

Arches and Ribbed Vaults of the Iranian Tradition

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Introduction

Brickwork, upon which architectural building was based during the Islamic period in Iran, was constructed by skilled masons who ensured that brick art never lagged behind other arts, and occasionally even took the initiative in solving structural problems. Although bricks are a most rudimentary construction material, brickwork soon reached heights of perfection, thanks to the progress of technology, the existence of master craftsmen in the country, and favorable climatic conditions.

Bricks were the principal building materials with which master artisans began innovation as they competed with one another. Due to the use of this material and the innovations of these master artisans, the Islamic architecture of Persia has a strong identifying character. The craftsmen of Persia in fact, during the first centuries when they started working with brick as their main building material, developed a wealth of technical resources never equaled elsewhere. The exceptional merits of Persian architecture can be attributed to some extent to the use of brick and the artisans' skills in working with that material.

Probably in Persia more than in other places, choosing a material more durable than wood, cheaper than stone, and more versatile than others was linked to territorial needs and led to composite forms and structural solutions, whose echo is recognizable far beyond the original Persian territory.¹ The brick used in Iranian semi-desert zones does not possess the tensile strength of stone, and is further weakened by the need for frequent mortar joints. Therefore, in these areas that also suffer for shortage of timber, alternative methods of spanning between walls had to be found.

Forms had to be adopted that, under uniform loading conditions, could exploit masonry's resistance to compression. Among these, the arch vault and dome were the simplest. Due to the fact that in Iran these domed or arched structures had always been built almost completely with

¹ Pope 1939, 901.

sun dried bricks, architects necessarily had to develop architectural forms closely related to the potential materials. These vaults also were designed to be adaptable to several spatial problems. To meet these problems, brick vaults and domes were developed in Persia with techniques never developed abroad as the Persian craftsmen mastered of the techniques and the materials they had available.

The tradition of brick building in Iran was already flourishing under the Sassanids (from A.D. 224 to 651); this period was the main source of knowledge of constructing buildings in brick for later masons. When the people adopted Islam and its new civilization, the stage was set for a new wave of artistic expression to add Islamic thought to ancient art, thus giving rise to a novel artistic taste. Over time, design became still more refined and masons set out to produce yet more significant work.

In the Islamic world, just as in ancient Iran, brick art continued to evolve. Islamic architecture almost exclusively used bricks, masterfully taking advantage of its qualities as an essential building element. With changing architectural styles over the course of successive periods, many innovations were introduced; everyday new buildings rose from the ground, contributing to the skyline and the examples of brick architecture. Thus mosques, palaces, houses and even bazaars were all based upon bricks, the basic materials of every man-made construction; excavations made across the Iran have clearly shown that bricks form the skeleton of all ancient buildings. This material has significantly contributed to the development of building techniques, also influencing architecture and attracting the attention of architects to its artistic potentialities. Today, the wealth of brick art left behind from past eras forms a vast field of research that deserves study.

The composition of today's mud-bricks is essentially the same as in the past. They consist simply of mud mixed with straw, found as close as possible to the site. In order to secure a proper fit between the consecutive layers, the brick-makers used a rectangular mold, which could be adjusted to various sizes and proportions at different times, to shape both sun-dried and fired bricks.

The size of the brick is widely standardized today, but bricks have been much larger in earlier periods. In Babylon, where the technique was taken over from the Sumerians, they measured

40.64 x 40.64 x 10.16 cm,² and at Persepolis they were 33.02 x 33.02 x 12.7 cm.³ In Sasanian times, there was more variation in brick sizes; bricks measured 38.10–50.8 cm x 8.98–12.70 cm. They were 22.86 x 22.86 x 5.08 cm in early Islamic buildings.⁴ Comparing these, we can say that in the pre-Islamic era each brick was 38.10–50.8 cm long on one side, through usually slightly elongated, and 8.98–12.70 cm thick. The brick currently used, continuing a tradition extending back to the pre-Islamic period, is square, usually with dimensions of 25 x 25 x 5 cm.

The availability of a certain type of gypsum mortar also played a role of primary importance, in addition to the bricks themselves. In most buildings, the only joining material used as mortar between clay bricks was chalk and plaster. In some cases we can find, along with chalk, large amounts of earth or earth and clay.

The binder used in Iran differs from the one used in Europe at the time and accordingly has a different behavior.⁵ When very fine powdered chalk as found in Persia is mixed with water, adhesion starts, but if more water is added, the mixture tends to lose its grip and remains a thick paste for a long time. Additionally, over time moisture can degrade the mortar even after it has set, thus weakening the bond between the bricks. For this reason permanent moisture is more harmful for pure lime mortar than water briefly running over the mortar. Thus, due its ability to set more rapidly, mortar made from gypsum—sometimes mixed with clay, sand, fine gravel, and even mud—was immediately preferred to lime mortar. This major property in fact, aided greatly in the erection of arches and then vaults over temporary or permanent armatures.

We have to consider that in Asia vaults represented a practical solution designed to cover even ordinary buildings such as private residences and shopping streets of the bazaars, replacing the earlier wooden roofs. It is already known that, between the end of the 10th and the start of the 13th centuries, a new construction technique for vaulting was developed. Based on crossing arches, it was highly innovative and its use came to surpass previous types of vaulting. It became a characteristic feature for the architecture of the Islamic world and then for different cultural ar-

²Diez 1939, 916.

³Schmidt 1939, 19.

⁴Wulff 1966, 163.

⁵Galdieri 1979, 6–12, 55.

east. The technical mastery of this style is attributable to the end of the 13th century, during the Timurid dynasty. But a full awareness and exploitation of it as a primary style belongs to the Safavid period, during the reign of Shāh Abbās, from A.D. 1587. In fact there was a resurgence of this style in the Safavid period, when architects created a multitude of impressive constructions in the capital Isfahān.

Although this style reached its peak in the 16th century, the iterations of these vaults in many, various types of buildings retained connections to past styles of vaultings. Indeed the presence of the arches inside the coverings is one of the main features for all the Iranian architecture. By looking at several common buildings, parts of the ancient urban fabrics, it is possible to discover different structural devices based on intersecting ribs.

In regards to bondings, making the arches in Iran is generally based on two main types. Knife-shaped bonding needs a light framing during the construction and creates an arch whose final curve is not continuous, but is made up of a sequence of lines corresponding to the length of the single brick. In this way, a bearing arch is made that, despite a potential collapse in the direction of construction, allows for several different constructive solutions. The Roman bonding, on the other hand, requires a heavy temporary supporting frame under the arch, which must not be removed until the two sides of the arch are joined. The finished structure is thus bearing without significant deformations.

Using combinations between these two main styles has allowed Iranian manufacturers to construct arches conceived as structural devices intended each time to transfer loads along predefined and different routes within the structure. Among them certain fundamental types can be singled out. We can easily find arches made up of a knife-shaped nucleus entirely enveloped by a Roman bond, arches made by Roman bonding with knife bonding on one or both sides, and arches with an upper knife-bonding part and a Roman one below it, or vice versa. All of these are arranged with Roman bonding up to the shoulders. (Fig. 1)

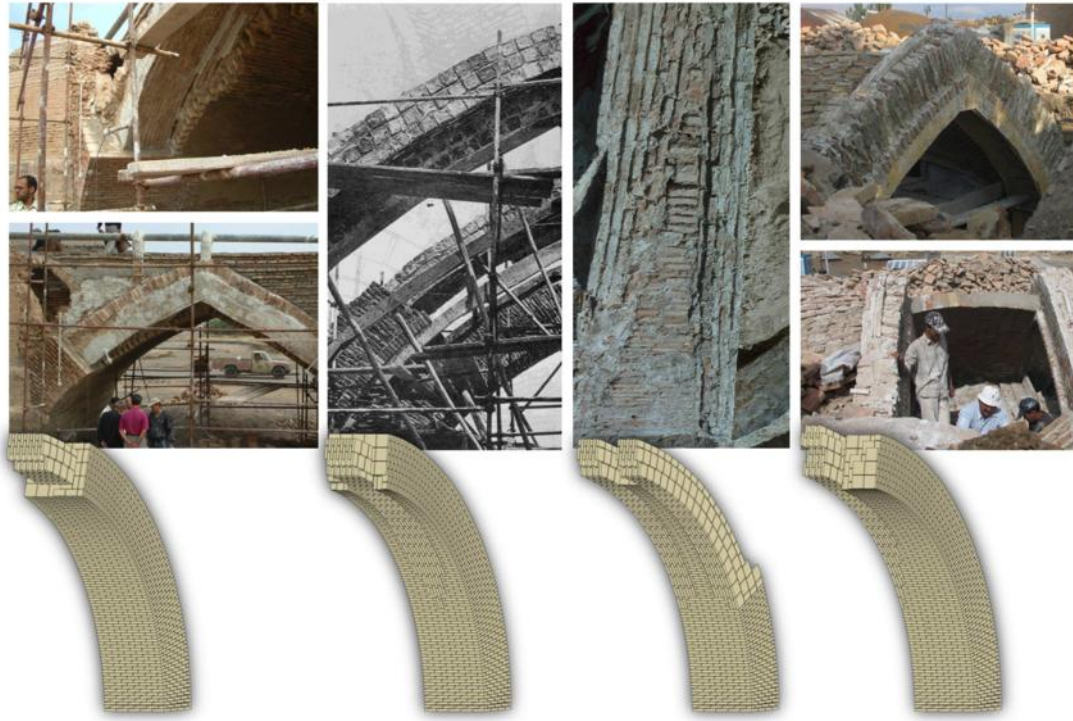


Fig. 1: Pictures and axiometrical view of the different kinds of arches.

Looking at several examples of entranceways of houses or the *iwans* inside a large number of mosques can give a good idea of the kind of ribs and coverings we are speaking about. Surely one of the most surprising examples is the well-known west *iwan* of the Friday Mosque of Isfahān. Here the structure can fairly reasonably be attributed to the Safavid period. The covered entrance has huge dimensions and the ribs show a surprising thickness and a disposition. Moreover, underneath this device is not visible at all. Thus this can be useful to clarify that, even if generally speaking about structures with crossed ribs,⁶ the vaults we are concerned with have arches that, while spanning in different directions, channel their loads and intersect leaving the central area free from load bearing functions.

Most of the times thus, due to their suitability, these intersecting ribs are used to cover irregular spaces. But shortly after their first usage, they were the preferred method to cover commercial spaces, public baths, or every kind of building that needed light and air.

⁶That is “those made up by a primary resistant skeleton with a fairly slim section and by a secondary filling zone that defines the architectural space itself” (Galdieri 1983, 61-75).

In spite of a huge number of experimental formal solutions, making the supporting arches can be considered from a technical point of view as the reiteration of a well-known working rule of knife-shaped bonding. This is primarily due to the need for a quick and handy construction site. Exceptions are related to the primary load bearing ribs. In some cases, due to structural and constructional needs of size or planimetric irregularities, they can be made with combinations of Roman and knife-shaped bondings as previously described and often built upon a Roman bonding constructed up to the shoulders to guarantee a better load-bearing function.

Therefore, the rib generally consists of a series of parallel arches made with squared bricks. These parallel arches are often odd in number from three upwards, depending on the span of the vault. One or more of these can often arise from the totality of the structure and become visible from the intrados of the vault. These arches are not only structural parts but become the architectural ones too. The remaining ones are mostly not visible at all.

Choosing a knife-shaped bonding is not mere formalism or arbitrariness but rather the logical solution for structural and constructional problems. In fact, this bond creates a perfectly load bearing arch, that simplifies the critical junction points. Regarding these critical points where ribs meet, there are several possibilities for implementation, all commonly used based on the requirements of construction sites and on the craftsmen. All the different solutions are based on two basic criteria. In all cases, the main parallel ribs have to be completely constructed so that they maintain their load-bearing function.

In most cases, for those ribs springing in different directions towards the primary ones, single bricks are shaped while building, up to the best suited size and shape to fill the space left by the combination of arches. At other times, while building the primary ribs, spaces for interlacing bricks of the secondary rib are left or created. In this way, bricks of the secondary arch are partially inserted into the structure of the primary one, providing a better interlocking.

Up to the 13th century, it is not possible to refer to a well-defined architectural typology because there is no evident rule and the execution of the existing examples is not always traceable as belonging to a unique methodological process. Through several experiments, the creation of an interesting form of vaults has been reached that, even if exported all over the world, expresses strictly local features.

Still more interesting is the fact that the methodology and its related architectonic elements, after a period of relative disappearance, have recently been revived as a feature of architecture and architectural study in this region. Over the last half century, due to the relatively high cost of traditional construction, lack of proper construction material and the lack of qualified trained people, the practice to use this kind of ribbed vault has disappeared to be replaced by flat roofs and the use of modern materials, like steel and concrete. But restoration work started in the 1960s on the major buildings with extensive ribbed vaulting in Isfahān and consolidation work on the commercial vaulted spaces inside the bazaar of Tabriz started in the 1970s have renewed study and use of the vaulting technique. In more recent years, architects, probably trained from these earlier restoration efforts, have discovered many of the architectural issues involved in the methods of brick vaulting. These developments made it possible to recover the use of certain traditional materials and the application of execution rules too. Nowadays this kind of ribbed vault, made using the structural method now called *kārbandi*, is a widespread element and used most of the time in preserving the old building techniques. Otherwise it is implemented with the partial introduction of new modern materials.

To figure out the whole architectural element we can refer to the definition that Fallahfar gives: it is “a composition of diagonal arches that intersect when spanning in different directions, in which case the points of intersection are used to form a vault.”⁷ This explains the basic concept behind the architectural form.

To this day no drawings are prepared for the construction of an ordinary building. The common practice is that owner and builder “draw” the plan on the actual site by marking the walls with powdered lime of gypsum. Thus, we can assume that, when creating these vaults, a certain geometrical composition is conceived and firstly represented on the floor as the result of a unique line that, reiterated several times while linking together the edges of the space, intersects creating a sort of starred grid. (Fig. 2)

⁷ Fallahfar 1999.

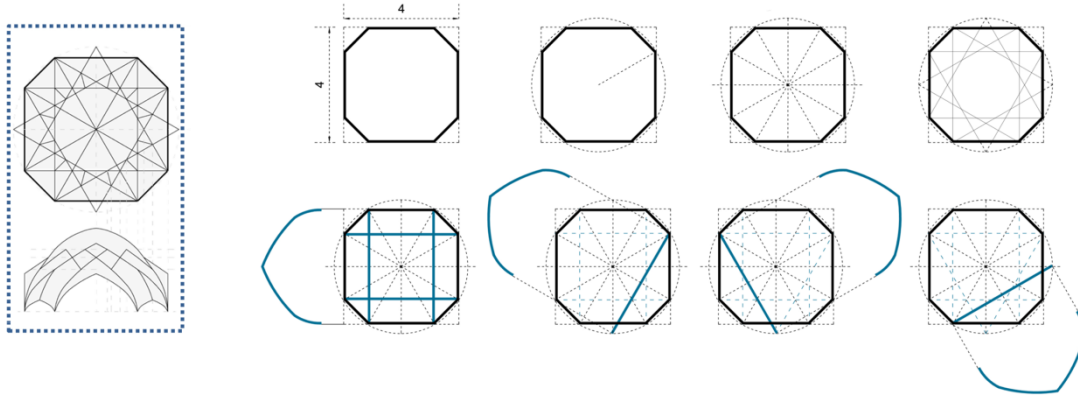


Fig. 2: Sketches showing the geometrical composition

This process of laying out the plan is nearly always physically achieved by using a string that helps to define the precise position of the frame and the arches involved and it allows one to control intersections as well. Afterwards, the grid is built at the level of the impost of the arches by putting the frame from time to time above these lines. The frames involved can be constructed by tracking the projection of the arch's curve with the help of a wire or without the use of any tool. Often, under this frame, wooden scaffolding is constructed. In this case, the wooden frame is removed and reused after the arch is completed. Usually in fact there are no more than two timber-made frames, with the diameter as the maximum dimension of the room being covered; these are removed after the completion of the arch and again positioned for the following ones. After creating the frame, the construction of the load bearing ribs starts. All the ribs in a vault are made using the same curved shape.

Generally arches are pointed or, less frequently, low-pitched or sometimes broken. The first type, even if they have a geometrically unusual curved shape, have weak oblique thrust. The second one often is used for hinged arches, thus leading to better perimetric stability.

Generally, the curved shape that generates the profile of the vault is composed of three or five ribbed arches, named collectively a *khalil*. After being properly sized in relation to the space being covered, the geometry of this curved shape allows for better behavior at the level of the shoulders of the arch. Using the same profile provides the same height to all the arches, thus allowing them to be proper supports. Usually their construction is done in steps: first making the one or the two parallel primary ribs and then the perpendicular or transverse intersecting ones. At

this point the subsequent, thinner ribs can be made, spanning transversely or diagonally with respect to the previous one.

These ribs—and the following ones, if necessary—do not all have a primary load bearing function. Some serve the practical function of supporting a landing or providing a transition between part of the vaults with different inclinations. Others do not support any other structure above and are used for a constructional rather than a structural purpose. The ribs are not always made following the same formal and spatial way, thus allowing for the existence of several declinations for these structures. Over time, the ribs were laid out in different ways, to the point that the inner and outer shells of the ribbed vault have substantially different profiles. With the changing layout of arches, in most cases it is quite impossible to understand the position of the bearing ribs without examining the roofs. (Fig. 3)

Differentiating the internal spaces and the external appearances of domes rapidly spread throughout various regions of the Middle East and Central Asia, thus contributing to the creation of a new type of coverings built in several stages, with intrados and extrados independent of each other. Indeed these become the basic topics that were to affect the style of much of the vault architecture that spread later on.

Quickly, the discovery of this fast and repeatable construction technique, taken from the ancient and solid brick tradition, encouraged several types of ribbed structures. The advantages these techniques allowed, the use of which implied a high level of craftsmen knowledge, therefore gave way to an extremely wide distribution of the system of load-bearing ribs within the Persian territory. This spread and full control of the system gave workers a greater willingness to experiment with new structural and formal solutions. Thus the relationship between form and structure, from this moment on, seems to be as ambiguous as ever. In the Safavid period during the 16th century, this led not only to examples in which the structural part totally coincides with the architectural one; it also led more often to what seems the complete disjunction between these two components. Very often, though, the structural part is completely hidden and not on display in the interior space.

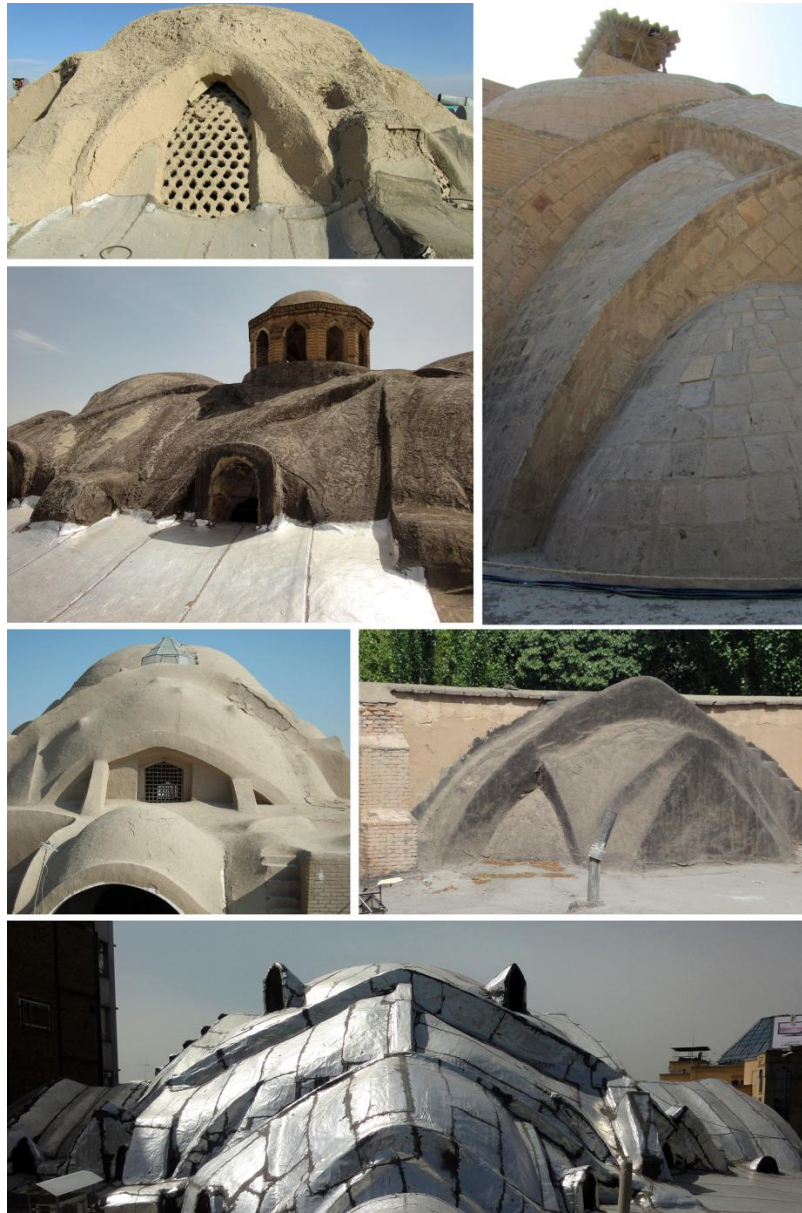


Fig. 3: Several pictures showing the different styles of extrados of vaulted structures

In any case, the focus of the design for the building was on open interior spaces, which the ribbed vaulting provided. As a result we find that while the architectural apparatus can have very complicated solutions and geometries, the structural one may be simplified and refined.

With regards to the interior spaces, the arches have a different function; they are often not spanning in different directions and do not intersect for support. In these cases, the arches usually are

attached to a dome. From these components, ribs or domes, an intricate system of timber hangers develops that, attached with gypsum mortar to the brick structures to suspend *muqarnas* vaults (a sort of corbel used as a decorative device), again gives local Iranian character to a more generalized form.

From this architectural feature, Persian builders were able to develop further topics. Iranian *muqarnas*, in fact even if recalling a well-known Islamic element, are made in a way that again has never been well-developed abroad. They are realized as a lightweight design made with plaster and wood. Thus from the structural ribs mentioned previously, several levels of wooden brackets are hung using ropes with gypsum mortar. (Fig. 4)



Fig. 4: Detail of the ribs sustaining the timber lintels and the ropes for the *muqarnas* ceiling in the Mausoleum Habib Ibn Musa in Kāshān.

After these corbels are hung, the designs are completed with plaster and eventually covered with tiles. This process combines together a structural need with a decorative overlay as can be seen, for example, in the *yazdi-bandi* of the Hasht Behesht Palace (Fig. 5) or inside the most of the houses of the old city of Kāshān. (Fig. 6)

Very particular solutions are the ones used for example in the Ali Qapu Palace and in the west *iwan* of the Friday Mosque, parts of the Safavid ensemble of Isfahān. (Fig. 7)



Fig. 5: Fig. 5: Hasht Behesht Palace in Isfahān. View of the alveolate ceiling of the central covered space from the inside.

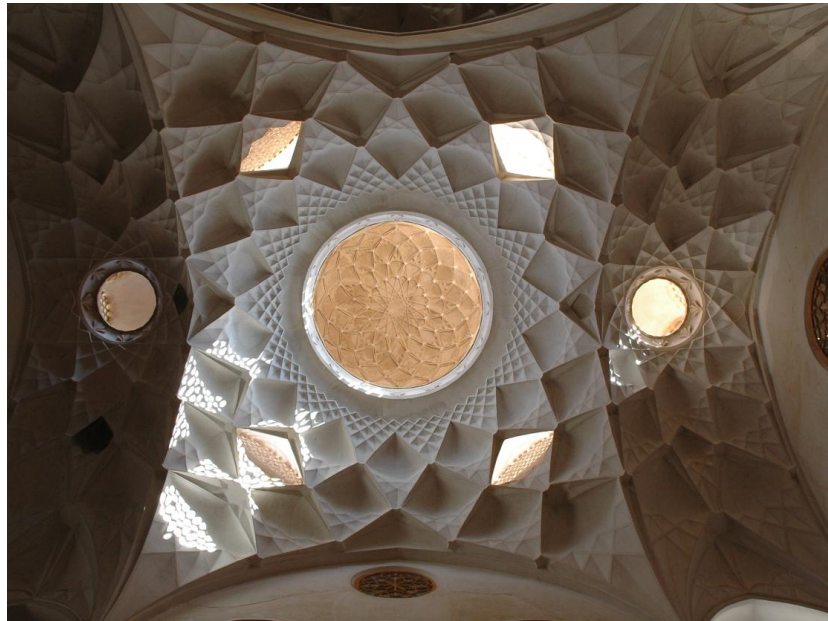


Fig. 6: Ameriha House in Kāshān. View of the *yazdi-bandi* decorative ceiling from the inside.

Indeed these are only few examples of buildings in which almost all the rooms present some highly innovative type of stalactite or alveolate ceilings, made of sheets of plaster suspended from the vaults with ribs completely hidden behind them.



Fig. 7: Ali Qapu Palace in Isfahān. Detail of the alveolate ceiling

References

Diez, E. *The Principles and Types*, in Pope, A. U., *A Survey of Persian Art and Architecture*, vol. II, (London and New York, 1939).

Fallahfar, S. *Farhang-i wāzahā-i mi'mārī-i sunnatī-i Īrān*, (Tehran, 1999)

Galdieri, E. *Esfahan: Ali Qapu. Analisi Architettonica*, (Rome, 1979).

Galdieri, E. *Isfahān: Masjid-I Gum'a 3: Research and Restoration Activities 1973-1978. New Observations 1979-1982*, (Rome, 1983).

Pope, A. U. *A Survey of Persian Art and Architecture*, vol. II, (London and New York, 1939).

Schmidt, E. F. *The Treasury of Persepolis and Other Discoveries in the Homeland of the Achaemenians*, vol. XXI, (Chicago, 1939).

Wulff, H. E. *The Traditional Crafts of Persia. Their development, technology and influence on Eastern and Western civilizations*, (Cambridge and London, 1966).