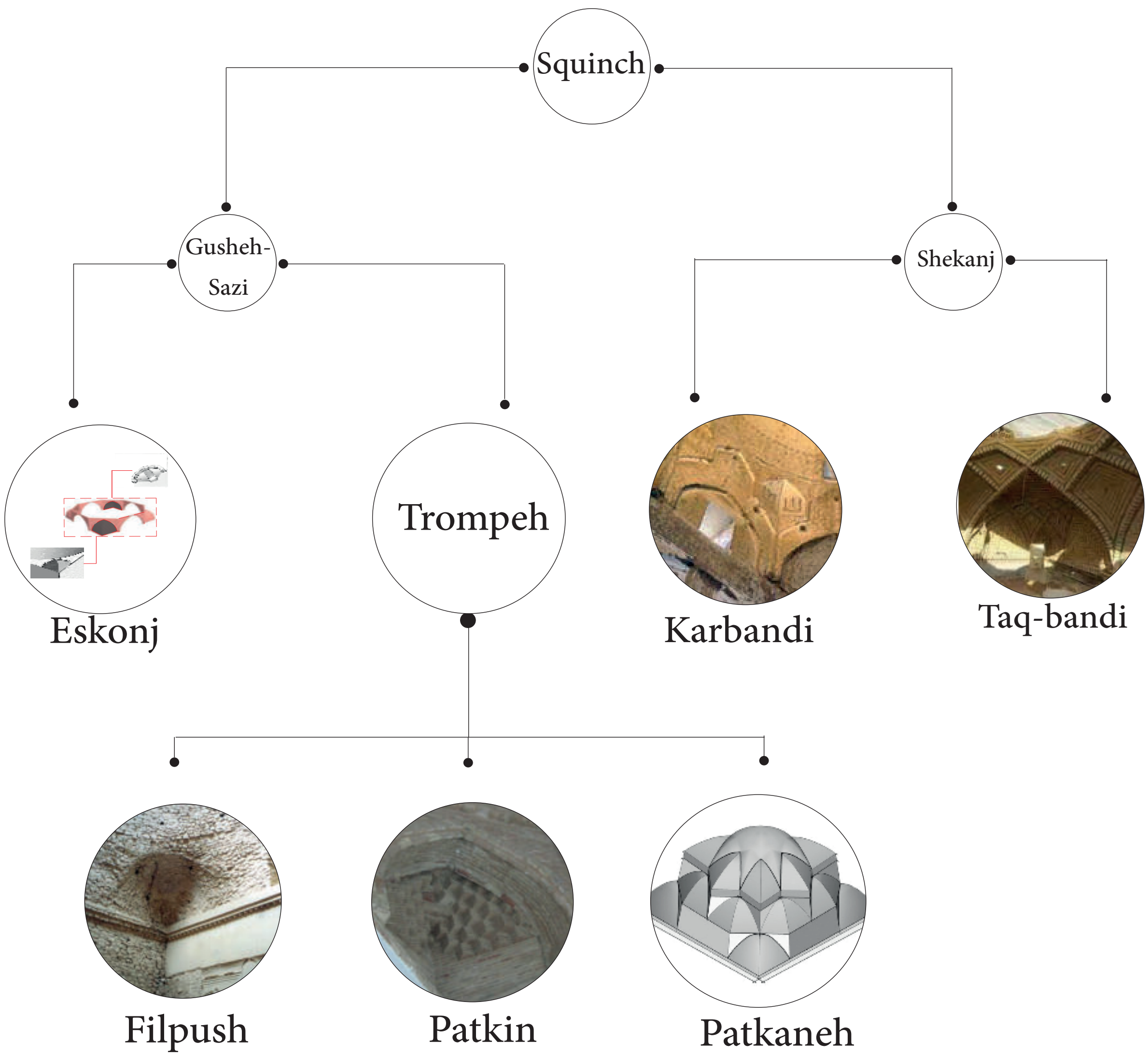


Diagram. 2 different types of squinches of Iranian architecture.

-Gusheh-sazi

This refers to the architectural technique of transforming a square or rectangular base into a polygonal or circular plan to support a dome. It involves a sequential geometrical transformation: from a four-sided base to an eight-sided, then sixteen-, thirty-two-, sixty-four-sided, and ultimately a circular plan. In the case of rectangular plans (closer to a square), transformation may result in a hexagonal, dodecagonal, and eventually an elliptical base (Fig. 69).

Gusheh-sazi itself includes two main subtypes:
• Eskonj (or Sekonj): A form of squinch using intersecting arches or vaults.
• Trompeh: A stepped squinch method, often appearing as projecting niches or corbelled platforms.

Historically, the earliest squinch constructions were executed in wood. In fact, not only the squinch system but also the outer shell of the dome itself was often built from timber (Fig. 70) [71].

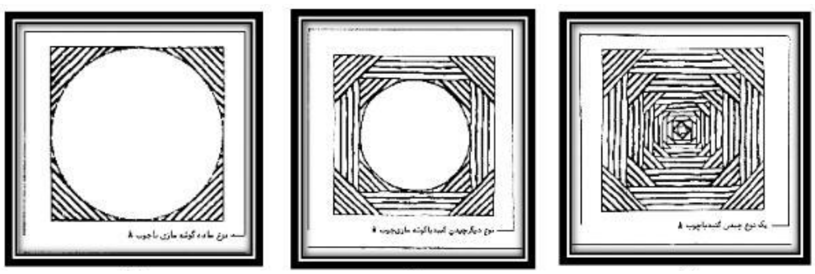


Fig.69 Gusheh-sazi (Corner Transformation), reference: [71].

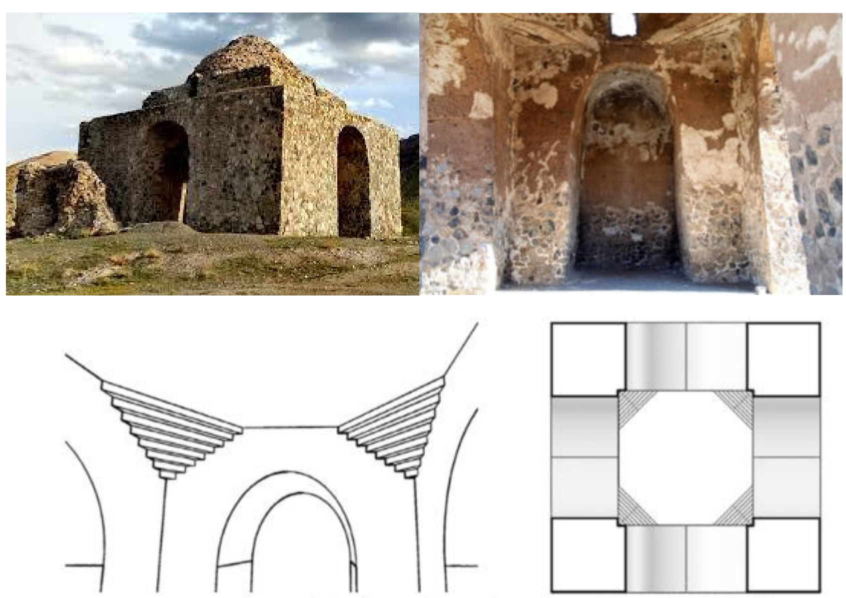


Fig.70 Baze Hoor- the first Gusheh-sazi in Iran, reference: [71].

-Eskonj

The Eskonj (also spelled Sekonj) consists of two oblique vaults that intersect at a single point, forming the transitional element in the corners of a square or rectangular base. The construction of these arches can vary depending on different bricklaying techniques, yet the defining feature remains the intersection of two slanted arches.

It is important to note that the loads of the dome are not directly transferred to these corners. Instead, the Eskonj serves primarily as a geometrical and architectural solution for transforming the base to a more suitable form for dome placement, rather than acting as a major structural support (Fig. 71) [71].

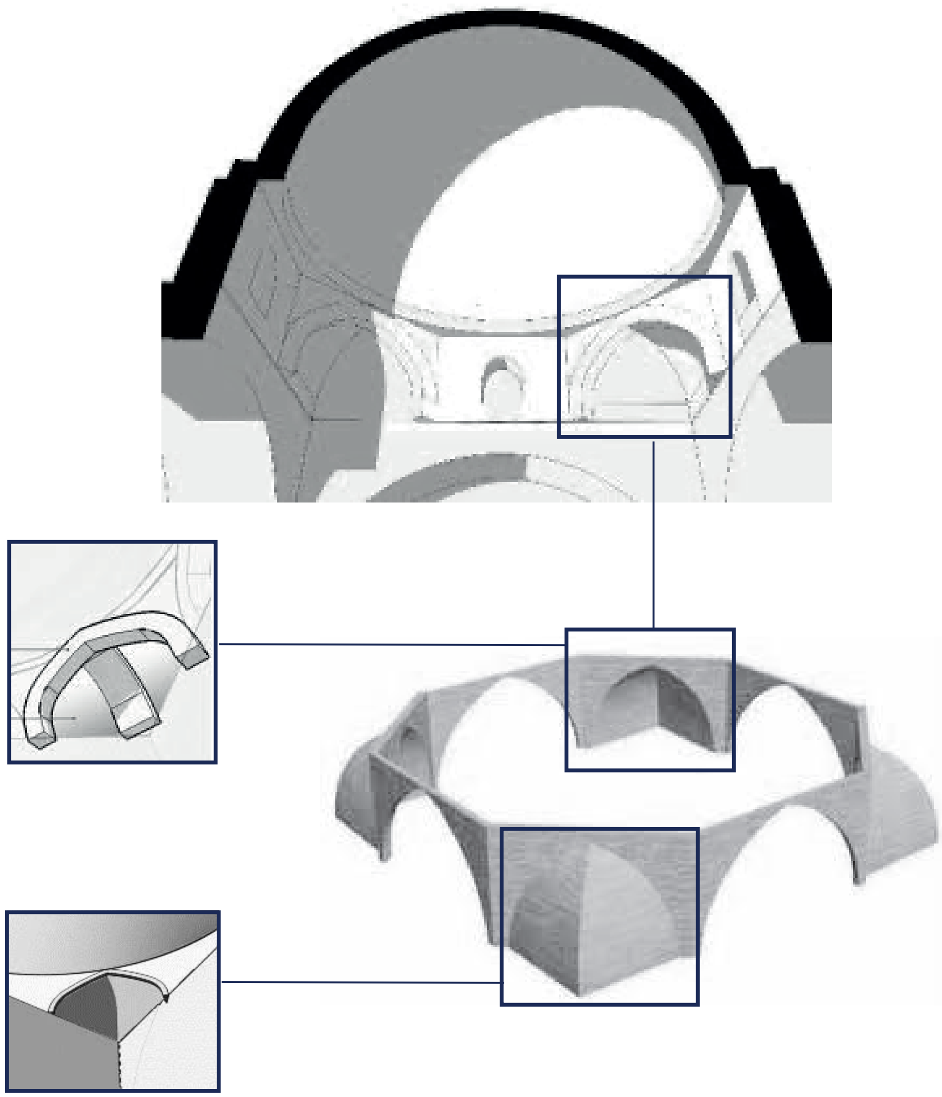


Fig. 71 The details of Eskonj, reference [71].

-Trompeh

1- Filpush

One notable subtype of Trompeh is the Filpush, which manifests in three architectural variations. In this particular form, the construction process begins from the corner (zero point) and resembles the spiraling growth of a seashell. Layered arched segments are superimposed step by step until the desired elevation is achieved—namely, the point at which the square base transitions into an octagon.
Technically, the term Filpush refers to a Cone structure that originates from the junction of two perpendicular walls and fills the corner space with layered vaults. It serves as a spatial and geometric mediator for supporting the dome.
In pre-Islamic architecture, domes often rose to considerable heights. However, in the post-Islamic period, there was a deliberate shift toward reducing the height of coverings, which made Filpush squinches especially useful for lowering the springing point of the dome while preserving its structural stability (Fig.72) [71].

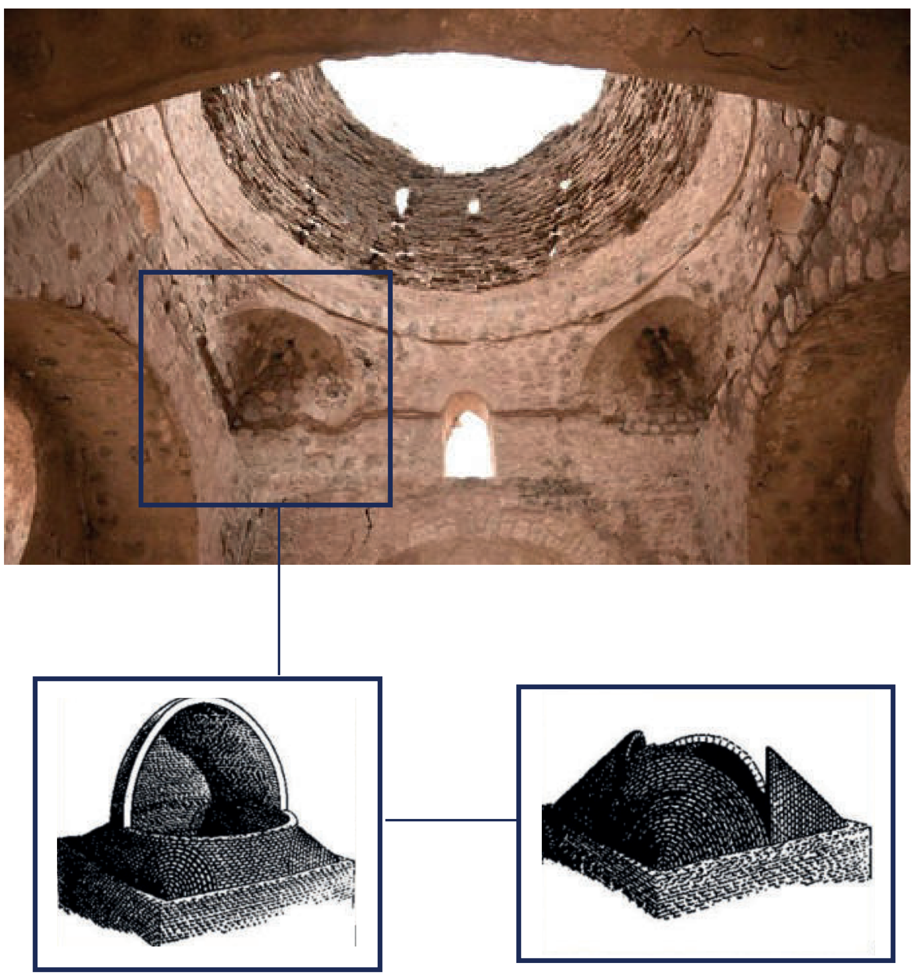


Fig. 72Trompeh: Filpush, Reference: [71.

2- Stepped Corbelling Squinch- Patkin

This type of squinch construction is characterized by the gradual projection of the walls, layer by layer. In this technique, horizontal brick courses are extended slightly outward in each row, creating a stepped appearance when viewed from below.
Such construction results in a tiered, corbelled form, allowing for the progressive transition from a square base to a polygonal or circular plan. Though structurally modest compared to arched squinches, it is an economical and historically significant method, often used in early and vernacular architecture (Fig.77,78) [71]. The earliest examples of this technique are wooden structures, the oldest of which can be seen in the Bazeh Hoor Fire Temple which is described in previous part (Fig. 73).

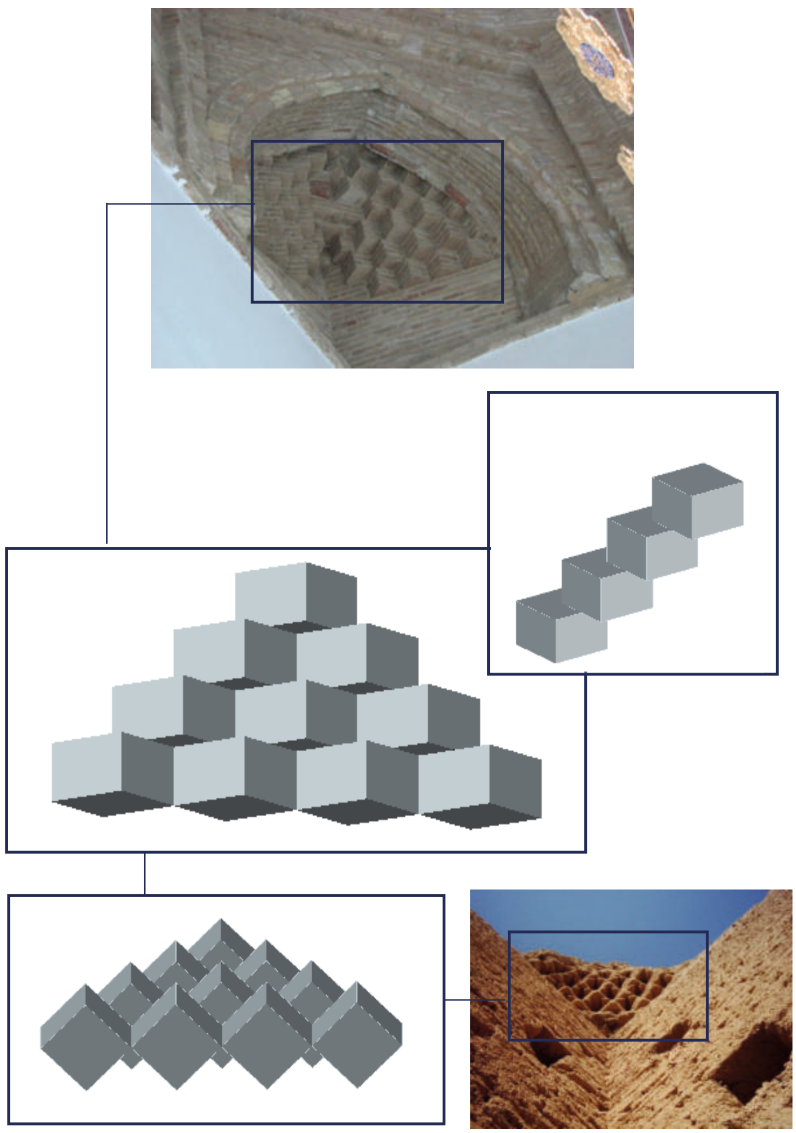


Fig.73 the sketch of Stepped Corbelling Squinch- Patkin, reference: author based on [73].

3- Patkaneh

The Patkaneh, is a form of squinch composed of stacked, progressively projecting niches. These niche elements are set one above the other, gradually extending outward to create the corner transition necessary for dome construction. Etymologically, the term Patkaneh implies a vault constructed, and it is fundamentally built by first erecting the lower tier of niches, then systematically placing the upper rows atop the lower series. Architecturally, this technique completes the corner composition by combining visual rhythm and spatial transformation. It also serves a decorative as well as structural function, especially in transitional zones where polygonal or circular bases must be supported on square foundations. Patkaneh are employed not only for constructing domes but also in the construction of Iwans and their semi-domes, and in certain types of vaults such as kolombo. (Fig.74,) [64, 71].

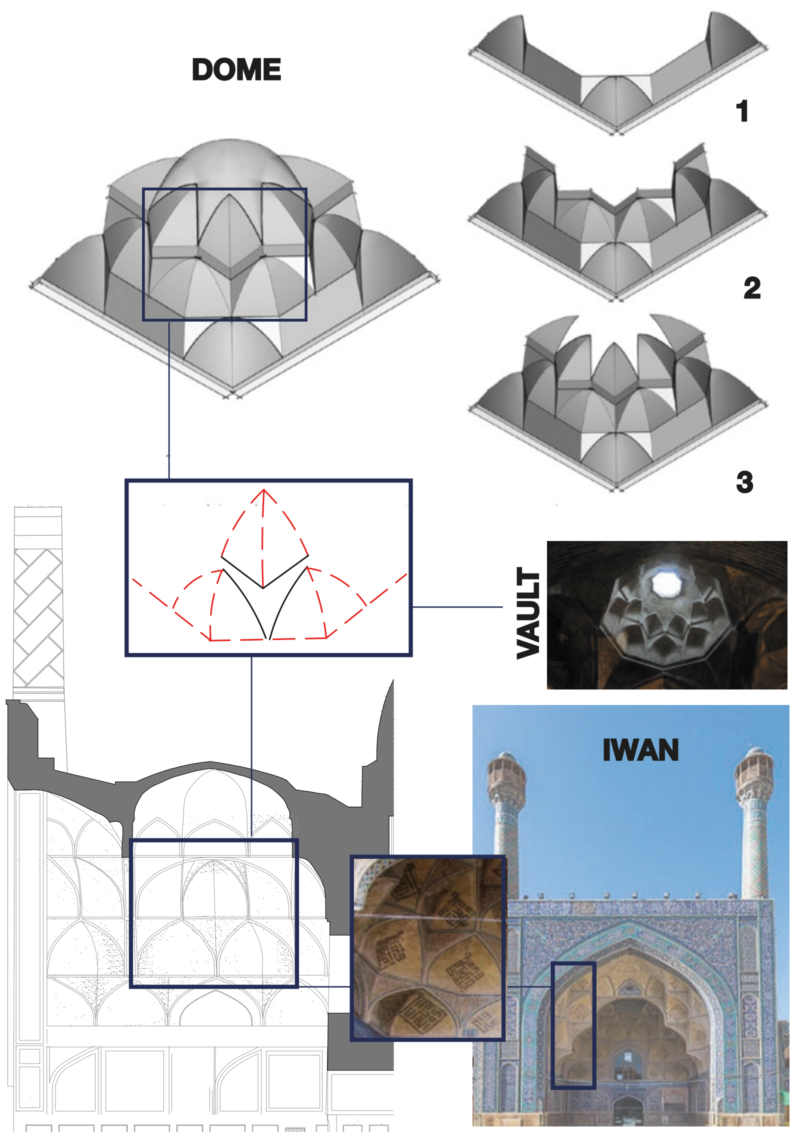


Fig. 74 the sketch of Patkaneh, reference: author based on [72].

It should be noted that in Iranian architecture, the term Patkaneh refers to a series of superimposed vaults that possess a structural function, primarily responsible for load transfer within the transition zone. This structural role is precisely what distinguishes the Patkaneh from Muqarnas. Although at first glance the two may appear visually similar, their construction technique and mechanical behaviour are fundamentally different. Muqarnas elements are non-structural and function as decorative suspended forms, whereas Patkanehs are load-bearing systems formed by the stacking of vaults in successive layers. In cases where one of the vaults in the Patkaneh ensemble is positioned at the corner of the transition zone, its form typically transforms into that of a Eskonj, adopting the geometrical characteristics of this element while maintaining its structural continuity. More generally, the term Patkaneh can refer to any composite system of multiple interlocking vaults arranged in superimposed layers to bridge between different geometrical configurations such as from square to octagon while transferring loads to the supporting piers. Moreover, the term Patkaneh also refers to any assemblage of superimposed load-bearing vaults, as previously discussed. These systems may appear in a wide variety of structural and geometrical configurations, ranging from simple arrangements of overlapping arches to highly intricate compositions. Despite this diversity, all such examples share the same structural principle of vertical and lateral load transfer through successive vaults. The increasing complexity of certain Patkaneh forms reflects not only the creative ingenuity but also the advanced geometric knowledge of Iranian master builders, who developed sophisticated spatial solutions by manipulating vault geometry and curvature while preserving the structural logic of the system (Fig. 75) [72].

Fig. 75 Patkaneh of feizieh school, Yazdreference: [71].

-*Shekanj*

Shekanj, like Gusheh-sazi, serves the same structural purpose of transforming a square base into a circular or polygonal form, yet the two differ in both form and spatial location within the construction. While Gusheh-sazi elements are typically positioned at the corners, gathering the structural load and geometry inward from the corners to form the transitional zone, Shekanj elements composed of multiple intersecting units. Each of these units contributes to subdividing and transforming the surface into several smaller geometrical parts, gradually preparing the base for the placement of the dome. The Shekanj system, a refined method of squinch construction, consists of two primary types: Taq-bandi and Karbandi. While both forms are architecturally similar to the Eskonj in terms of antiquity, they became more prominent in post-Islamic architecture due to changes in design constraints—particularly the deliberate reduction in dome height. In pre-Islamic architecture, the absence of such limitations meant earlier methods were more commonly employed [65, 71].

1- Taq-bandi

This technique begins at the drum (bashn) of the dome, where the corners are progressively stepped forward by a quarter of a brick in each layer. As a result, the opening is gradually reduced on all four sides, creating a more confined and elevated base.

1. Eight-Vault Stage:
   - Four arches are constructed at the corners and four at the midpoints of each side, effectively transforming the square base into an octagon (8-sided figure).
2. Transition from Octagon to Sixteen-Sided Base:
   - A barnakhsh arch (decorative filler arch resembling a keel arch) is placed atop each existing arch.
   - These arches are non-load-bearing and are fixed to the flanking walls.
   - Like earlier steps, each barnakhsh is advanced by a quarter of a brick to further narrow the opening.
3. Peykaneh Layer:
   - A peykaneh—a type of ornamental layer—is then built atop each barnakhsh.
   - These act as aesthetic and structural complements.
4. Sanbuseh Filler Units:
   - The spaces between peykanehs are filled with sanbusehs—curved triangular segments—which help approximate a circular profile for the dome's base.
5. Final Transition:
   - A final incremental forward shift of brickwork is executed before the dome is seated atop the fully formed transition zone (Fig. 76) [64, 71].

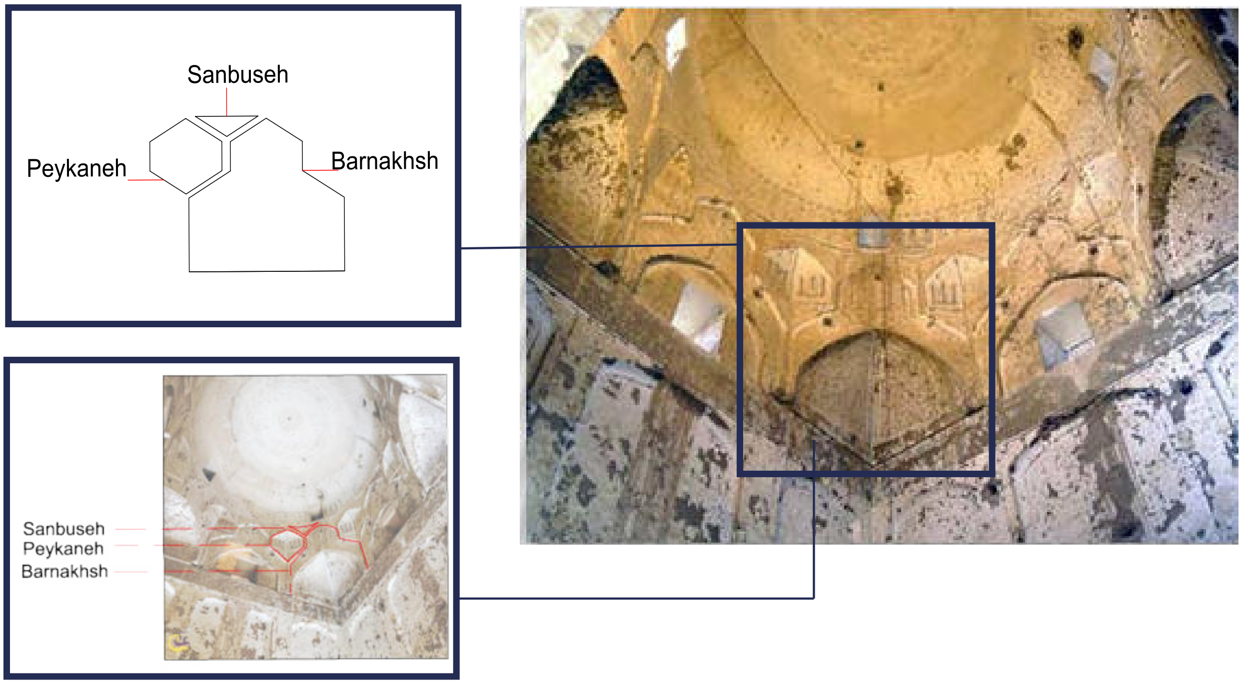


Fig. 76 the components *of* Taq-bandi, reference: author based on [65, 71].

2. Karbandi

Karbandi is a sophisticated form of Shekanj that shares fundamental construction principles with Taq-bandi. However, it accomplishes the conversion from a square base to a circular dome support without requiring significant vertical elevation, making it ideal for structures with height limitations.

Construction Method:

The process begins with the creation of an eight-vault system—four arches placed at the corners and four at the midpoints of each side—thus transforming the square base into an octagonal plan.

From this point forward, the Karbandi system is applied:

- A geometric rib work is constructed directly above the octagonal base.
- This transformation results in an immediate shift from an 8-sided to a 32-sided plan, which provides a near-circular platform for the dome.
- The dome is then placed atop the ridges of the ribbed structure, known as Gariwar, completing the transition.

Structural Components of Karbandi:

1. Sanbuseh (Curvilinear Triangular Segments):

These form the uppermost elements of the Karbandi, helping shape the dome's circular base with elegant geometric continuity.

2. Shaparak (Butterfly Units):
Found in intermediate tiers, these elements create the mid-zone of the ribbed lattice, contributing to both structure and ornamentation.
3. Pa- Barik (Slender Feet Units):
These are the lowest elements, providing the visual and structural foundation of the Karbandi framework (Fig. 77,78) [71].

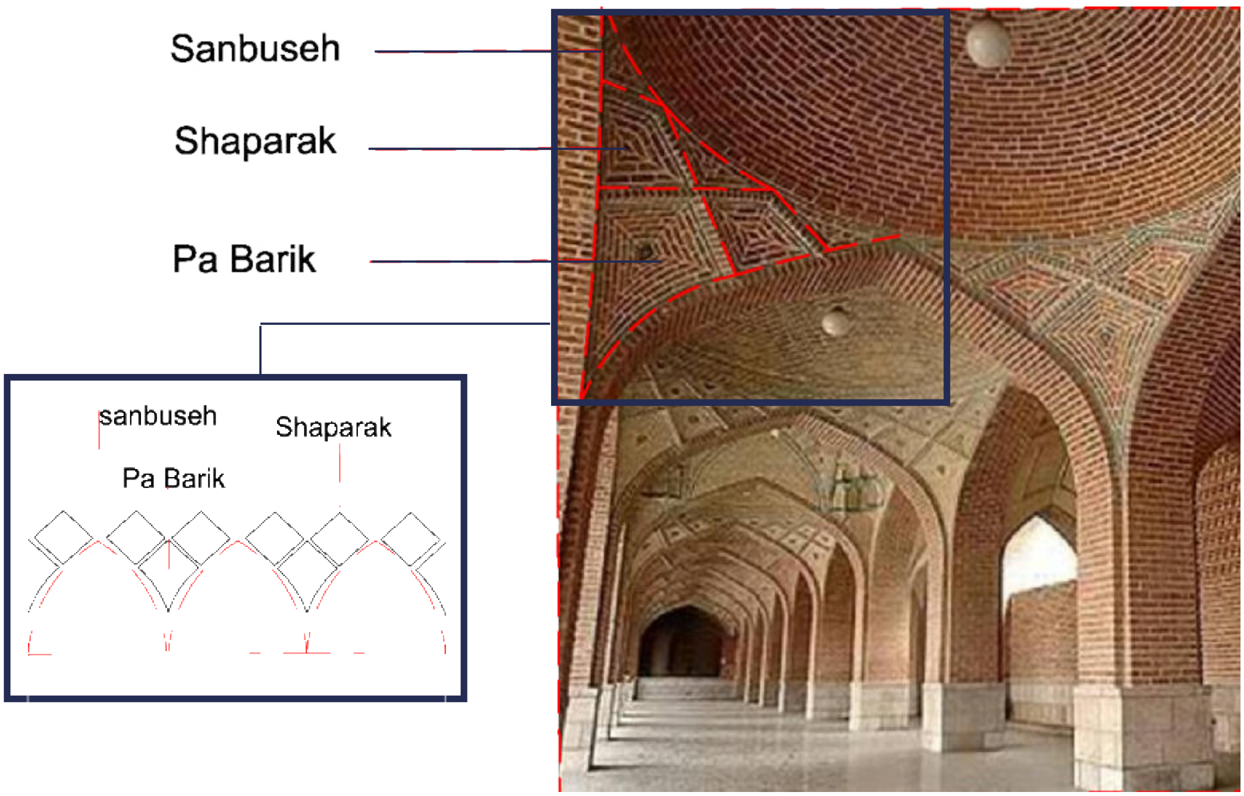


Fig. 77 the components of Karbandi, reference: author based on [71].

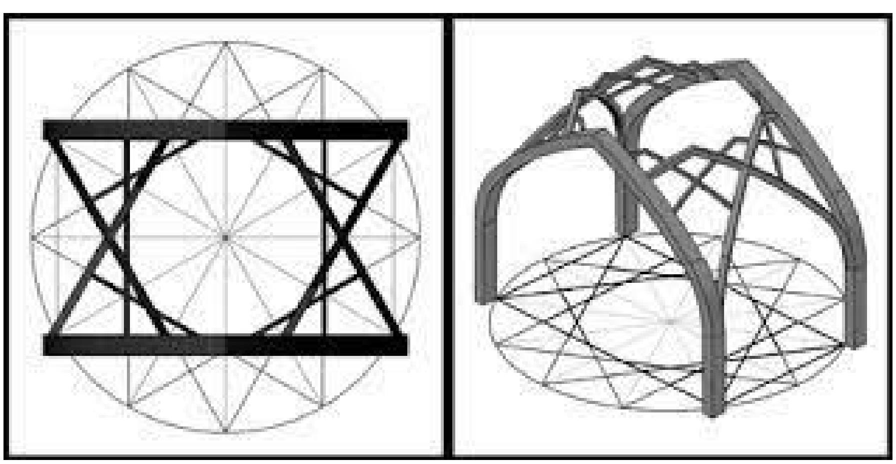


Fig. 78 the components of Karbandi, reference: [71].

In Persian architecture, the karbandi is not derived from a spherical base but from intersecting arches placed at specific chords on the base circumference. These arches are rotated around the vertical axis of the dome, creating patterns of modular symmetry, often reinforced by decorative elements. The complexity of the karbandi dome depends on several variables:
- the number of divisions of the circumference
- the angular span between chord endpoints
- the number of intersecting arches
- omitted or partial arches (which define central voids or shamseh)
- the symmetry axes determined by the layout of the underlying space

This geometric system allows for both mathematical control and aesthetic flexibility, often producing latticed domes with pronounced visual rhythm. The Iranian tradition, as Vale notes, demonstrates a higher degree of systematization, including the use of bent arches (out of plumb) and multi-layered arrangements that combine several karbandis in one space (e.g., the Tabriz Bazaar). In contrast, the Spanish-Muslim examples exhibit simpler schemes, with fewer intersecting arches and less modular layering. While both traditions prioritize symmetry, the Persian version amplifies this through high-contrast brick joints, decorative ribs, and symbolic alignments (e.g., from square base to celestial circular dome). Persian examples also often include non-structural ribs for ornamentation, emphasizing geometric abstraction over mere structural necessity [73].

3.2.2 Typologies of dome from the structural point

In traditional Iranian architecture, domes are typically constructed with two distinct layers: an inner shell known as the Ahiyaneh, which covers the interior space, and an outer shell referred to as the khud, which defines the external profile of the dome.
The spatial relationship between these two shells can be categorized into three main structural configurations:

1. Tightly Adjoined Double-Shell Domes

In this configuration, the khud (outer shell) is constructed directly upon the ahiyaneh (inner shell), with both layers nearly superimposed throughout. The only visible deviation between the two occurs at the tip of the dome, where the khud extends slightly to create a pointed apex, providing the necessary slope to shed rainwater and snow. This arrangement results in a structurally unified dome with minimal air gap and was often used when material economy and simplicity of construction were prioritized. The best example is the Sheikh-lotf-allah dome in Isfahan (Fig. 79).

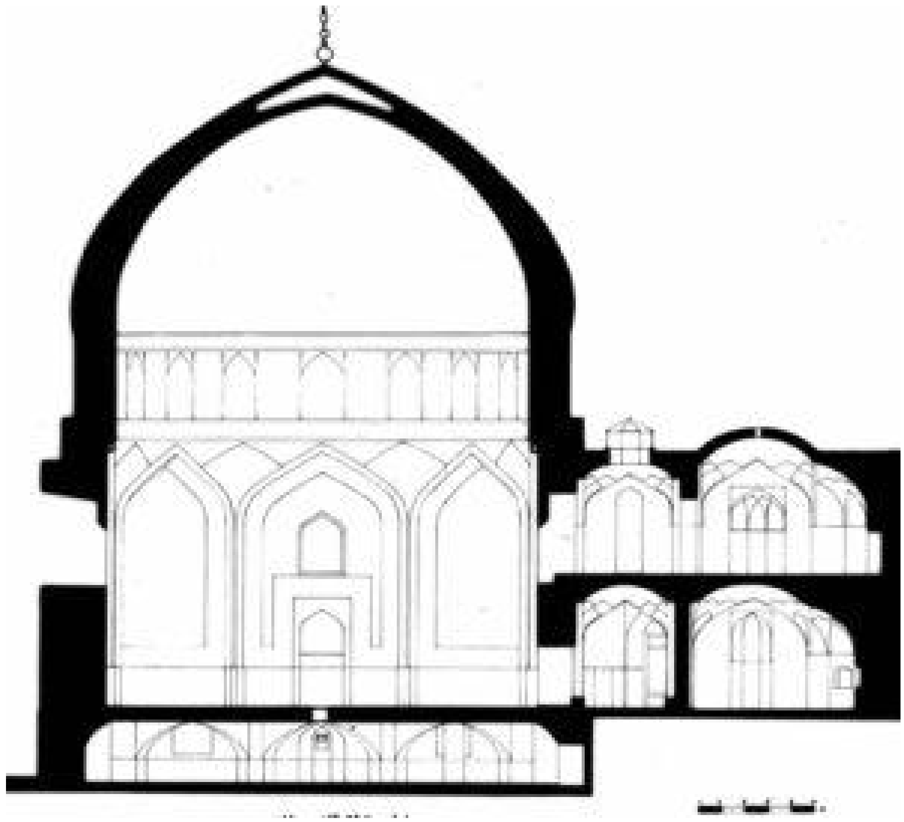


Fig. 79 the section of the dome of Sheikh-lotf-allah in Isfahan as a good example of the Tightly Adjoined Double-Shell Domes, reference: [30].

2. Partially Detached (Hollow-Cavity) Double-Shell Domes

In this system, the inner and outer shells remain in contact up to an angle of 22.5 degrees from the horizontal plane, a point known in Persian architectural terminology as the shakargah. Beyond this angular threshold, the two shells gradually separate, allowing for a hollow cavity between them. Structurally, this configuration functions similarly to a continuous double-shell dome but offers the advantage of being lighter in weight, improving thermal insulation and reducing load on the supporting elements [71]. In this type of dome, the separated sections are bonded together (Sandoghchini) with brick masonry to maintain the structural continuity of the dome and to enhance its resistance to seismic forces (Fig 80).

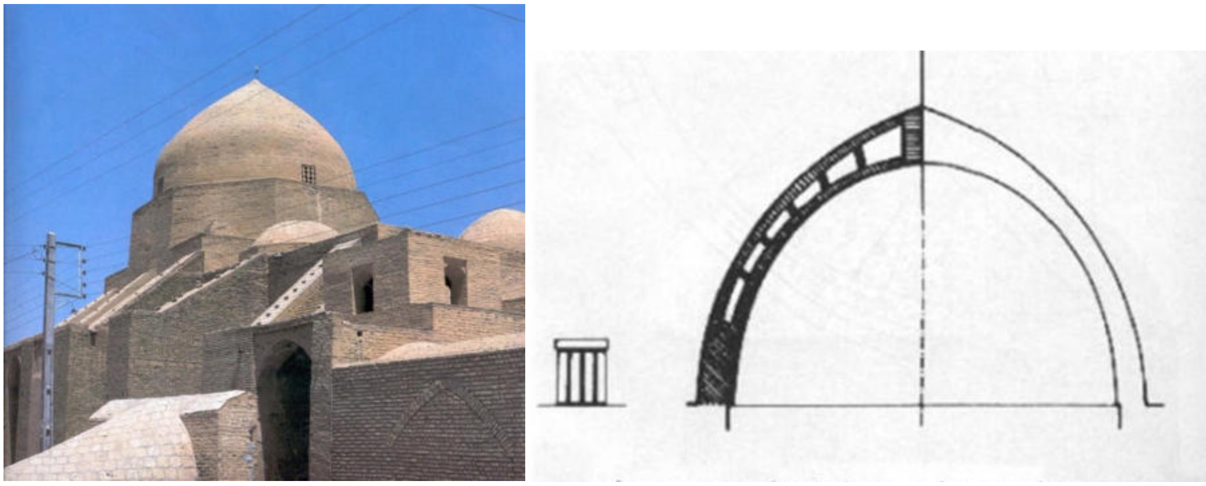


Fig. 80 the dome of Jameh mosque in Ardestan as a Partially Detached (Hollow-Cavity) Double-Shell Domes, reference: [30].

3. Fully Detached Double-Shell Domes

This is the most advanced and complex form. In this type, the khud and ahiyaneh are entirely independent of one another, functioning as discrete structural systems. In these domes, the khud and the ahiyaneh are separated by a relatively large gap, and in order to support the khud on the ahiyaneh, small masonry walls are constructed on top of the inner shell. These walls, known as khashkhashi, serve as the supports upon which the outer shell rests. These khashkhashi walls were bonded together at the center so that, in terms of load transfer and the forces acting on the double-shelled dome, they would function integrally and unify the dome as a whole. At the same time, while ensuring the lightness of the structure, the khashkhashi elements provided continuity and connection between the two shells and enhanced the dome's resistance against seismic forces. (Fig.81,82,83) [71].

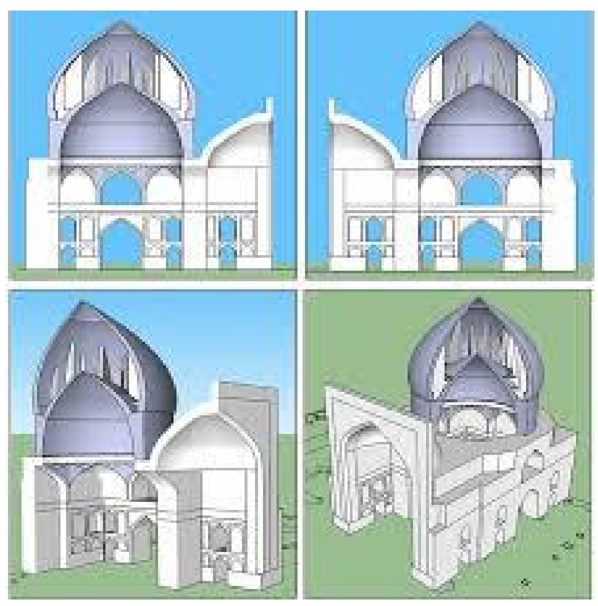


Fig. 81 the section of the dome of Jameh abbasi mosque in Isfahan as a fully Detached Double-Shell Domes, reference: [30].

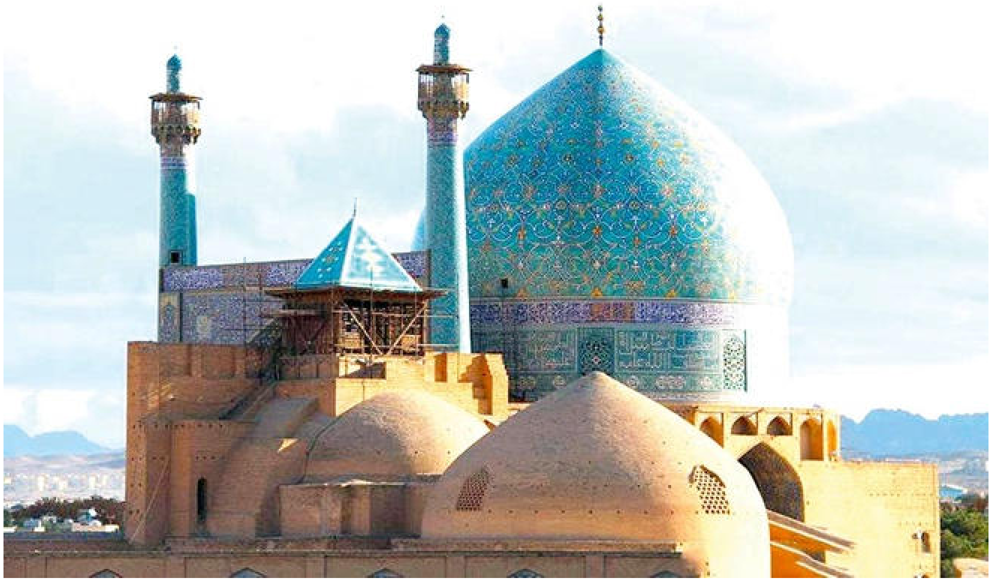


Fig. 82 the dome of Jameh abbasi mosque in Isfahan as a fully Detached Double-Shell Domes, reference: [30].

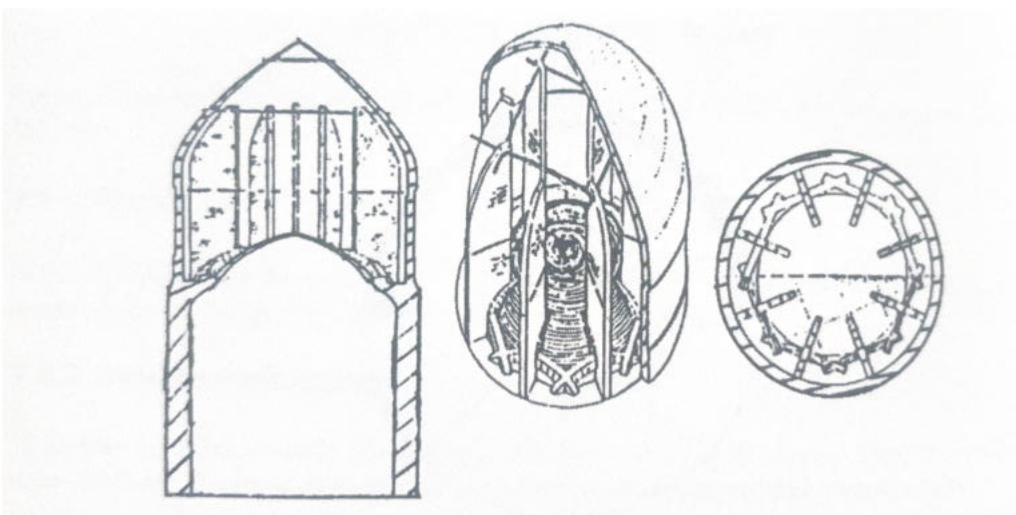


Fig. 83 the section of the dome of Jameh abbasi mosque in Isfahan and its Khashkhashi reference: [71].

Moreover, there are a few domes with three shells in Persian architecture such as Bayazid Bastam (Fig. 90), Goharshad mosque and Amirchakhmaq Yaz. The base of these domes is square in most cases; the two internal and midle shells have quite a low rise compared to the external one.

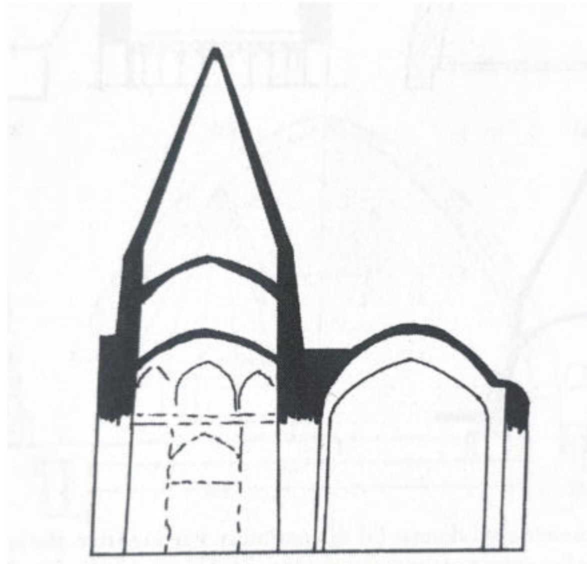


Fig. 90 the section of three shells dome of the Bayazid Bastam in Isfahan reference: [65].

A recent study offers valuable insight into the thermal performance of traditional domed structures in Iranian architecture. The findings indicate that domed roofs consistently exhibited the lowest annual energy consumption, approximately 9–10% lower than flat roofs. This improved performance is attributed to the reduced surface area exposed to external thermal loads and the natural thermal lag associated with the dome's double-curved geometry. The dome’s form minimizes heat transfer while delaying indoor temperature fluctuations, resulting in enhanced thermal comfort. The study further compared ventilated versus unventilated domes. Domes equipped with ventilation openings outperformed their sealed counterparts, particularly in both heating and cooling seasons, by promoting passive airflow and better interior climate regulation. ASHRAE Standard 55 psychrometric charts confirmed that ventilated domes maintained indoor conditions closer to comfort thresholds throughout seasonal extremes [74].

Typologies of domes based on their form

In Iranian architecture, domes are also classified according to their external form. Among these types, the Nar dome is the most characteristic of Iranian architectural tradition and became widely employed after the advent of Islam (diagram. 3).

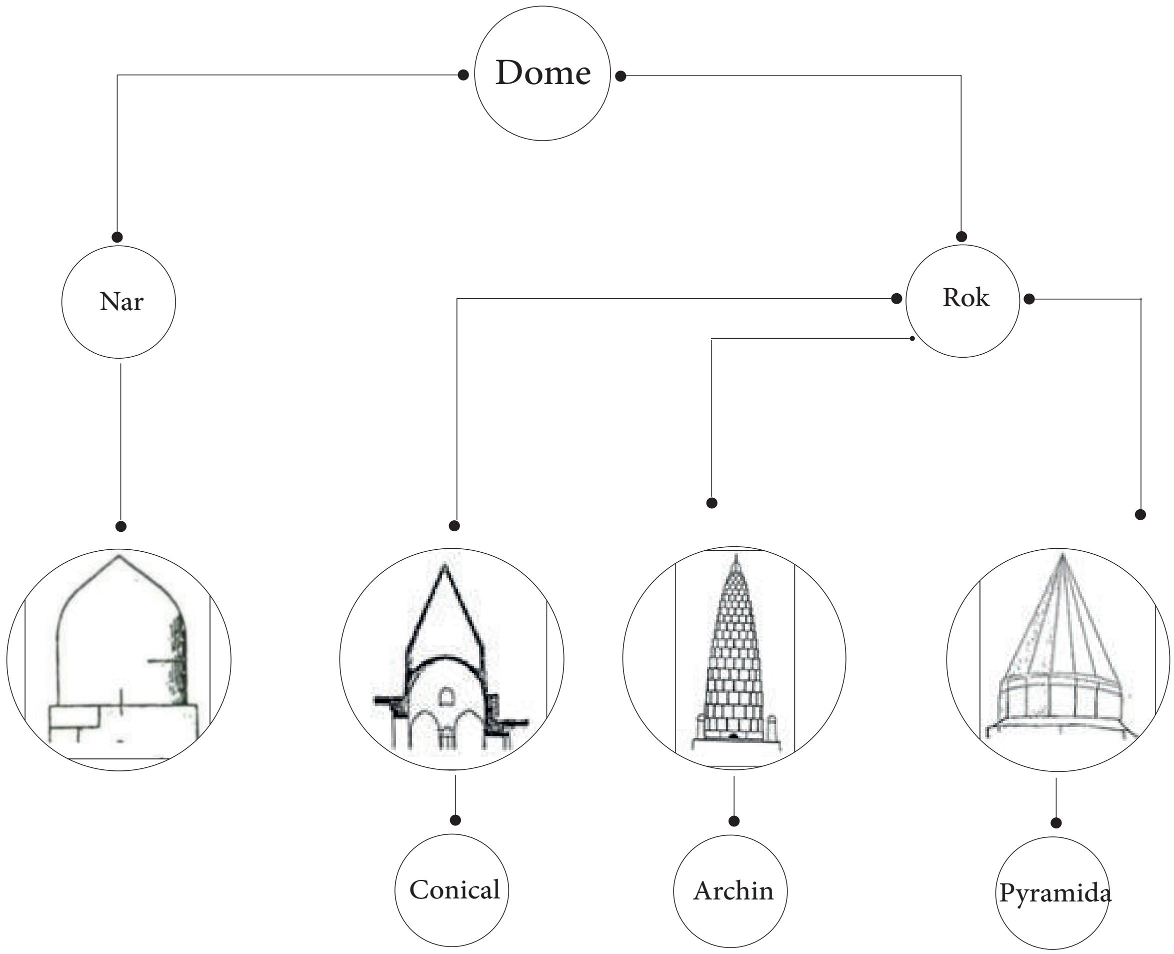


Diagram. 3 Typologies of domes based on their form, reference: [75,82]

3.2.4 Construction Process of Iranian Domes

Iranian domes are constructed using two principal techniques: without a supporting skeleton and executed through, and Tarkin (ribbed construction). In the first method the construction progresses course by course and from the backside upward, since Iranian domes, due to the absence of centering or formwork, cannot be built from the inside. At the outset of the work, a device known as shahang and hanjar was employed. The shahang is a vertical rod usually wooden erected at the geometric center of the domed chamber. This rod is firmly fixed in place from the surrounding sides to prevent any movement. To stabilize the shahang to the dome walls, between eight and ten wooden struts are typically used. Then, at the two points corresponding to the foci of the intended elliptical profile, precise marks are made on the shahang, to which two delicate chains are attached. These chains, referred to as the hanjar, are used to delineate the desired elliptical curve. Subsequently, the dome builder would proceed to lay the bricks from the backside, course by course, carefully controlling the curvature of the dome with the aid of these chains [74].

It should be considered, domes were typically constructed in brick or adobe, and the arrangement of materials followed two principal methods: gerd-chin and rag-chin. In the gerd-chin technique, the brick courses are oriented toward the center of the dome and laid radially. In contrast, in the rag-chin method, the brick or adobe courses are set parallel to the horizontal plane. Rok domes cannot be built using the gerd-chin technique; therefore, all of them are constructed exclusively in the rag-chin manner (Fig. 91).

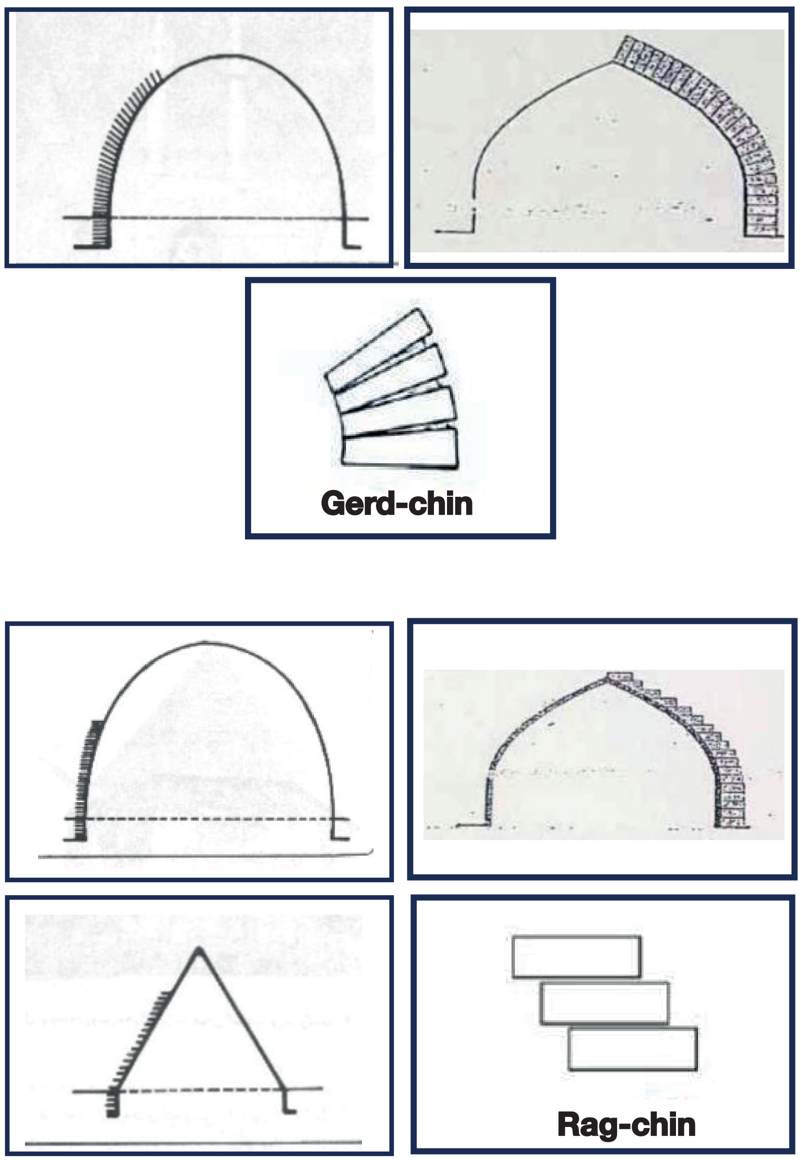


Fig. 91 Typologies of dome construction based on brick-laying techniques, reference: [74].

Moreover, Ribbed domes (tarkin) in traditional Iranian architecture were typically constructed without the use of the shahang and hanjar devices, which were essential tools in the construction of brick-masonry domes of smaller scale. The reason for this deviation lies in the considerable height and span of such domes, which in some cases reached between 16 and 18 meters in rise. The geometric control of curvature through suspended devices was therefore replaced by a pre-fabrication process executed at ground level. In this method, the ribs (tark) which serve both as structural reinforcements and as defining elements of the dome's surface geometry were first shaped on the ground using gypsum to trace the desired curvature and profile. Once these elements were precisely formed and allowed to set, they were elevated and installed around the circumference of the dome's base at the required inclination. It is notable, that a gypsum centering seems to be the right choice for the spans maximum five meters. Beyond that, centering made from wooden plates becomes a more practical option. The intermediate spaces between adjacent ribs were subsequently filled with layers of brick masonry (Fig.92) [74].

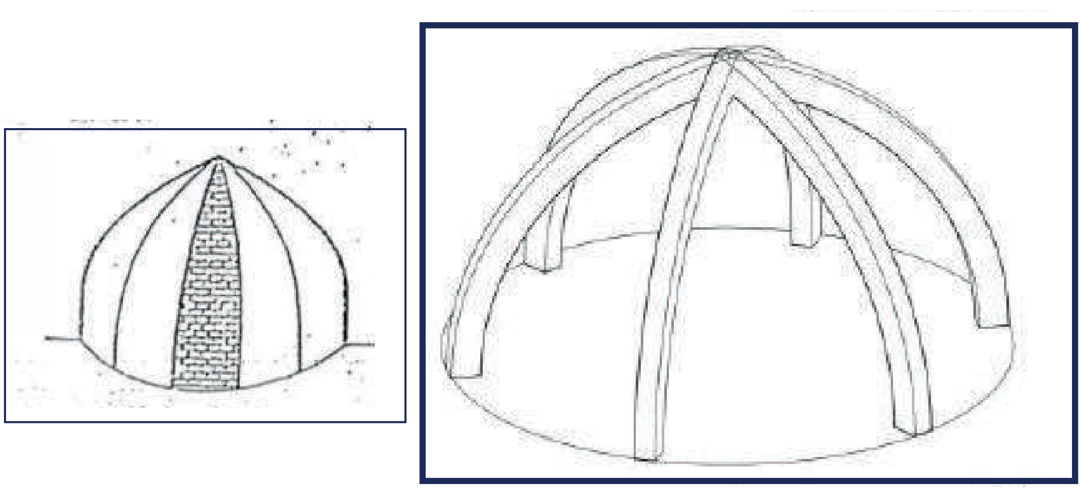


Fig. 92 Ribbed domes and brick-laying, reference: [74].

Mechanically, loads (dead load, live load, and incidental lateral actions) are first borne by the dome shell and are transmitted along the ribbed lines as predominantly compressive forces. The ribs concentrate and channel these compressive trajectories downwards into the transitional zone. this zone converts the radial flow of forces into concentrated thrusts taken by the four main piers. In this process the ribs act both as stiffening members (increasing local curvature and reducing membrane tensile demands) and as preferential load paths that limit the circumferential (hoop) tensile stresses that would otherwise develop in a thin, unribbed shell [91]. Comparative studies of Seljuk domes indicate that such ribbed/segmental construction reduces meridional bending and horizontal thrust on the drum, thereby decreasing the need for massive external buttressing and improving the overall stability of the system [93]. The construction details enhance this mechanical behaviour. Thin mortar beds and tight interlocking geometry between adjacent ribs increase frictional shear transfer and composite action, so that the ribs behave as a unified structural ring rather than as independent arches. Where present, shallow surface niches and lightening recesses within the supporting walls reduce self-weight without interrupting primary thrust lines, because the dome’s thrust is redirected through the ribs and pendentives rather than through the wall fabric immediately adjacent to these recesses (Fig. 117) [94,95].

Isfahan, the Capital of Culture of Iran

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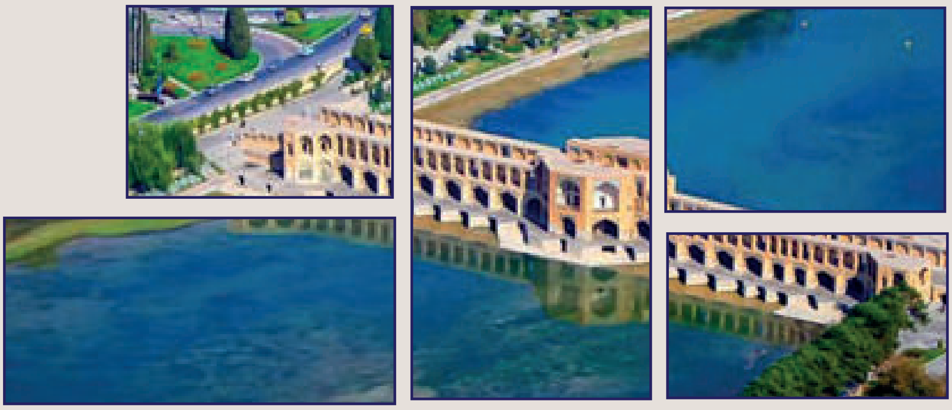
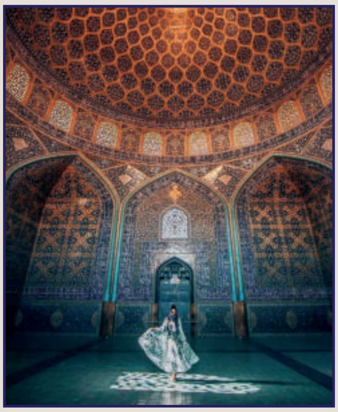
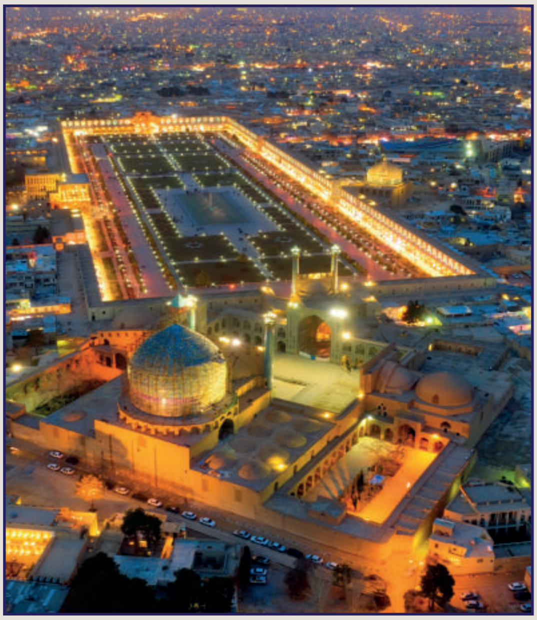






4.1. Isfahan: Historical, Geographical, and Urban Context

The city of Isfahan, situated at the heart of the central plateau of Iran, possesses one of the richest and most complex historical trajectories among Iranian cities. Its strategic geographical position nestled between the Zagros Mountains to the west and the vast deserts to the east has made it a natural intersection for cultural exchange, commerce, and settlement development throughout history. Archaeological investigations conducted across the Isfahan plain provide strong evidence that human occupation in the region dates back to prehistoric times, particularly the Neolithic and Chalcolithic periods, when early communities began to establish permanent settlements due to the availability of fertile soils and water resources. These early settlers developed small-scale agricultural systems supported by seasonal floods and fertile alluvial plains along the Zayandeh rud River, which acted as the primary source of fresh water and a life-sustaining artery for the entire region(Fig.93) [75].

Fig. 93. The map of Iran and thelocation of Isfahan.

4.1.1 Pre-Islamic Periods

The historical significance of Isfahan began to emerge prominently during the Achaemenid Empire, when the region evolved into a vital administrative, economic, and military hub within the empire's vast territorial network. Its strategic location at the intersection of the imperial road systems connecting Persepolis, Susa, Ecbatana, and Mesopotamia allowed the city to function as a central node for governance, taxation, and trade. Archaeological findings from the Isfahan plain and surrounding settlements indicate the presence of administrative complexes, storage facilities, and organized residential quarters from this period, reflecting the Achaemenid policy of regional integration and infrastructural investment. Moreover, evidence suggests that the Royal Road, one of the empire's most significant communication arteries, passed near the Isfahan region, enabling the rapid movement of troops, officials, and goods across the empire (Fig.94) [75].

Fig 94. Persian Royal Road in Achaemenid Empire, Reference: Internet Archive.

The formal development of Isfahan as a recognizable urban center occurred during the Sasanian period, when historical texts first recorded the name "Aspahan" or "Spahan," likely referring to its function as a military garrison for imperial forces. this stage marked the transformation of the region from a scattered agrarian landscape into a fortified administrative center. Historical and archaeological studies reveal that under Sassanian rule, the region witnessed a deliberate program of urban expansion, defensive construction, and hydraulic engineering. The Sassanians fortified the area with massive ramparts and military garrisons, securing it against nomadic incursions and regional rebellions. These fortifications, combined with the city's geographical advantage in controlling access to the Zagros Mountain passes, established Isfahan as a key defensive stronghold within the empire's western frontiers. In addition to its military importance, Isfahan also became a cultural and administrative hub under the Sassanians (Fig.95) [75].

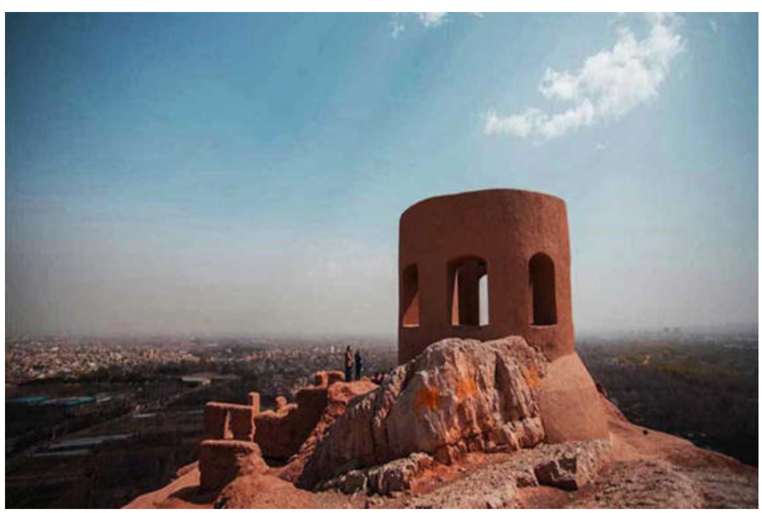


Fig 95, Mount Atashgah in Isfahan dates back to the Sassanian era and served as a fire temple for Zoroastrians, Reference: [75].

4.1.2 Islamic Periods

Following the Islamic conquest in the 7th century CE, Isfahan entered a new phase of political, economic, and architectural development. Initially functioning as a military garrison town, it gradually transformed into a commercial, cultural, and intellectual center under successive Islamic dynasties. By the 8th and 9th centuries, the city's bazaars, caravanserais, and religious institutions flourished, reflecting its role as a hub for regional trade and scholarship [76]. The Seljuk era marked a pivotal transformation in the historical, architectural, and socio-political trajectory of Isfahan, particularly after its designation as the imperial capital by Sultan Malik-Shah in the late 11th century CE (Fig.94) [76]. The elevation of Isfahan from a provincial center to the heart of an expanding empire triggered extensive urban development programs aimed at consolidating political authority, and establishing the city as a hub of knowledge, commerce, and administration. in this period, Under the supervision of prominent viziers, including Nizam al-Mulk, the Seljuk administration pursued a cohesive city layout that integrated residential quarters, commercial districts, and monumental architectural complexes into a unified framework [77]. Adjacent to the mosque, a network of madrasas, hospices, and civic institutions was established, reflecting the Seljuk ambition to position Isfahan as an intellectual powerhouse. These madrasas functioned as centers of theology, philosophy, and the sciences, attracting scholars such as Al-Ghazali and Omar Khayyam, who contributed to the flourishing of thought during this period. The Seljuks also invested heavily in water management and environmental adaptation. Sophisticated qanat systems, stone-lined water channels, and underground reservoirs were constructed to address the city's growing population and increasing demand for sustainable water distribution. This hydraulic infrastructure facilitated the expansion of public baths, gardens, caravanserais, and bazaars, while ensuring year-round irrigation for agricultural lands surrounding the city. The Zayandeh Rud River was strategically integrated into the city's urban fabric, supporting both the functional and aesthetic qualities of Seljuk Isfahan. Moreover, the connectivity between residential quarters, commercial zones, and monumental complexes was carefully orchestrated. The bazaar network stretching from the Jameh Mosque to the city gates became a key organizing spine that linked socio-economic activity with religious and political spaces [77]. The Mongol invasions of the early 13th century inflicted severe devastation upon Isfahan; however, under Ilkhanid rule, the city gradually recovered and transformed into a significant center of art, architecture, and urban development. The Mongol elite, having embraced Persian cultural traditions, became patrons of restoration projects, focusing on mosques, bridges, caravanserais, and civic spaces, many of which had suffered from neglect or destruction. This period witnessed remarkable architectural innovations that reshaped Isfahan's urban landscape [75-77]. The Safavid dynasty marked a transformative period in the urban, architectural, and cultural history of Isfahan, culminating in its designation as the imperial capital under Shah Abbas I in 1598. With this strategic relocation, the city evolved into a meticulously planned center of political power, economic activity, religious identity, and aesthetic expression, becoming a symbol of Safavid statecraft and Shia imperial ideology. During this period, Isfahan's urban fabric underwent unprecedented restructuring, guided by deliberate strategies to centralize governance and display imperial grandeur. Shah Abbas's ambitious planning produced a network of axial boulevards, gardens, and monumental structures anchored by the iconic Naqsh-e Jahan Square, a UNESCO World Heritage site today. Adaptive reuse of pre-Safavid structures demonstrates how earlier urban patterns were incorporated into a coherent Safavid plan, unifying diverse socio-religious functions [78]. A significant social and cultural development was the relocation of Armenians from Old Julfa to Isfahan around 1606. The newly established quarter of New Julfa became a vibrant economic and social hub, with Armenian merchants significantly contributing to the city's commercial prosperity through the silk trade and international networks. Beyond commerce, Armenians influenced the architectural landscape by introducing churches that combined traditional Armenian forms with Safavid decorative motifs, enriching Isfahan's urban fabric with a distinct cross-cultural identity. This settlement exemplified Shah Abbas's deliberate policy to enhance the city's cosmopolitan character and to integrate diverse artistic and urban practices into its spatial organization [79,80]. Engineering and ideology converged in Safavid Isfahan, exemplified by monumental complexes such as the Shah Mosque, Sheikh Lotfollah Mosque, Ali Qapu Palace, and Chehel Sotoun. These works combined structural innovations with sophisticated ornamental mastery [81]. The first European to record his journey to Isfahan was Pietro della Valle, who described the city as surpassing anything in Constantinople or Christian lands [10]. Jean Chardin famously declared Isfahan "the greatest and the most beautiful town in the whole of Orient," [12]. Beyond his writings, Chardin produced a detailed map of Isfahan, meticulously documenting Naqsh-e Jahan Square, mosques, bazaars, bridges over the Zayandehrud, and courtly life, which remains one of the most comprehensive urban records of the Safavid capital (Fig. 96) [12].

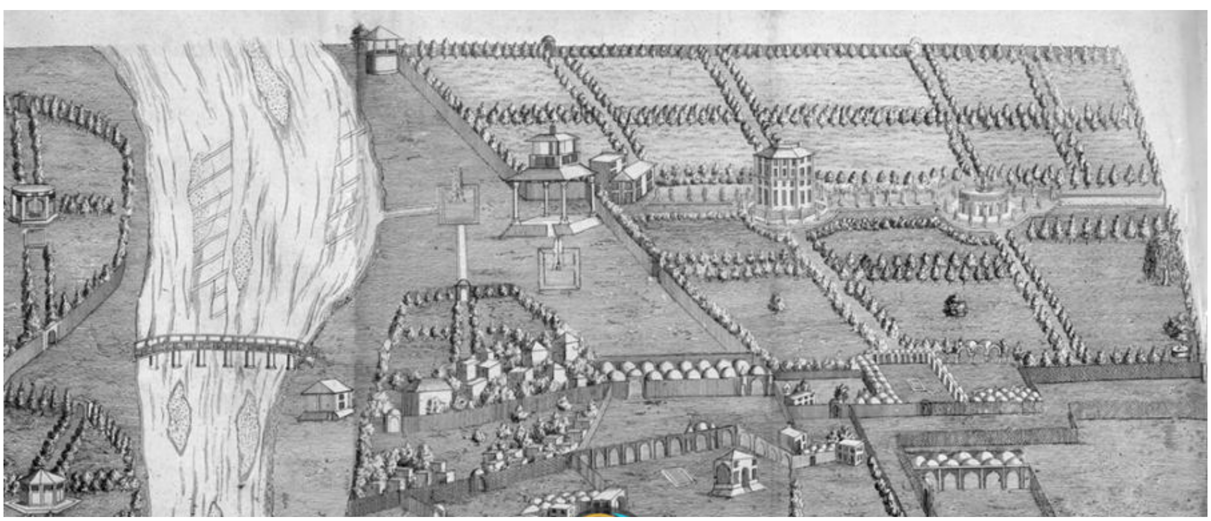


Fig. 96 Isfahan map by Chardin, Reference:[35]

During the Qajar era, Isfahan underwent profound socio-political and cultural changes as it transitioned from its Safavid legacy toward new forms of urban adaptation. While the city lost its status as the political capital, it remained an important regional cultural and economic hub, primarily due to its strategic location and vibrant artisanal traditions. Following the Safavid decline and the devastation caused by the Afghan invasion, Isfahan entered the 19th century with a fragmented urban structure and significant socio-economic challenges. One of the defining aspects of this period was the rule of Masud Mirza Zill al-Sultan, the son of Naser al-Din Shah, who governed Isfahan from 1874 to 1907. His memoirs and administrative records reveal both his ambitious urban policies and his controversial interventions in the city's architectural and social fabric (Fig.97) [82].

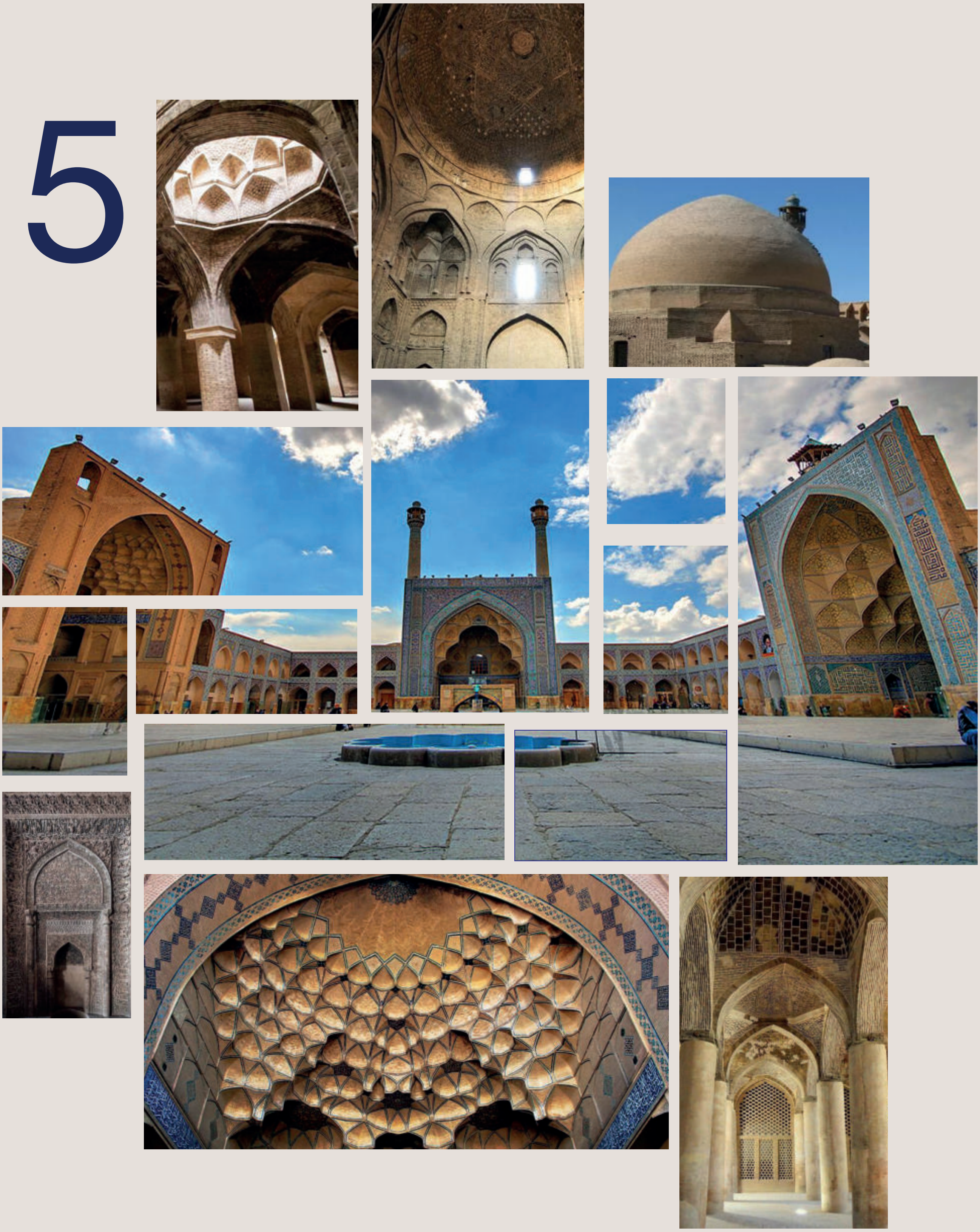
Fig. 97 Masud Mirza Zill al-Sultan, the son of Naser al-Din Shah, who governed Isfahan from 1874 to 1907 Reference: Internet Archive.

While Zill al-Sultan promoted infrastructural projects, including street widening, the introduction of new administrative quarters, and military barracks, his rule was also associated with the destruction of several Safavid monuments and gardens, often criticized by contemporary historians and travelers. Despite the absence of large-scale urban expansion, Isfahan's urban morphology adapted to the socio-economic realities of the 19th century [82]. Following the decline of the Qajar dynasty and the consolidation of power under the Pahlavi monarchy, Isfahan entered a period of profound urban and architectural transformation. Under Reza Shah Pahlavi and later Mohammad Reza Shah, state-led modernization policies introduced new planning frameworks, infrastructural projects, and architectural forms that redefined the city's spatial structure. The establishment of wide boulevards, administrative buildings, and public squares reflected the central government's ambition to create a modern national city while simultaneously diminishing the prominence of Safavid-era layouts and organic bazaar-centered neighborhoods. One of the most significant drivers of Isfahan's modernization during the Pahlavi period was the foundation of its textile industry, which transformed the city into Iran's principal industrial hub. Beginning in the 1930s, several large textile factories, including Shah Isfahan Textile Factory, and later Nassaji Iran and Textile Company, were established through state and private investments (Fig. 98) [62].

Fig. 98 Risbaf, the historical fabric factory in Isfahan, Reference, personal archive.

Isfahan Jameh Mosque,
the museme of Iranian Architecture

5



The Jameh Mosque of Isfahan, inscribed on the UNESCO World Heritage List as a museum of Iranian–Islamic architecture, is organized around a four-Iwan courtyard plan. Its present form is the result of nearly a millennium of continuous construction, modification, and restoration. Because architectural elements from almost every major period of Iranian architecture are represented within the complex, it is often described as a living museum that encapsulates the historical evolution of architectural practice in Iran.

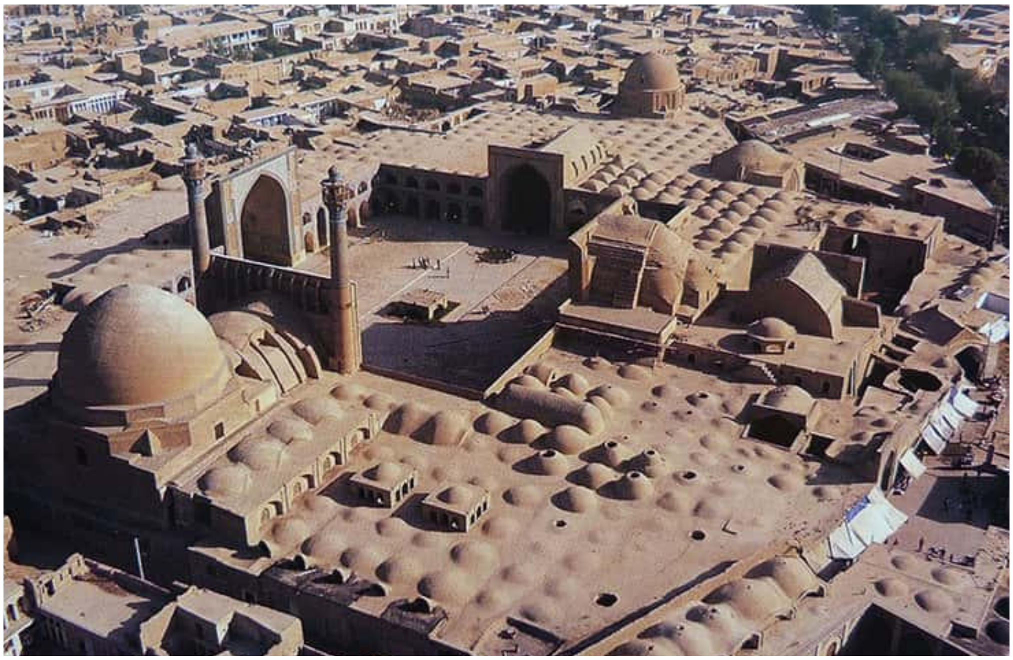
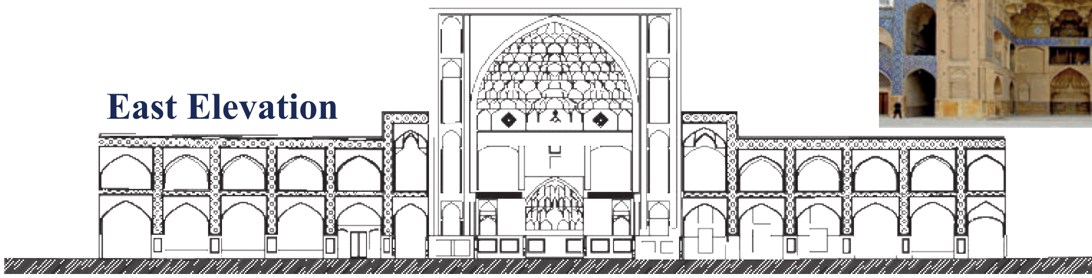
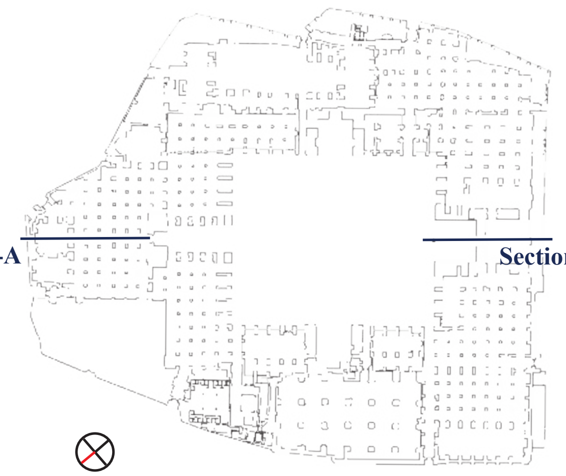
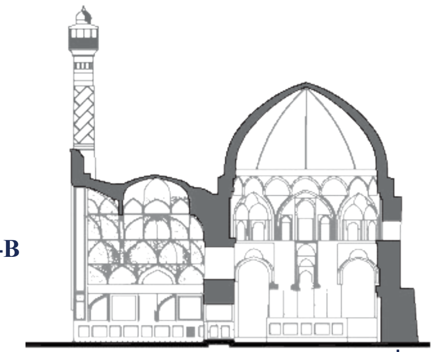


Fig. 99 Isfahan Jameh Mosque, Reference: internet archive.

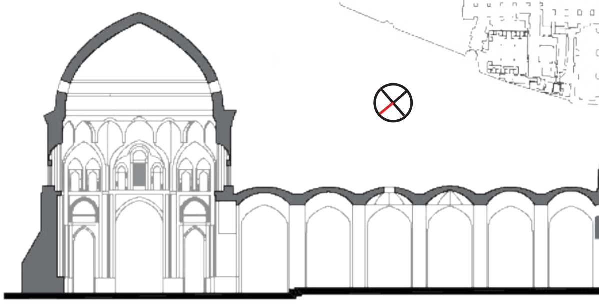
East Elevation



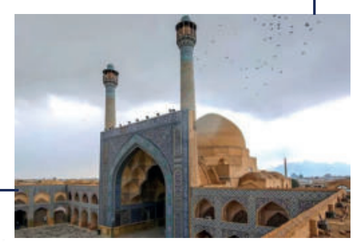


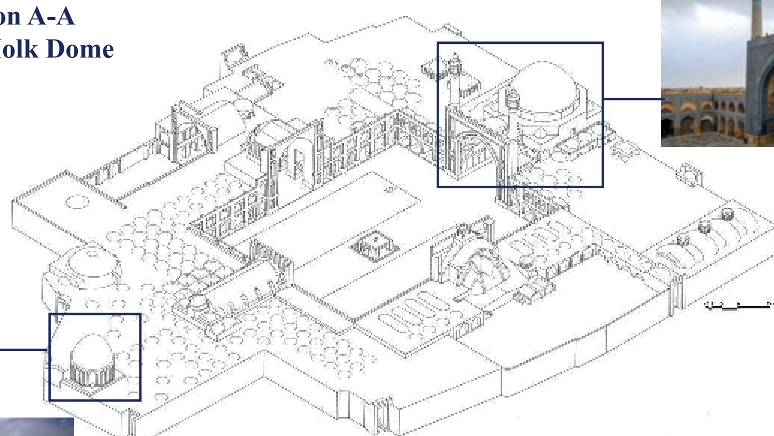


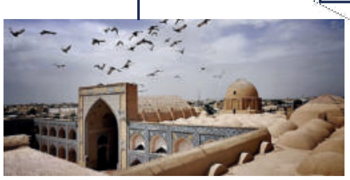
Section B-B
Nezam-al-Molk Dome



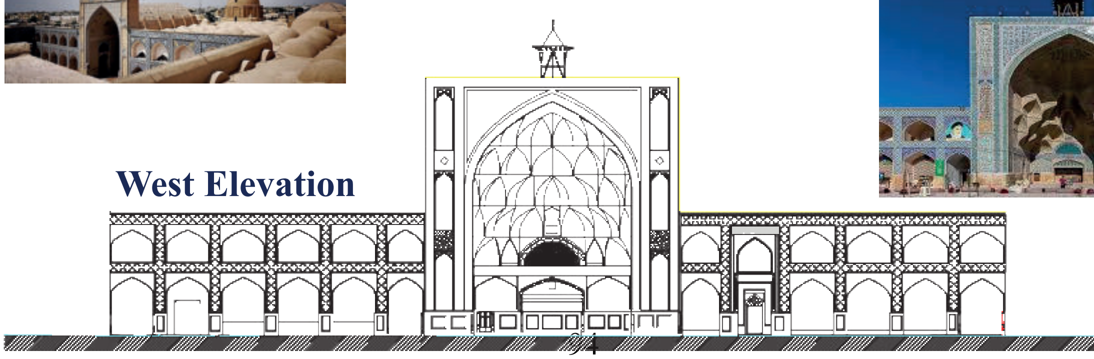
Section A-A
Taj-al-Molk Dome







West Elevation



5.1 Historical

The earliest known structure on the site of the Jameh Mosque of Isfahan dates back to approximately 771 CE, corresponding to the Abbasid period. This early structure was characterized by simple brick columns, mud-brick walls, and stucco ornamentation, reflecting the architectural language of early Islamic mosques in Iran [83]. Archaeological and architectural studies indicate that this mosque was built upon, or integrated into, an earlier Sasanian structure, possibly a fire temple or an administrative complex (Fig.100) [83,84].

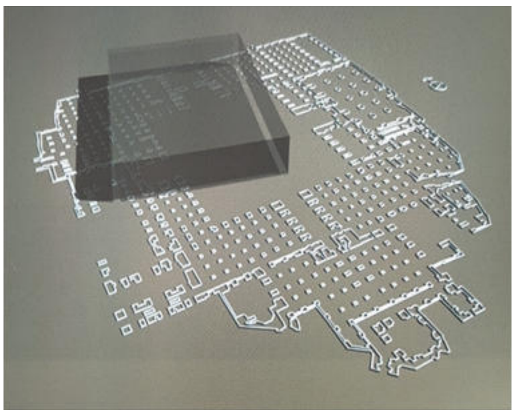


Fig.100 Phase One: Construction of the Original Mosque Structure, the current plan is visible in the background, Reference:[85]

In the mid-9th century, a large hypostyle prayer hall measuring approximately 88 × 128 meters with over 200 columns supporting the wooden roof of the prayer hall, was constructed. which functioned as the religious and civic nucleus of medieval Isfahan [85]. The Mosque retained a rather austere decorative scheme (mainly geometric stucco patterns) while its structural innovations laid the groundwork for the subsequent Seljuk transformations of the 11th century. The mosque not only symbolized religious authority but also served as the central venue for political gatherings, education, and judicial functions within the growing urban core of Isfahan (Fig. 101) [86].

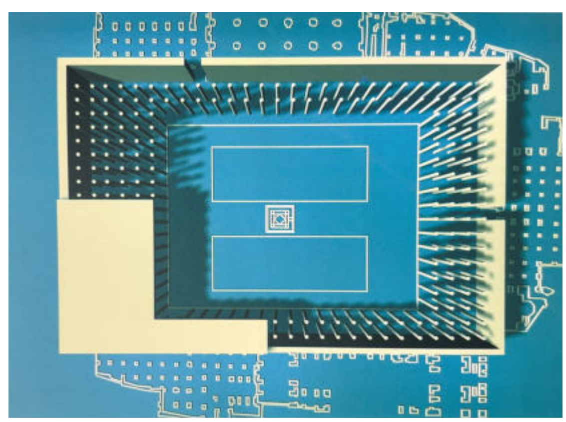


Fig. 101 Phase two: Renovation and Expansion of the New Mosque, the current plan is visible in the background Reference: [85].

During the 10th–11th centuries, architectural developments reflected evolving urban identity and ceremonial functions. This era saw the introduction of geometric brick arches, polylobed vaults, and the erection of twin minarets flanking the courtyard entrance, marking significant advancements in structural and decorative techniques [83]. These features also embodied a synthesis of pre-Islamic Persian architectural motifs with Islamic forms, illustrating a layered cultural narrative in the mosque's fabric. Moreover, during this period, the covered space of the mosque was expanded with diverse brick columns, and the facade of the building was decorated (Fig. 102) [84].

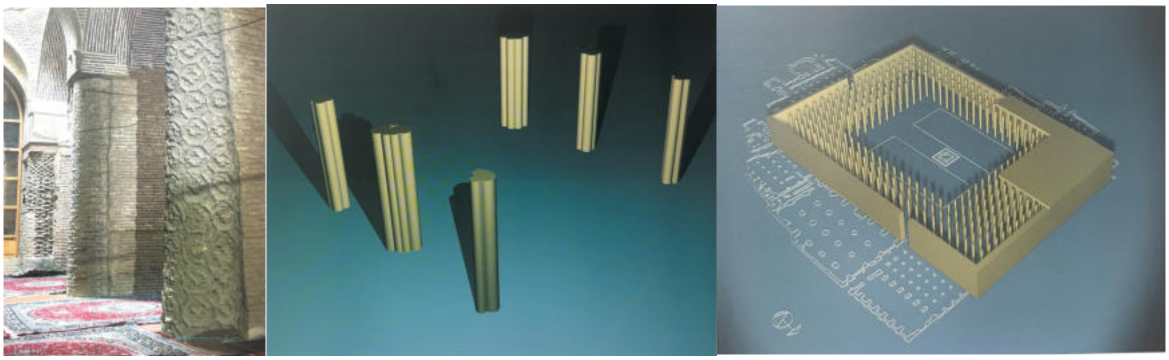


Fig. 102 phase three: different kind of columns of Buyid period and additions part in the Buyid Period, the current plan is visible in the background Reference:[85].

The Seljuk period marked a transformative era in the architectural history of the Jameh Mosque of Isfahan which setting new benchmarks in structural ingenuity and ornamental sophistication. This transformation involved the addition of monumental architectural components that restructured both the vertical and horizontal dynamics of the mosque. Central to this transformation were the two famous domed chambers Nizam al-Mulk south dome and Taj al-Mulk's north dome that each pushing the boundaries of medieval Islamic dome construction [86]. Alongside these major domes, the mosque was expanded with a vast system of auxiliary spaces, including long, vaulted corridor networks, smaller secondary Iwans facing the courtyard, and side chambers known as gushvareh, all of which created a complex hierarchy of spaces and circulation paths. The south Iwan, known as the Qibla Iwan, emerged as the principal visual and symbolic focus of the mosque. Measurements reveal the diversity of vaulting strategies employed, ranging from simple barrel vaults to complex groin vaults and domed bays, many of which are embellished with unique brick patterns, intricate geometric compositions, and deep relief muqarnas elements. This meticulous vaulting program created a spatial rhythm across the prayer halls, facilitating both acoustic optimization and visual diversity while maintaining a cohesive structural order (Fig. 103) [87].

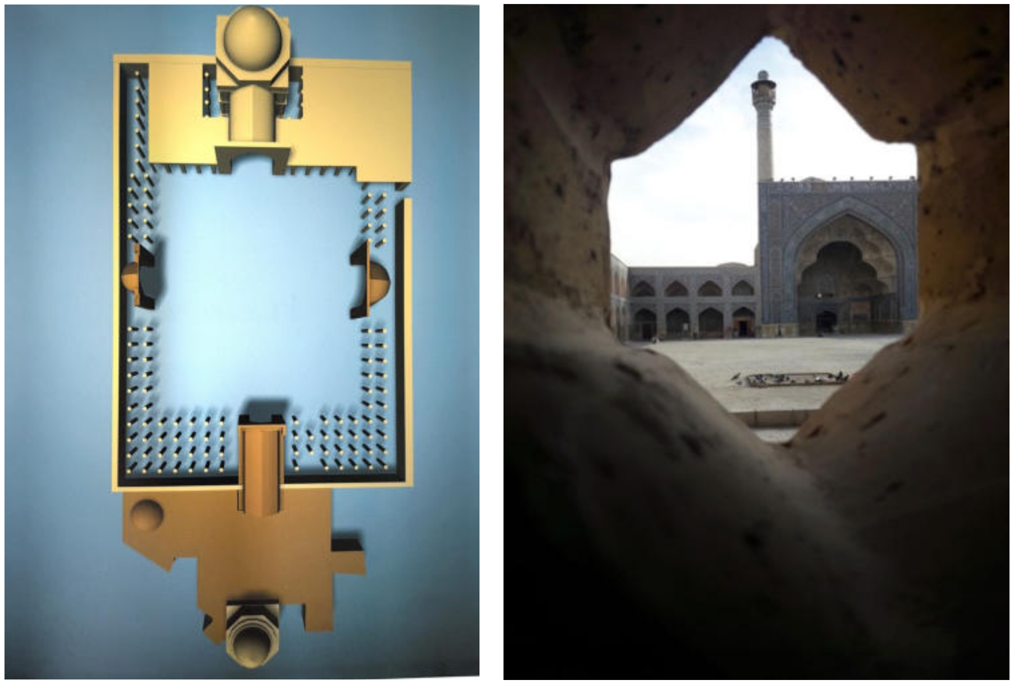


Fig. 103 The Seljuk period Plan with additional parts 4 Iwan and 2 Domes, Reference:[85].

Following the Seljuk era, the Ilkhanid period marked an important phase of restoration and artistic enrichment for the Jameh Mosque. This era witnessed the introduction of new ornamental styles, especially the development of polychrome glazed tilework known as the “Minai” technique, which blended Persian artistic traditions with Mongol influences. The mosque’s main facades, Iwans, and domes were adorned with vibrant blue, turquoise, and ochre tiles featuring floral and geometric motifs that signified a cultural synthesis and political stabilization after the Mongol invasions [87]. Structural repairs were also essential during this time, due to damages from earlier conflicts and natural wear. Architectural surveys reveal that many vaults and domes were strengthened, with a particular focus on conserving the mosque’s hypostyle halls while enhancing the decorative schemes. In this period, the Oljaito prayer hall was added to the mosque (Fig.104) [88].

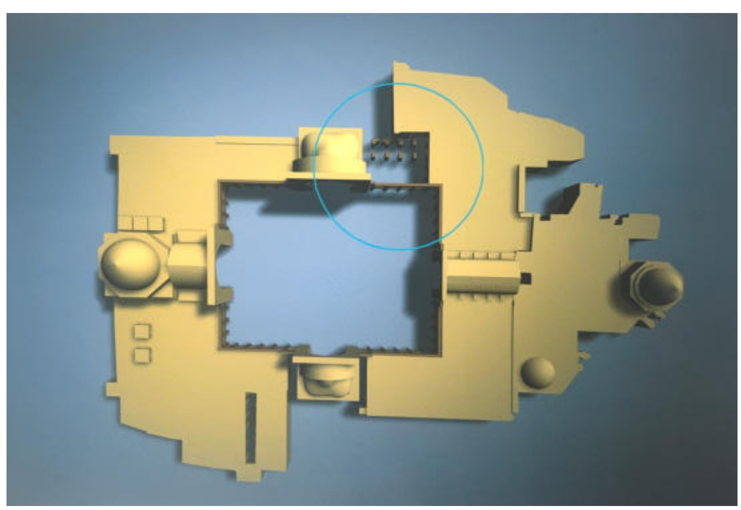


Fig. 104 the Ilkhanid period changes, in figure the location of prayer hall is shown, Reference:[85].

The Timurid period brought further architectural embellishments, focusing particularly on the enhancement of decorative elements and the refurbishment of structural components. Polychrome tile mosaics were refined, and intricate glazed brickwork became more prevalent, often featuring complex vegetal patterns and calligraphic inscriptions [86]. While the mosque's overall structure remained largely intact, these enhancements reflected broader Timurid efforts to revive and celebrate Persian artistic heritage within the Islamic architectural canon. In this period, the Beit al-Shata prayer hall was constructed on the western side of the mosque, which is renowned for its unique four-part vaults (Fig.105).

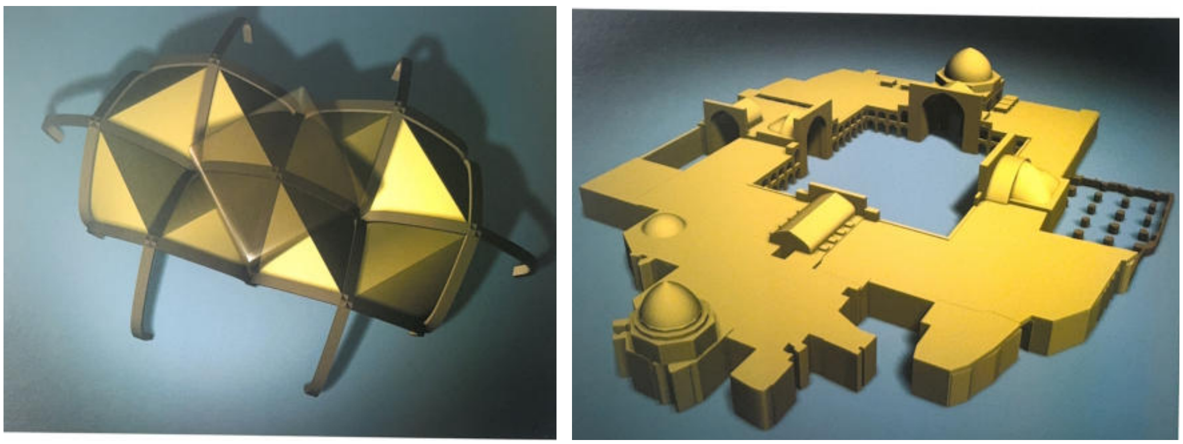


Fig.105 the Timurid period change, Beit al-Shata prayer hall and its Groin vaults, Reference:[85].

In the periods leading up to the Safavid era, the mosque was equipped with two minarets on the southern Iwan. During the Safavid period, the mosque was further expanded with new courtyards and Iwans, as well as restoration of older elements. These projects aimed not only to repair aging structures but also to enhance the mosque's function as a major religious and social center in the capital [86]. Structural advancements during this period included the reinforcement and partial reconstruction of domes, integrating seismic-resistant design principles. Additionally, auxiliary spaces such as the madrasas and khanqahs adjoining the mosque were expanded or newly constructed, reinforcing the mosque's role as a hub of religious education practice. Lighting strategies were refined by the strategic placement of stained-glass windows and mirrored vaults, which modulated natural light to create an ethereal spiritual ambiance within the prayer halls (Fig.106) [84].

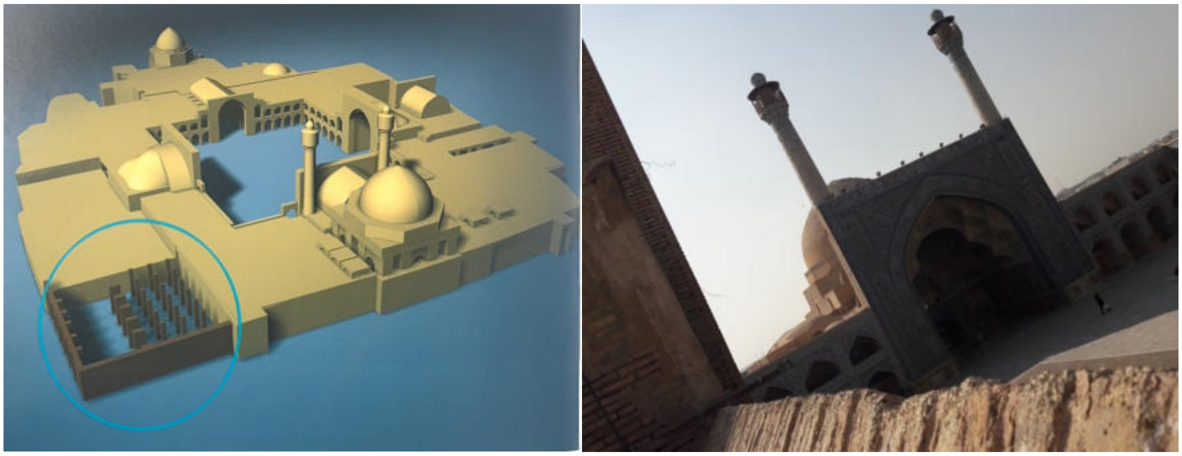


Fig. 106 the Safavid period change, Shah Abbasi prayer hall, Reference: personal archive & [85].

During the Qajar dynasty, the mosque's evolution shifted from expansion to preservation, with interventions focused on restorative maintenance rather than significant architectural addition. The aesthetic language of the mosque became more subdued, reflecting the Qajar's conservative tastes and economic constraints. Tile mosaics were simplified, and some earlier Safavid polychrome tiles were replaced or overlaid with plain glazed ceramics and brickwork featuring modest patterns, reflecting a transitional aesthetic that balanced respect for tradition with pragmatic restoration [86].

5.2 Jameh Mosque Domes

As mentioned earlier, during the Seljuk period, two domes were added to the plan of the Jameh Mosque of Isfahan: first, the southern dome known as the Nizam al-Mulk dome, and later the northern dome, also called the Taj al-Mulk dome. The south and north domes exemplify advancements in ribbed dome construction, employing sophisticated squinches to facilitate the structural transition from the square prayer hall to the circular drum [89].

5.2.1 Nezam al-Molk Dome

Khaje Nezam al-Molk, the Seljuk vizier, constructed a monumental dome with a span of over 15 meters and a height exceeding 30 meters in the Razi architectural style (the architectural style in the 4th century in Iran). The outstanding Southern Dome Chamber of Nizam al-Mulk is located at the southern end of the main axis of the Great Mosque of Isfahan the construction of the dome marked the beginning of the transformation of the hypostyle mosque into the recognized Iranian style of mosque architecture, characterized by its four-iwan design. To obtain the space required to build the sanctuary, masons knocked down twenty-four columns, corresponding to seven bays perpendicular to the wall of qibla. The corresponding bays replaced by a huge dome chamber, possibly the largest dome of the time in Islamic world in that time [84]. This dome was originally completely free-standing, meaning that its eastern, western, and northern sides lacked any covered spaces, and some of the structures currently visible around it was added later. The three staircases surrounding the dome indicate the separation of the dome structure from the adjoining prayer hall through an inner circumambulatory corridor. These staircases were originally constructed to provide service access during the dome's construction and also functioned as pathways to the outer shell of the dome for inspection, maintenance, and preservation purposes (Fig.107) [90]. The interior of the chamber exhibits a wealth of brickworks, massive quadrilobate pillars, a great mihrab all surmounted by a ring of Kufic inscription and a rich brick cupola.

Fig. 107 Nezam al-Molk Dome, reference: personal archive.

5.2.1.1 Nezam al-Molk Dome Construction

The current ground floor of the building descends by 40 cm with two steps. The current floor of the chamber is paved after the excavations of 70s, by square fired bricks 22x22 cm in dimensions. However, the original Seljuk pavement is of 40x40 cm baked bricks, about 10cm below the current floor. The building is made of uncovered fired bricks (without mortar), each measuring 22x22x4.6 cm. The texture of surfaces, inscriptions, ribs, squinches and ornaments are all in brick. The interior and exterior mass-composition of the building is composed of three main sections:

1. The lower base, which is square in plan and extends up to the level of 10.83 m from the ground level
2. The zone of transition from the height of 10.81 m to 17.55 m
3. The domical section with the circular base at the height of 17.55m and reaching the inner apex at 26.54 m. The lower part of the building is a regular square, 14.85 m in dimensions. (Fig.108) [83,91].

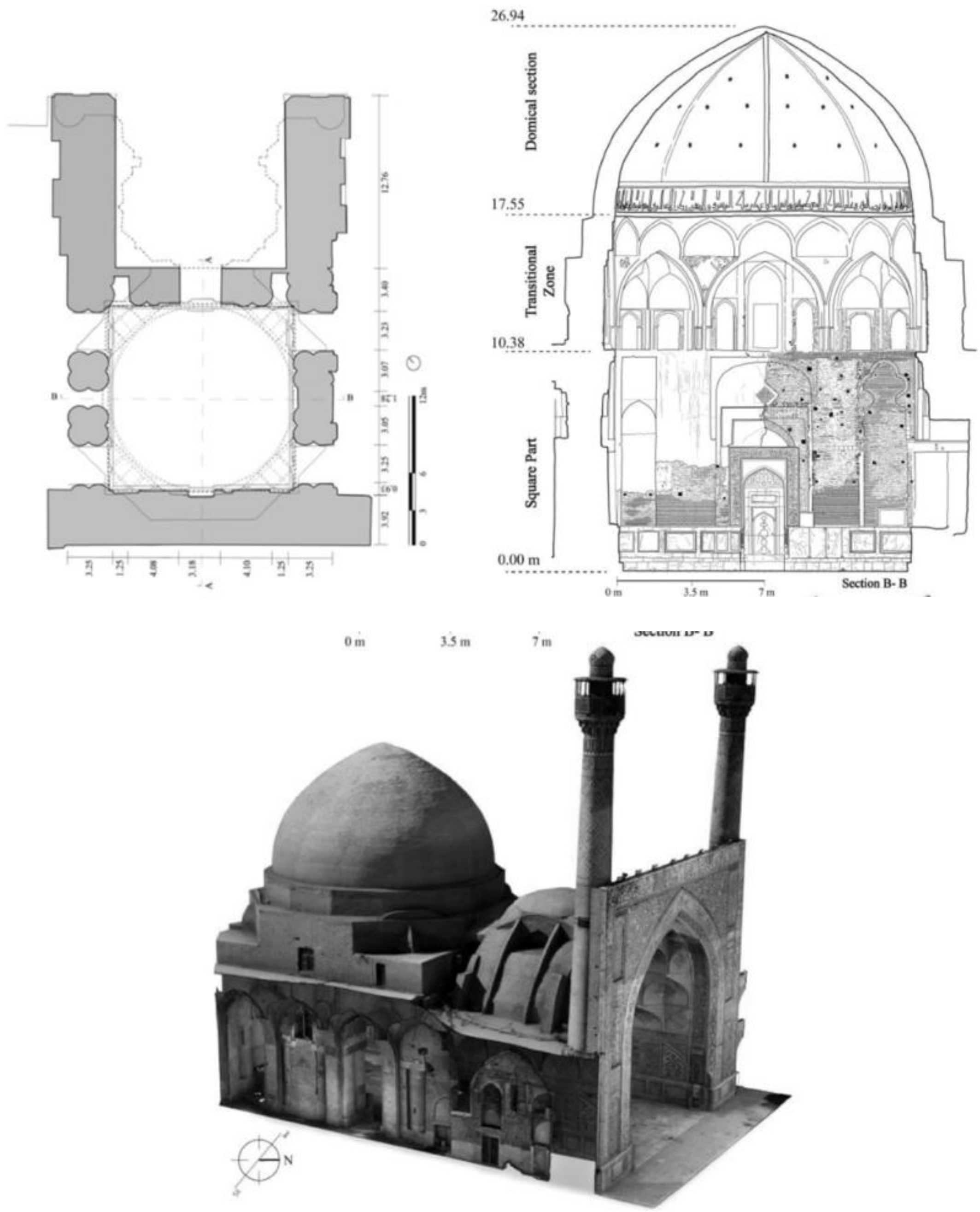
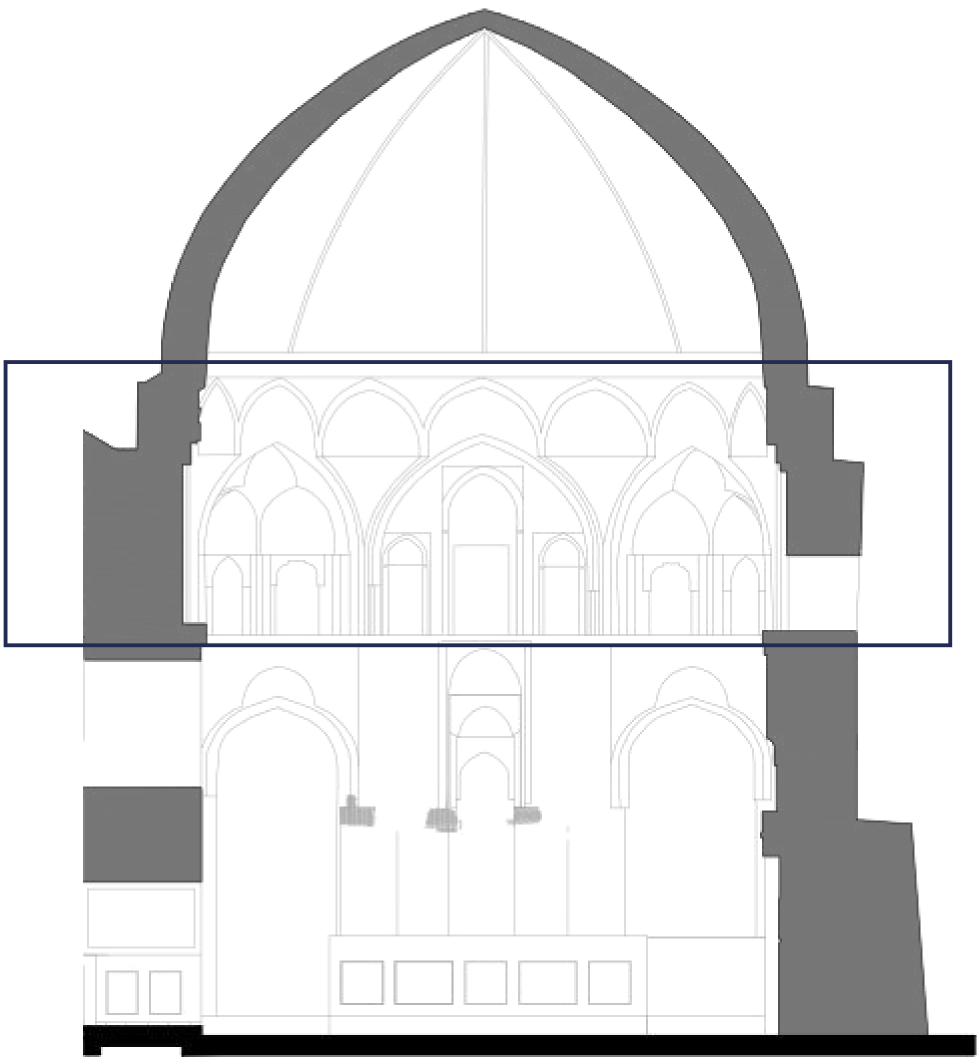


Fig. 108 section and the isometric view of the dome and Iwan, Reference: [91].

5.2.1.2 Transition Zone

The zone of transition is built over the lower base part and mediates between the square of the ground plan and the circle of the dome. The transitional zone is a symmetrical arrangement of colonettes, vaults, blind-niches and indentation. The geometrical composition of the transitional zone consists of a regular octagon surmounted by a hexadecagon and a narrow rim of icosidodecagon (thirty-two-sided polygon), on which the springing ring of the dome rests. The regular octagon measures 6.15 m in the sides, 6.75 m in height and 135° degrees in inner angles (Fig.109) [91]. It includes eight large pointed arches. four arches are positioned at the corners (shoulder arches), and frame the very innovative Iranian Eskonj. In other words, the pointed vaults in the corners are in the form of Skonj. while the other four are placed at the midpoints of each side (arches between shoulder arches). The vaults of the octagonal zone provide springing for a rim of hexadecagonal zone, consisting of Barnakhsh and blind-vaults, each measuring 2.90 m0.05m in span and 2.10 m in height (Fig. 110) [91,92].



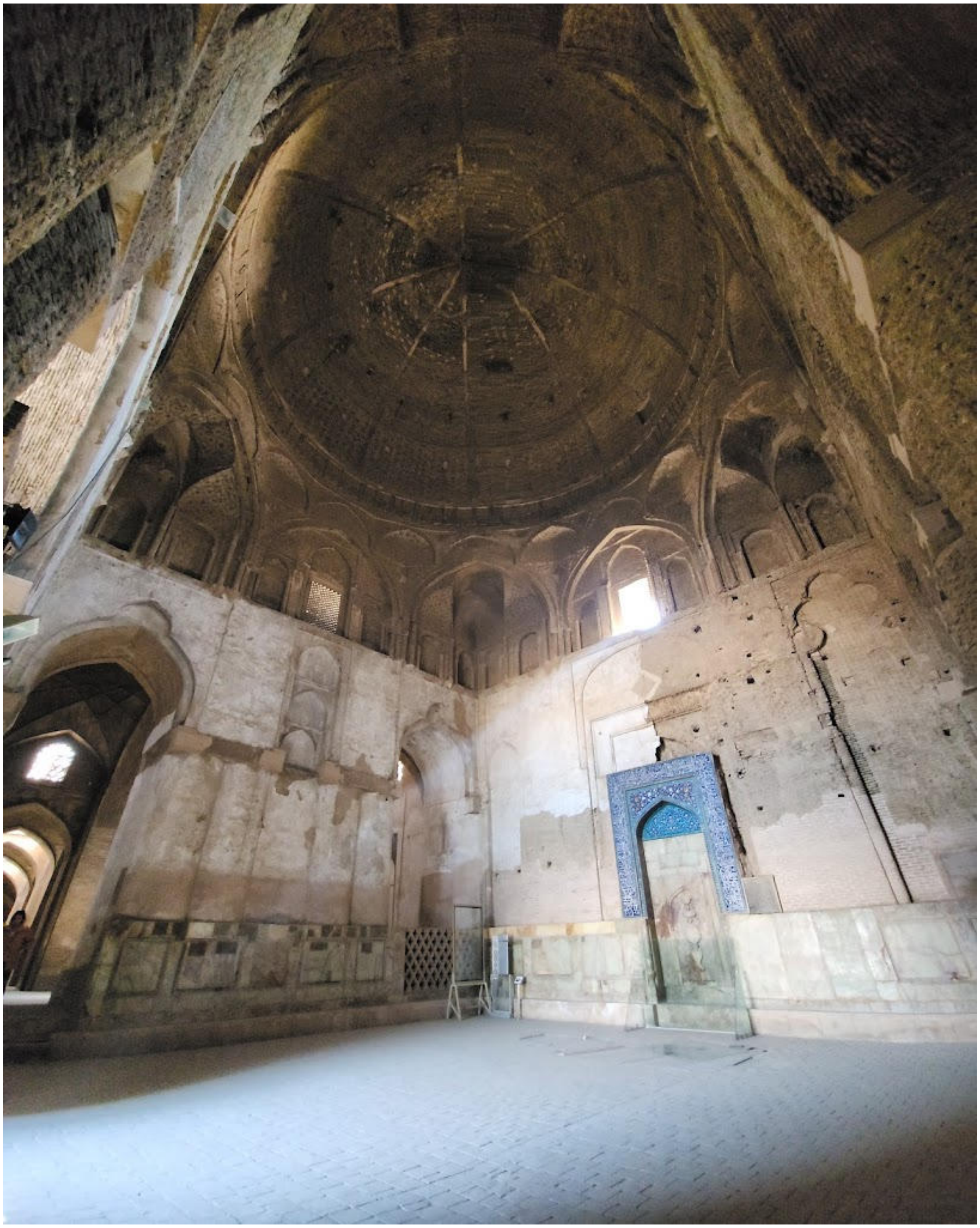


Fig. 109 the zone of transition of Nezam al-Molk Dome, reference: [85].

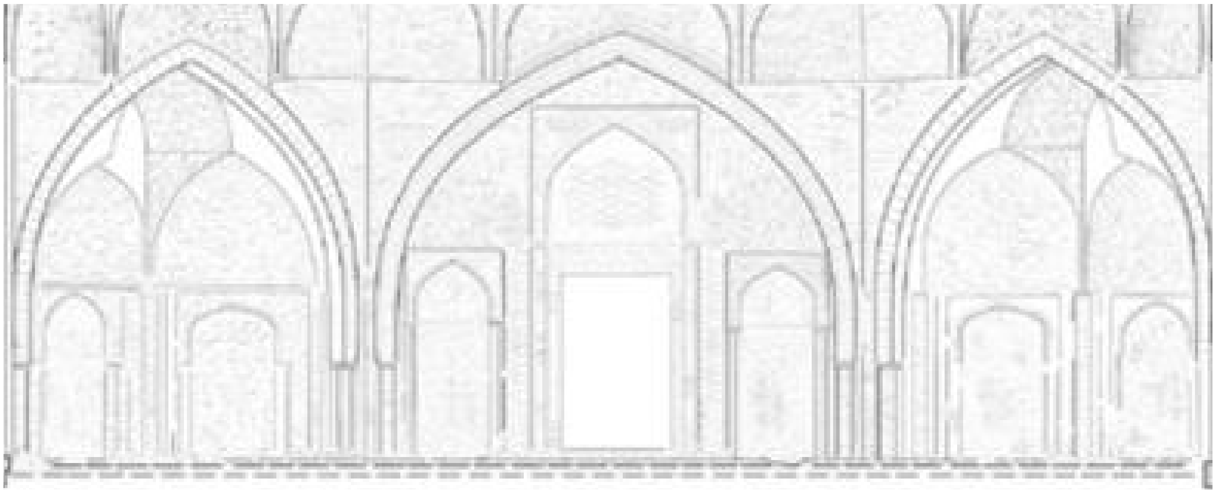


Fig. 110 the zone of transition of Nezam al-Molk Dome, first level of transition, reference: Author based on [85].

Moreover, there is another structural system at the first level that contributes to bearing and transferring the loads. As shown in Fig. 110, the Patkaneh are clearly visible within the four corner vaults. As mentioned earlier, they are structural components that play a fundamental role in redirecting both vertical and lateral loads from the massive dome toward the four principal piers, thereby effectively stabilizing the overall structure. Their curvature not only facilitates the smooth transition of the square spatial configuration into an octagonal geometry but also ensures the harmonious integration of the upper arches supporting the drum (Fig. 111).

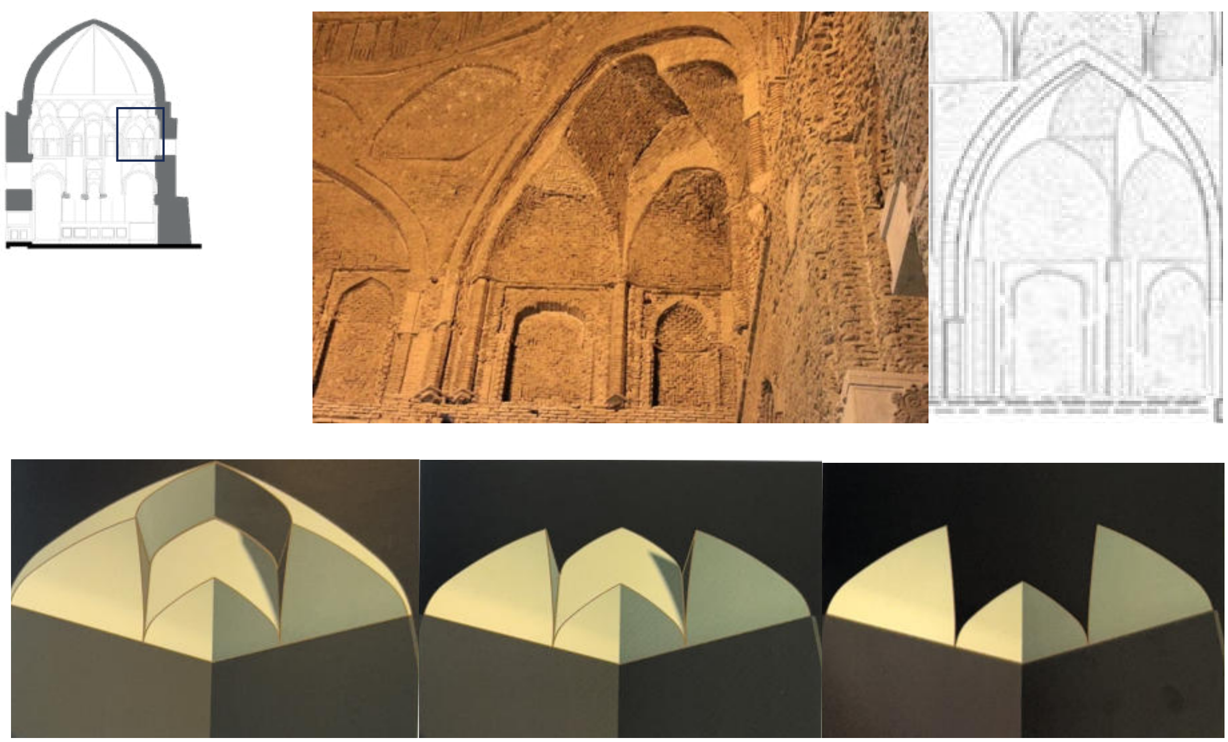


Fig. 111 the Patkaneh of Nezam al-Molk Dome, reference: [85].

As discussed in Chapter 1, the Patkaneh can be defined as a superimposed arrangement of vaults, in which the load is transferred from the crown of each vault to the supporting piers, and from each pier back to the crown of the arch below. In this case study, the Patkaneh is constructed in a particularly creative manner, differing from the conventional form while maintaining the same structural function as described [63].
Furthermore, given that a dome of this scale required massive supporting walls, the incorporation of shallow surface vaults (taq-nama) within the principal vaults effectively lightened both the structural mass and the wall thickness, contributing to the overall stability and material efficiency of the system. On the other hand, openings were created within the main vaults located at the midpoints of the square's sides to allow natural light to enter the interior space. Since the thrust of the dome is transmitted through the vault's ridge (tizeh-e taq) toward the piers and then to the walls, no significant load is applied around these openings, thus causing no structural disturbance. At the same time, these apertures effectively prevent the space from falling into darkness, enhancing both illumination and spatial perception (Fig. 112).

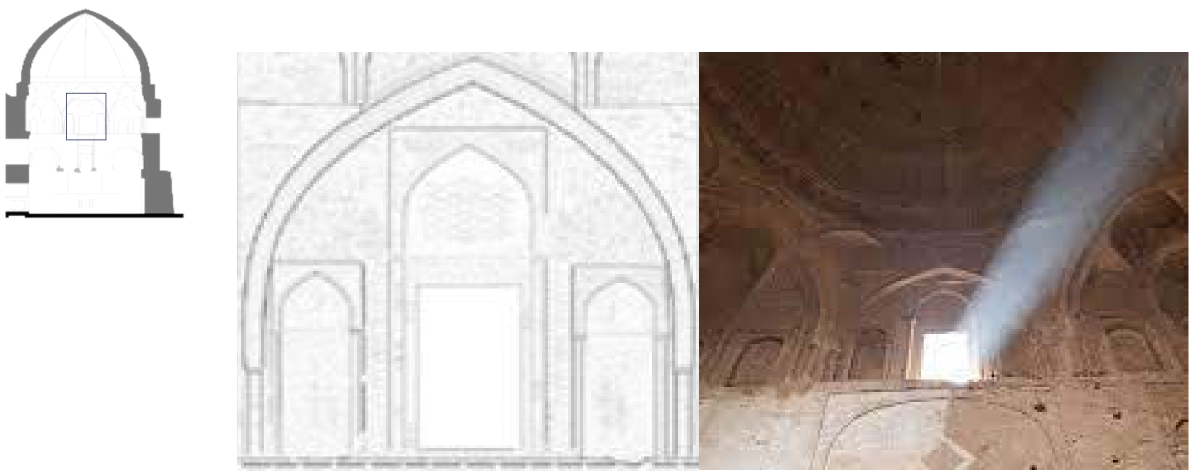


Fig. 112 the openings of transition zone Nezam al-Molk Dome, reference: personal archive.

In the next level of the transition zone, the octagonal base is transformed into a sixteen-sided configuration through a combination of construction techniques. The vaulting method is employed together with the execution of barnakhsh, but without the use of peykaneh. Eight barnakhsh units are constructed above the previous vaults, while eight additional blind vaults are inserted between the barnakhsh units in place of the peykaneh. These eight blind vaults are connected to the pendentives that fill the spaces between the vaults, and together all of these components divide the zone into sixteen sections. In the following stage, sanbusehs are introduced between these sixteen vaults, further subdividing the surface into thirty-two parts. This additional subdivision refines the structural geometry, creating a coherent base for the placement of the drum and the dome. The sanbuseh elements, acting as small intermediary vaults, contribute both to the uniform transmission of loads and to the geometric harmony of the transitional zone, ensuring a smooth transformation from the lower supporting structure to the upper dome shell (Fig. 113).

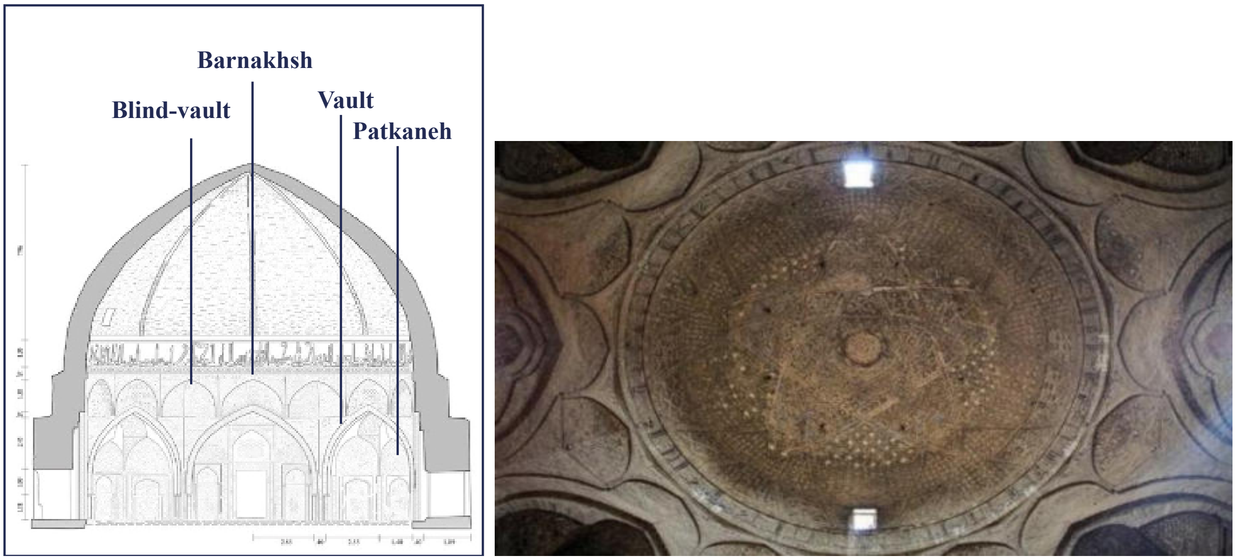


Fig. 113 the Patkaneh of Nezam al-Molk Dome, reference: [85].

5.2.1.3 The domed section

the dome spans 14.65 m and the thickness of the dome at the springing is 1.10 m, gradually reducing to 0.35 m at the peak. the height of the dome from the springing to the internal summit is 9.12 m, and to the external summit is 9.45 m. the spring ring of the dome begins at the height of 17.58 m and peaks at the level of 26.67 m in the interior and 27.00 m in the exterior. A band encircling the interior springing of the dome, with the height of 1.25 m, includes the main inscription made of brick in simple Kufic, which is the oldest epigraphic evidence discovered in the building thus far [91]. The geometric analysis of the dome reveals the dome of Nizam al-Mulk is a single-shell masonry structure with a continuous curvature, directly resting on the squinches and drum without any double-shell separation. the section of the dome consists of two particular arcs. in fact, the external profile of the dome is different with the internal profile. the external profile of the dome matches perfectly with a Shabdari. The springing line of the exterior profile is about 16.88. The first circle will be centered at Cl on the middle of the springing line, with the radius of 8.44m. The first circle generates the shoulders of the profile, rising out of the springing. The crowning arches generating the pointed contour are centered in C2 and C3, located on the perimeter of the first circle, at the diameter of the circle decided at the angle of 52°. In fact, the exterior profile of the dome represents a variation of the Shabdari arcs. The primary distinction of the other types of the Shabdari arcs lies in the location of the C2 and C3, in such a way that they will be located on the drop-lines of the springing, rather than on the perimeter of the first circle. On the other hand, the interior profile of the dome represents a four-centered arc (flattened Panj-o Haft arch). To draw the interior profile, half of the springing line should be divided into eight equal segments. The point H should be marked out of the bisector of the springing line such that OH is equal to OA. A circle centered at the 1/8 of the half of the span (C1) and with the radius of (C1B) generates the haunch of the arch (BE). The line C1E should be extended to a point C2 with a distance C1 C2 = AH. A circle centered at C2 with the diameter of C2E generates the crowning of the arch (Fig.114) [83,91,92].

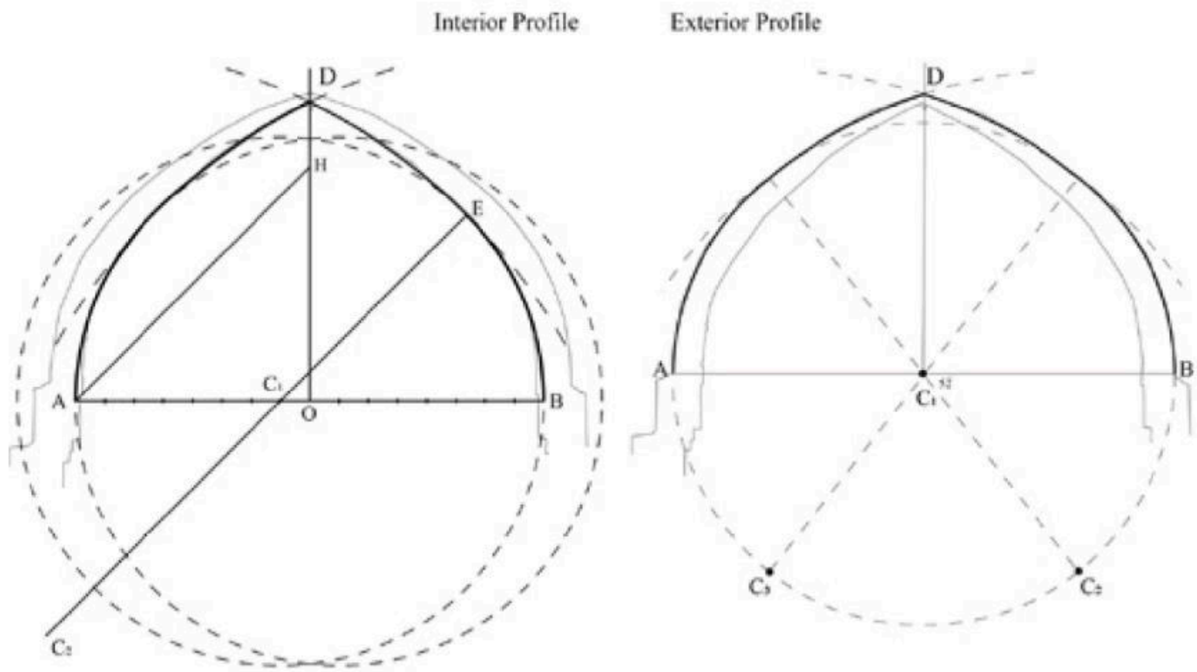


Fig. 114 the exterior and interior of Nezam al-Molk Dome, reference: [91].

Certainly, there should be an explanation to the application of the two profiles with respect to their structural behavior and morphological aspects. First of all, the proportion of the rise to the half of the span of the exterior profile is greater than one (OD/AO=1.1), posing a pointed-higher summit to the exterior, in consistency with the intention of the patron of the building, which was symbolization of the Seljuq authority. As a significant fact in the Iranian dome making, the thickness of the masonry domes gradually decreases toward the apex. This feature serves to reduce the load of the masonry of the upper sections of the dome. The strategy involves the use of a four-centered arch in the interior, where the proportion of the rise to half of the span is higher than the corresponding proportion on the exterior (OD/AO=1.27). Consequently, an interior profile with greater rise in comparison to the exterior profile, results in a narrower thickness on the apex of the dome. [83,91,92].

The massive dome is situated between the ribbed structural divisions (tarkbandi). The Tark observed in this dome have primarily developed along the structural load-bearing arches (rib arches), which serve as the main supporting elements of the dome. Each ribbed arch is designed in the form of a curved structural segment with a considerable thickness, enabling it to transfer the vertical and lateral loads of the dome onto the supporting walls and piers. When viewed from below, however, the actual depth and thickness of these ribs are visually concealed, giving the impression of a lighter structural system. Internally, the surfaces of the rib arches are covered with plaster decorations, while two distinct layers of brick framing the plasterwork remain visible, revealing the careful integration of structural and ornamental techniques within the dome’s architectural composition (Fig.115) [85].

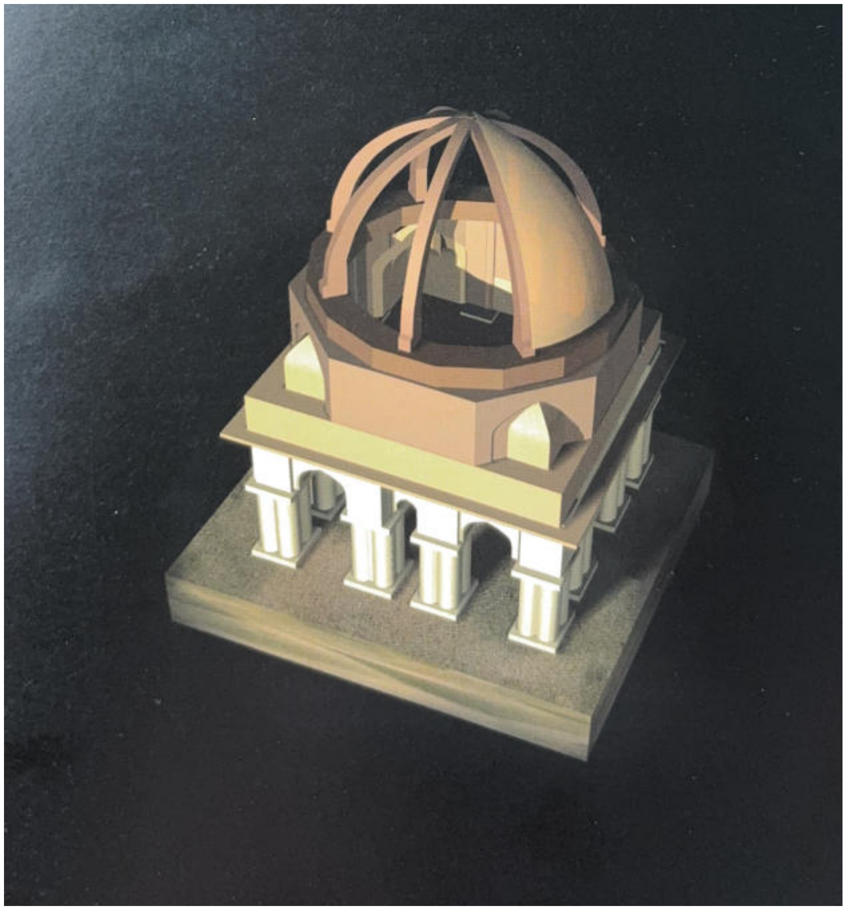


Fig. 115 the structural divisions (tarkbandi) of Nezam al-Molk Dome, reference: [85].

regarding the construction technique of the ribs, they would have needed centering, specifically they multi- centered types which have complex geometry and are difficult to draw. consequently, they are difficult to implement without centering. typically, the Iranian solution to this problem involves building a gypsum centering rib, which serves as a model and guide. a centering rib is a temporary wooden or gypsum non-load bearing structure that is built to help masons to maintain the right geometry (refer to Chapter 1, Section: Types of Domes and Ribs). in respect to the large span of the dome chamber, it can be speculated that the centering served for the construction of the ribs of the domed chamber were made of several pieces of wooden plates assembled on the ground. then the centering will be mounted on the building (Fig.116) [91]. Having lined them upright on the axes of the octagonal zone (each apex of the transverses), they rely on a central wooden post and were joined at the summit. Importantly, the survey of the upper part of the dome revealed the remnant of the central wooden post used during the construction process on place. The eight wooden centering with a few centimeters thickness demarcate triangular frames. The next step is to build up the courses of bricks parallel to and aligned with the curvature of the centering. The bricks were laid out in pitched form (Par in Persian architectural terminology), bonding together with the help of gypsum-clay mortar. The resulting structure will be self-bearing, allowing the masons to remove the wooden centering.

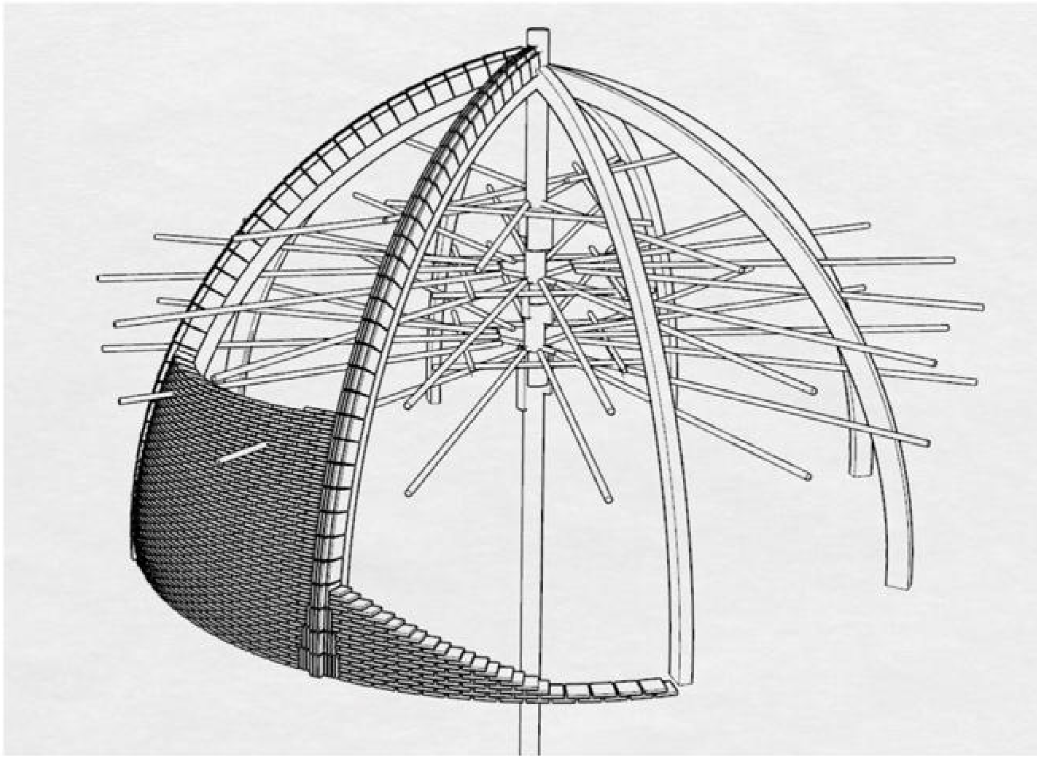


Fig. 116 the reconstruction of the centering ribs and scaffolding of the construction of the dome, reference: [91].

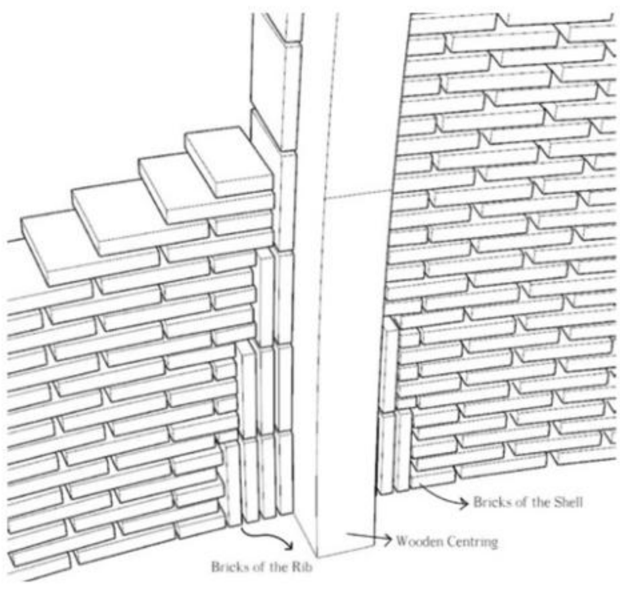


Fig. 117 the schematic drawing of the details of the centering, ribs and course of the shell of the dome, reference: [71,91].

Conclusion

This thesis set out to investigate the structural logic, geometric intelligence, and historical significance of dome and squiches construction in Iranian architecture, focusing on the Nizam al-Mulk Dome in the Jameh Mosque of Isfahan as a representative and exemplary case. Through an interdisciplinary methodology combining historical research, the analysis of Persian and English sources, field-based geometric reconstruction using AutoCAD, and structural interpretation, the study demonstrated the depth and sophistication of traditional Iranian building knowledge.

The findings highlight that Iranian dome construction especially the development of squinch-based transition systems cannot be understood solely through formal description. Instead, it reveals an embedded system of geometric reasoning and craft-based engineering that evolved incrementally through centuries of practice. The Nizam al-Mulk Dome exemplifies this evolution: its transition zone depicts an exceptionally refined combination of squinches such as Vaults, Eskonj, Patkaneh, Barnakhsh, Sanbuseh and etc,. which work as intermediate courses, and rib-like structural elements, all organized through proportional logic rather than mechanically imposed centering frameworks. also, they are fundamental roles not only for transition zone, but also for transmitting loads from the heavy dome to the ground. This dome represents not only a technical achievement of the Seljuk period but also a crystallization of the accumulated knowledge of earlier architectural traditions.

Ultimately, this thesis positions the Nizam al-Mulk Dome as both a historical monument and an epistemological key to interpreting the broader tradition of Iranian architectural engineering. By bridging historical documents, architectural observation, and structural reasoning, the research advances our understanding of how Iranian builders synthesized craftsmanship, scientific intuition, and symbolic design. The study reaffirms the necessity of continued academic engagement with traditional construction knowledge to ensure that this remarkable heritage remains accessible to future generations of scholars, architects, and conservation specialists.

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