Politecnico Di Milano

Faculty of Architecture and Society

Master of Science in Architecture

The Recognition of Rib Development in Persian architecture

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Abstract

There is a relation between elegance and science in which an aspect of it has been reflected in architecture. In order to recognize such relevance, one must contemplate the various part of architectural design like structure in one complex, as an artistic approach in interaction with science. The biggest and most challenging part of structural design is to choose a form which is constructional and proportionately in relevance with aesthetics purposes. This becomes boldly visible in traditional architecture of Persia. Among historical structures, curved covering hold an important role owing to its efficient form to cover spaces and become the climax of creativity in building design and among the structural members of this kind of coverage; rib is the most important one. The reason lies in the fact that it indicates the utmost abilities and innovations of the architect to convert four square plans to circle (Chapireh sazi) also meticulous convex coverage of the space using ribs. There are different speculations regarding the root causes of creation of the curved coverage with ribs in ancient Persian architecture. So realizing the core reasons behind constructional, structural, and ornamental reasons design of this kind of architecture requires a considerable and special attention. Principally recognition of ribsب geometry, different combination of ribs in cupola and corners, furthermore rib development during time is the goal of the research.

To better identifying different types of geometric combinations, many varied examples of any coverage by rib are examined, following below classification: Chapire sazi of Se-konj and Patkaneh, Coved domes and vaults, Ribbed vaults, Patkaneh and Karbandi vaults, and rib development in contemporary samples.

Regarding to the historical sequence, evolution of using the rib and getting more complicated constituents, regardless of the structural and building role of them, the geometry of domes slips would be examined through collecting drawing and pictorial documents related to each case studies, so that finally, the sum of the geometric components would be obtained and it would be an entry to propose a sample to modern architecture with new form composition.

Astratto

C'è una relazione tra eleganza e la scienza in cui un aspetto di essa è stata riflessa in architettura. Al fine di riconoscere tale rilevanza, bisogna contemplare le varie parti della progettazione architettonica come la struttura in un unico complesso, come un approccio artistico in interazione con la scienza. La parte più grande e più impegnativa del progetto strutturale è quello di scegliere una forma che è costruttiva e proporzionalmente in pertinenza con finalità estetiche. Questo diventa coraggiosamente visibile nell'architettura tradizionale della Persia. Tra le strutture storiche, rivestimento curvo tenere un ruolo importante grazie alla sua forma efficiente di coprire gli spazi e diventa il culmine della creatività nella progettazione degli edifici e tra i membri strutturali di questo tipo di copertura; costola è la più importante. La ragione sta nel fatto che essa indica le massime abilità e le innovazioni dell'architetto di convertire quattro piani quadrati a cerchio (Chapireh sazi) anche meticolosa copertura convessa dello spazio con costole. Ci sono diverse speculazioni per quanto riguarda le cause della creazione della copertura curvo con costole in architettura antica persiana. Realizzando così le ragioni fondamentali alla base costruttiva, strutturale e ornamentale ragioni progettazione di questo tipo di architettura richiede un notevole e particolare attenzione. Principalmente il riconoscimento della geometria costole », diversa combinazione di nervature in cupola e gli angoli, inoltre, lo sviluppo costola durante il tempo è l'obiettivo della ricerca.

Per identificare meglio i diversi tipi di combinazioni geometriche, molti esempi vari di qualsiasi copertura da parte costola sono esaminate, in seguito sotto la classificazione: Chapire sazi di Se-konj e Patkaneh, cupole e volte a padiglione, volte a vela, Patkaneh e Karbandi volte, e lo sviluppo costola campioni contemporanei.

Riguardo alla sequenza storica, evoluzione utilizzando la nervatura e ottenere componenti più complicati, indipendentemente dal ruolo strutturale e costruzione di loro, la geometria di cupole scivola sarebbe esaminata mediante la raccolta di disegno e documenti pittorici relativi a ciascuna casi, così che alla fine, la somma delle componenti geometriche sarebbe ottenuta e sarebbe una voce di proporre un campione di architettura moderna con nuova composizione forma.

Chapter One General points

1-1: Introduction

Architecture is a mixture of science and art, taste, belief, trusts and expertise skills which in parallel with civilization and culture and by the passage of time displays its time. However it is not static and is shaped based on ancients and trades of the predecessors (Abolghasemi, 1987).

Codification of architecture depends on diverse factors; study of architecture also has broad domains and different cases. Researches on architecture shall investigate its formation trend, especially in Iranian architecture which has been focusing on force lines. This factor is the supreme forming factor and other factors specially dimension and sizes depend on it. Iranians have always been focusing their attention on positive aspects of architecture, such as: reason, stagnation principles, scientific and technical issues of the building, human scale, utilizing local material, avoiding losses and etc. The criteria for obtaining correct formation of the coverage and loading material and their locations and dimensions are power lines on which the architect has full surround. (Abolghasemi, 1987)

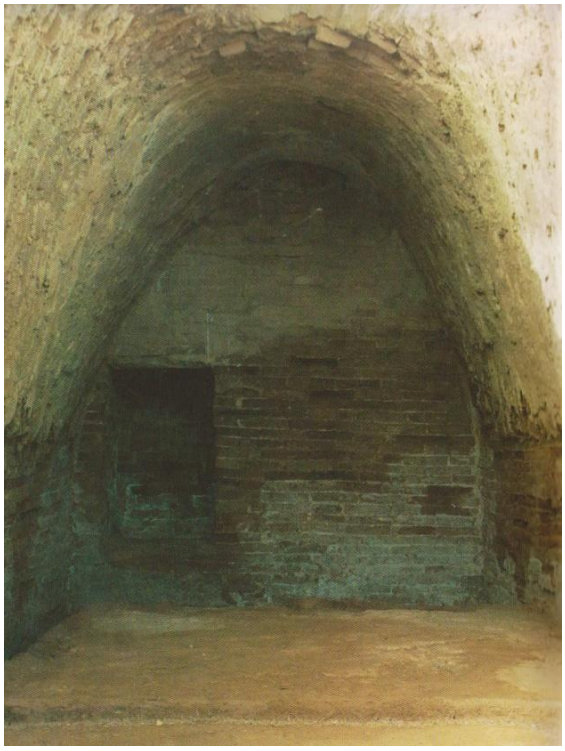

Figure 1 : Tabati Ahar shrine in Haft Tappeh Khuzestan, 3400 years ago

When the architect thinks of producing a work, simultaneously and even previously has obtained its coverage. The coverage needs some factors compatible with its span, volume, weight and

structure to transfer its power to the land, the formation of which is determined by coverage power and power lines and justifies dimensions and sizes. Coverage is innovated depending on time and needs and by the passage of time and passing its complementary trend come handy in different methods of architecting and reaches their utmost aesthetics.

Among all the coverage, curved ones are culturally significant for the individuals and is one of the great achievements of the Iranians to the world of architecture (Pirnia, 1984: p.93) and because of the knowledge applied in its construction, is of utmost significance among all traditional structures of the world.

By focusing on Iranian fire temples, palaces, mosques and tombs, one can realize that designing and constructing larger and more beauteous vaults and domes was the utmost abilities and innovations of the architects to interest governors and people. Achieving such aim challenges architecture mind so as to be able to spontaneously think if the aesthetics and structure. Such challenge were not worthless but many vaults and domes were made as the result of such challenges which although have some similarities, there are also some differences in their design and applicability. Also, cornering which means transferring square surface to circle in the space which was one of the significant structural issues in the world of architecture, were designed for the first time, by Iranian architects.

The domes designed by Iranians are various both in shell formation and in the number and unity among the shells. In this regard, Iranian domes are classified to various criteria. Also, the structure of the domes for covering larger spans has advanced architecture to a great extent. By the passage of time, the architects have separated the domes to two shells and utilized rib in different places. We managed to examine and analyze curved coverage or rib and attempted to investigate the relationship between form and structure in architecture, traditional coverage, data gathering of curved coverage or rib and realizing their structural behavior. Taking these points into account, one can find out about what had occurred by rib in cornering, vault and domes so as to be able to later on investigate Iranian traditional structures. The ideas, aims, questions and achievements behind this research will be given in this section. The research aims that by detecting and applying the combination of rib which has a great role in Iranian architecture curved coverage, come to new combinations of curved coverage or rib.

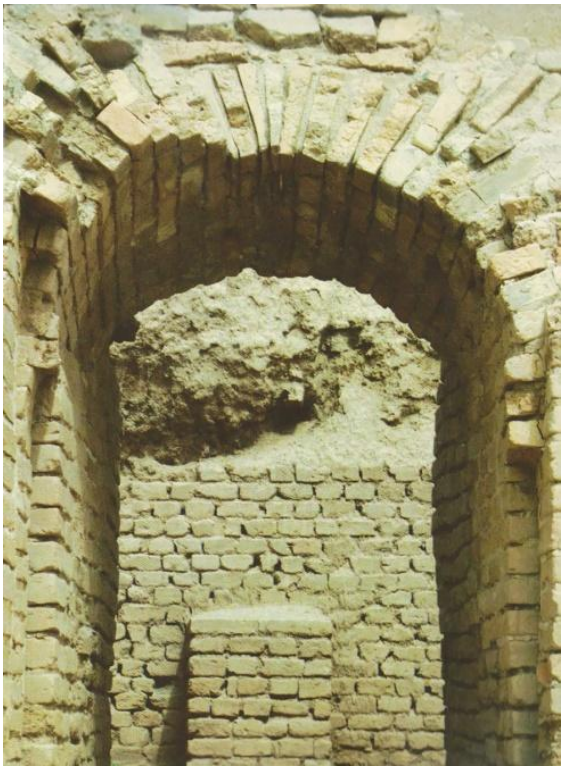

Figure 2: Choghazanbil temple, one of the entrance with Illamid arch

1-2: Background

Studying curved structures such as vault and dome has interested two groups of researchers. One group includes mathematicians and structure engineers. This group has attempted to understand mathematical and mechanical logic of vault structures. The second group in art history and architecture have attempted to understand the core of these materials and investigate them in formation point of view (Memarian, 1391: p. 613) What we follow in the present research is a combination of subjects in architecture, architecture history, ancient structure and restoration knowledge and can be regarded as interdisciplinary. Therefore, we should take a look at its past in several aspects. This background includes different classifications of architecture, ancient structures and special construction form; however it mostly includes the second part.

1-2-1: Studies on ancient structures in the world

Architecture history is composed of different view-points including historical, archeological, artifice, mysticism and architectural. Each of these vie-points has focused their attention on one special aspect of architecture. None of these opinions were wrong, however none of them have rightly presented architecture history and have not stated all the aspects of this cognition (Golijani, 1384: p. 33) Of course we can be having a scientific attitude towards architecture structures which had been

Figure 3: Giorgio Cruci

scarcely applied. بGiorgio Cruciپ the researcher of ancient structures believes that although structure has a great role in architecture and is the single holding part of the building which is somehow mistakenly regarded as the building, is not that much heeded and scarcely, structural development is analyzed in special aspects (Cruci, 1382: p. 231). The structure may give us some important information regarding different methods which is not much detectable. Also, structures have their own logic, from which new forms are made like continuous threads: Structure is an effective factor in all architecture histories, including that of Iran (Pope, 1387: p. 1119). Here, detection of ancient structures, especially an important structure like curved coverage, is significant to find out the relationship between form and structure in architecture design.

Figure 4: Arthur U. Pope

1-2-2: Studies on ancient structures in Iran

Great archeologists, architectures and Iran-researchers such As: بAndre Godardپand بRolan Bezenvalپ had done useful attempts regarding ancient structures. Also, individuals such as بArthur Opham Popeپ بDonald Wilberپ بEugenio Galdiriپ and بAuguste Choisyپ Have referred to ancient architecture structures. But more investigation of their works reveals that there is still more need for researches. As an example, the close relationship between structure and other architecture factors such as form and space has not been accurately heeded, yet. Also, ancient structure systems, relying upon stagnation knowledge have not been given correct scientific classification.

Iranian researchers had approached ancient structures specially, from the late 60s Solar Hijri onward. Masters such as بMohammadKarim Pirniaپ بMehdi Farshadپ بGholamhossein Memarianپ بHussein Zomrashidiپ and بZohreh Bozorgmehriپ have supplied architecture community with valuable masterpieces in this regard. The most recent writing on Iranian ancient structures is the book entitled بIranian Architecture- Niareshپwhich has been authored by Dr. Memarian and prepared by بHadi Safaeipoorپ(dissertation counselor) might be regarded as the first comprehensive Persian writing on Iranian ancient structures. Also, individuals such as بBagher AyatollahZadeh Shiraziپ,بMehrdad Hejaziپ,بFarhad Tehraniپand بAliakbar Saeidiپ had done several attempts regarding ancient structures. They have published many papers and most importantly, they have attempted to develop the academic field of بAncient Structuresپ

Figure 5: Eugenio Galdieri

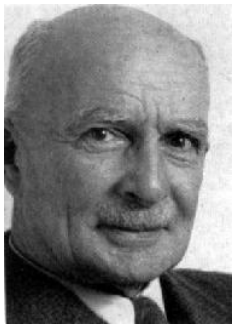

Figure 6: Andre Godard

Figure 7: Rolan Besenval

1-2-3: Studies on Iranian vault coverage

The oldest work on vaults and domes belongs to بGhiasaddin Jamshid Kashaniپ architect and mathematician of Ilkhanian era, of 14th and 15th century. بTaghvaEzajپ article in بMeftahalhesabپbook is in Arabic Language, the translated versions of which includes some writings by the engineer, Habib Maroof, researches of SaeidMardans and Mohammad Sheikh in 1967 in Cairo and the Russian version of the بTaghvaEzajپ article has been published by Britaniski and Rosefield on 1956 and on 1987 it has been translated to Persian. It shall be mentioned that based on these sources بKashanVaultپarticle has also been translated to Italian. In the present era, the valuable book, entitled بHistory of Engineering in Iranپauthored by Dr. Farshad, briefs on different issues including structure developments. However, the article بDome in Iranian Architectureپauthored by the passes master Pirnia, the book entitled بVault Structures in Iranپauthored by Dr. Memarian and also the book entitled بIranian Dome and Vault Materialپ written by Mr. Zomrashidi are among the most significant Persian works on Iranian Domes. However, among foreign translated books the most important ones on Iranian dome structures include the following: بVault technology in Ancient Middleپauthored by Benoval and بIranian Vaultsپby Godard, بIsfahan Jame Mosqueپand بAlighapooپauthored by Galdiri. However, the book entitled بVault Technology in Ancient Middleپmostly focuses on vaults and domes in Ancient Iran and local vaults and the book entitled بIranian Vaultsپmostly concentrates on vaults and less on domes. What is of utmost significance is the fact that researchers do not agree on the difference between vault and dome and also there are not any specified classifications for detecting different kinds of dome.

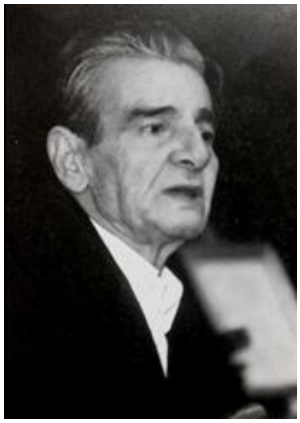

Figure 8: M.Karim Pirnia

Figure 9: Gh.Hosein Memarian

Figure 10: Bagher shirazi

1-3: Necessity

Iranian ancient architecture is a valuable heritage, given to us from thousands of years ago, but unfortunately, the values are forgotten, nowadays. Utilizing the values depends on its deeper understanding and one of the ways to understand it is finding out about the designs and effective factors in its formation. Among building structures, curved coverage is the most significant one and among the structural materials of this coverage, rib is the most important one. The reason lies in the fact that they indicate the utmost abilities and innovations of the architect to covert foursquare to circle and also meticulous coverage of the space using unique methods for making rib. To examine rib and structural analysis of this material we should first be given the reasons for using it and have a deep understanding of the relationship between building and structural formations of curved coverage. By so doing, the necessity of this kind of research in ancient architecture world becomes clear to manifest local identity.

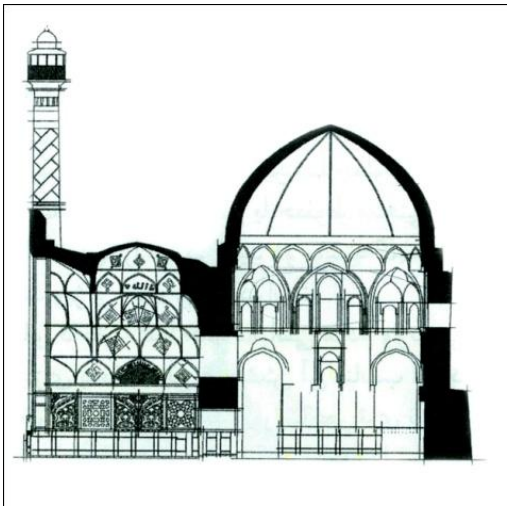

Figure 11: Nezam-almolk, Section of coved dome

Figure 12: Nezam-almolk dome, Jame mosque, Isfahan, Inverted plan

1-4: Hypothesis

- Ribs are one of the main elements of curved coverage in Iranian architecture which can be classified to different geometric-space types.
- Based on the obtained classifications, new combinations of curved coverage or rib can be stated.

Figure 13: Taj-almolk, Jame mosque, Isfahan, Inverted plan

1-5: Question (Aim)

- Cognition question: How are the rib combinations in curved coverage of Iranian architecture?
- Applied question: How can we find out about new combinations of curved coverage or rib, based on recognizing rib in Iranian architecture?

1-6: Motivation

Our motivation for choosing this kind of research is to navigate the attention of architects and researchers to Iranian architecture, so as to have them focus on Iranian architectsبshare of world achievements. In fact, it shall be stated that Iranian structure shall be regarded as a unifying factor with architecture where structure has an architecting behavior and helps the architect to display not only its primary purpose which is tolerating the stresses but also to increase the aesthetics of the building to help the spirits of the consumers. This background includes our personal interest in the background of Iranian architecture and structure abilities to ennoble architecture and belief in structure unity and Iranian architecture formation.

Figure 14: Jame mosque, Isfahan

1-7: Framework

1-7-1: Discipline

This writings are in the framework of Iranian architecture studies discipline. As the discipline includes some architecture history discussions is relatively interdisciplinary but is the subset of Architecture. The main addresses are those interested in Iranian architecture, especially researchers of ancient structures. Of course, the discussions and results shall also be included in Structure Technology and Restoration disciplines.

1-7-2: Skeletal domain

The domain of the study includes curved coverage, including vault and dome. Among the vaults, these will be mostly heeded: formal-structural detection and analysis of coved vault, ribbed vault, Patkaneh Vault and Karbandi Vault. Also, among the domes, Coved domes or rib will be heeded and among the Tholos places of dome, just cupola will be dealt with.

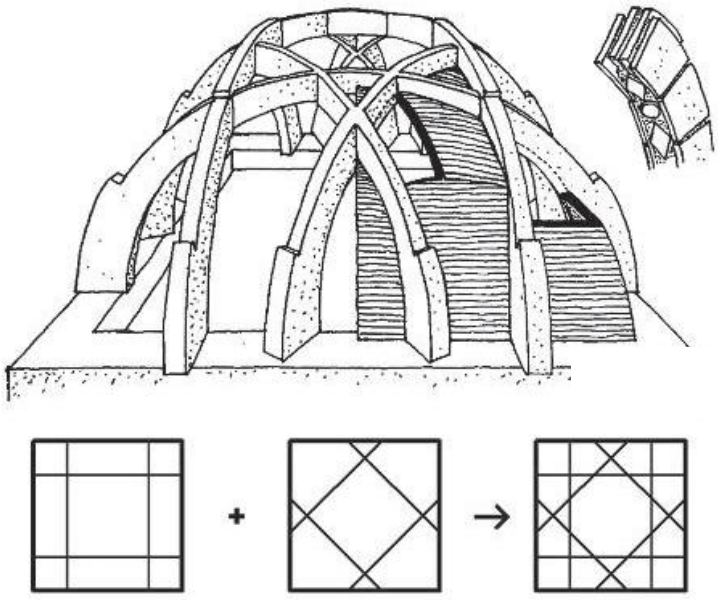

Figure 15: Ribbed Vault n.60, Jame mosque, Isfahan,

Combinaton of ribs as structures, form and ornament, Galdieri 1991

1-7-3: Time domain

To this aim, it is necessary to be familiar with various samples of this kind of architecture. Therefore the time span of the samples of the study starts from first samples of rib in second century and finishes with last samples from the twentieth century.

1-7-4: Location domain

The samples of this kind of dome are not just confined to current political geography of Iran and include a larger span of historical-cultural geography of Iran. Therefore, the location domain of the research includes Iran, Afghanistan, Turkmenistan and Uzbekistan.

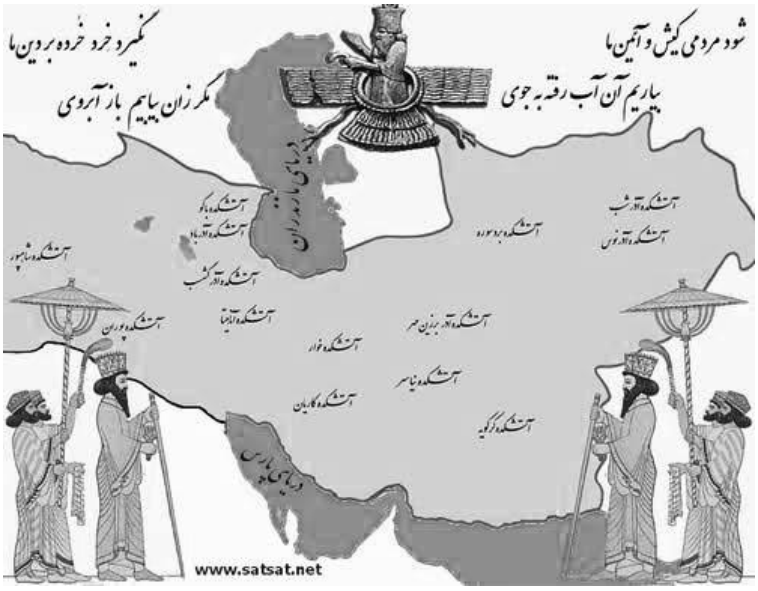

Figure 16: Map of ancient Persia

1-8 Method

1-8-1: Data gathering method

Data-gathering of this research included library studies which included written, listening and visual methods of books, articles and dissertations. For some of the buildings for which there was not enough information, we used Circle Method which includes observational and listening methods, using camerawork, measurement and researching professors and interviewing those who are expertise in the field.

1-8-2: Analysis Method

The next step after data gathering includes analyzing the data: The method through which the whole research process, from the problem till targeting the aim, is guided.

The present research was conducted using qualitative analysis which includes the following stages:

- Descriptive: Which meticulously describes key words which were brought about in data gathering section and the specific characteristics of each architecture material is explained.
- Interpretative-analysis: It will be conducted by analyzing one of the effective formation-structural domains on curved coverage of rib. It will be done, relying on theoretical guides for achieving various building-formation combinations. The dominant Iranian samples will be regarded as unified documents and analyzes of Circle and library results of the place of the rib in vault coverage designs will be investigated.
- Inductive: Finally, comparison of the results of theoretical frameworks and our examined samples will lead us to suggest new formation combinations of rib in curved coverage.

1-8-3: Research Process

As the first step of the study, related data gathering was conducted in different levels. First, issues related to ancient structures will be discussed. Then, documents for buildings with curved coverage such as Karbandivaults, Patkanehvaults and Coved domes will be examined. Then, issues related to formation and structure role of rib in curved coverage will be discussed which were gathered using library and Circle references. In the next step, the comparison of formation combinations of rib and the development of coverage with rib were examined, by the supervision of supervisors. The final step included accurate studies on the findings so as to present the results in an interpretive way.

1-9: Result

Suggesting new forms and combinations of ribs in curved coverage, taking into account rib in Iranian architecture

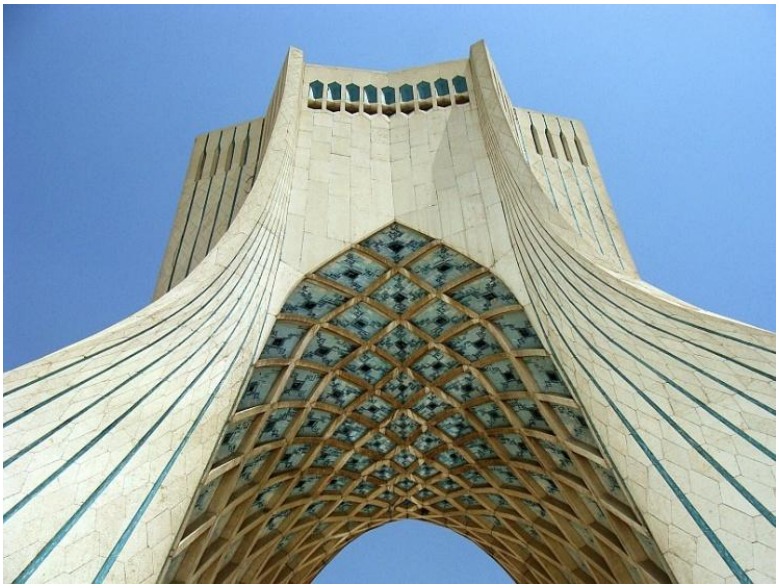

Figure 17: Shahyad tower, modern combination of ribs

1-10: Summary

The present research has been arranged in 5 sections. The first section was on the preliminaries of the research work. The second section informs and describes arch, rib, vault and dome in Iranian architecture. The third section deals with expansion and the relationship between formation and structural roles of rib in curved coverage. In the fourth section, case studies of curved coverage or rib will be analyzed and compared. The comparison will be separately done for central and corner space coverage, using pictures and maps. The fifth section presents the conclusion and suggests new methods and combinations regarding rib, taking into account the results and analysis.

Keywords: Curved coverage, Rib, Iranian architecture, Vault, Dome

Chapter Two: Theoretical Framework

Technical Knowledge of Building in Iranian Architecture

2-1: Introduction

Since people have done away with living in caves and scattered in mountains and plains, the first thing they were obliged to have was coverage to protect them, something similar to the one they had when they were in the caves.

Although at first the existence of broadened dormitories was not a necessity and they were just satisfied with the fact that their shelter could be protective of a small family, but not long after small families unified and made some groups. The small places they have dug in the land or small cottages made of wood, branches of trees, leaves and chips could not be shelter for groups. Necessity of broadened coverage brought about pillars and wooden cottages and cave cracks were replaced by seraglios and halls. However, the existence of a great deal of pillars (which normally had been placed so nearly) hindered sight and this weakness was more emphasized when ceremonies and feasts were taking place.

They have first tried to separate pillars as much as possible. To do so, they had no way but to provide some long, hard shafts but weakness of wooden shafts made it difficult. That was why the coverage of large spans became the biggest wish of ancient architects.

There were some samples of Forty-pillar building, but for the first time it was in Iran, Parseh or Persepolis City, that Persian architects could separate pillars to the extent possible (about 4.6 meters). Thatبswhile before that in smaller forty-pillar and verandahs, the thickness of pillars was at times more than the distance between them (Egyptian temples and etc.). (Pirnia, 1973)

Although such advance was really significant, the Iranians were not satisfied with it and wished for bigger and better ceremonies and kingdom feasts. After the time when Alexander attacked Iran and when Achaemenid kingdom was depredated, Iranian architects attempted to utilize a curved-structure organ named arch on the spans. That was why wooden roofs were replaced by vault and dome (which specially belong to Iranian architecture).

One of the other reasons for replacing Arch was the unavailability of wood in desert areas which was so scarce and valuable in those areas. On the other hand, its durability can also be taken as the reasons for its application. In fact, arch has made a great revolution in architecture technique. (Memarian, summer 2012)

Figure 18 : Choghazanbil, 1250 BC

Figure 19: Persepolice, 550-330 BC

Figure 20: Taq-e Kasra, 100 AD

Figure 21: Sarvestan Palace, 420-438 AD

2-2: Arch

Arch is a word used for a curved member which covers a doorway. The word بarchپis has been used contemporarily. In fact, vault is a structure member which is applied for space coverage but previously it was just used as an organ which covers a doorway.

What differentiates an arch from its rival, namely stony or wooden shaft is the method of energy transformation to abutments. A wooden shaft vertically transforms its weight to a wall or abutment imposed on it. (Pirnia, 1994)

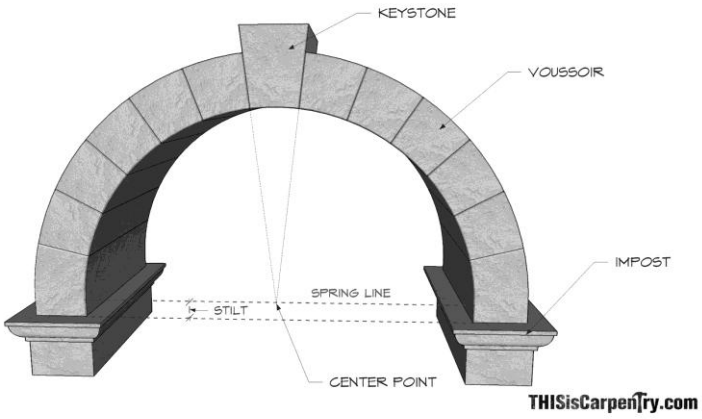

Figure 22: Arch

2-2-1: Structural-executive application of arch

It was so to be used for large spans of 20 meters and for domes it was up to 43 meters. It cannot be applied for such spans. It can be stated that formation, development and broadening of arch has had a significant role on the quantity and quality of architecture spaces. (Memarian, 1984)

2-2-2: Components of arch

Arch is composed of different components. Getting familiar with these components help to have a better understanding of the formation and executive tasks.

- Abutment: Each arch is placed on a vertical structure organ. This organ shall transfer the load of arch and its upper components to bottoms. Size of this organ greatly affects the

stagnation of arch. One of the important notes on the stagnation of arch is the width of the abutment.

- Impost: The place from the arch curve begins.
- Pier: A vertical, having a proper height as the arch curve continues.
- Haunch: The curved line of the arch.
- Span: Size of the span affects the stagnation of arch. There is a close relationship between the span and thickness of the arch.
- Rise: If a cross line is drawn on line of span which reaches the edge the obtained line will be the Rise.
- Springing line: The cross-point of two symmetric bows which make a point in edged arches.
- Intrados: The curved line which is below the Extrados. As each arch has a special thickness, Concave can be regarded as the inside surface of the arch.
- Extrados: It is not observed in all kinds of arch. In public dwellings it is placed below bricks or other tiles. As the thickness of arch in its length is not static and till reaching the edge decreases in some stages, it has different formations and its side view is not similar to that of concave.
- Voussier: Imposition of brick rows composes an arch.

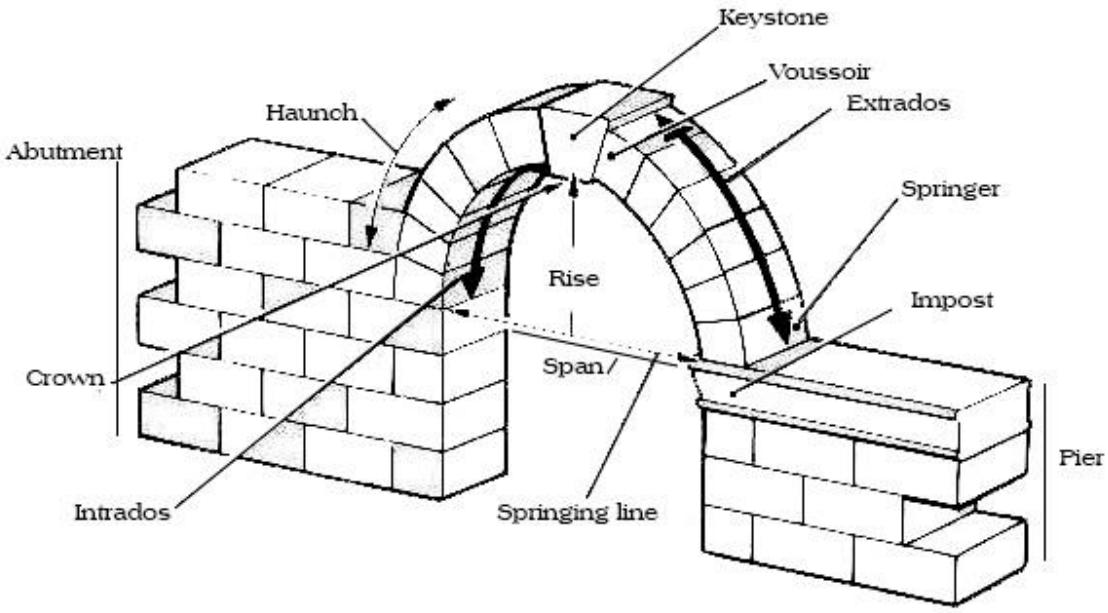

Figure 23: Arch Component

2-2-3: Arch morphology

There are various kinds of Iranian arches. They can be classified based on different classifications. The below samples are given to display the variety of these classifications.

1. Catenary and Pointed Arches: It is classified based on the side view of the formation. Pointed shafts are made of crosses of two symmetrical curves in the edge point. In this case we will have formation dissociation crown. Catenary arches such as circle and oval are unified in crown spot and here no breakage can be observed.

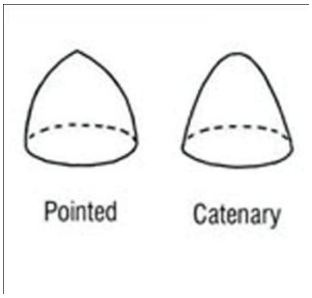

Figure 24: Category of arch

2. Transverse and decorative Arches: It is classified based on the structure duty. Transverse arches are applied on large spans and style arches are used for small spans. (Bozorgmehri, Zohreh, 1981)

Transverse Arch

It is one of the important structure organs in Iranian architecture. Rib is a transverse arch. This transverse arch tolerates weight of the arch and transfers the forces to the bases. Based on the sizes of the span, dips have different thicknesses. But what is important is the fact that in Iranian architecture, the thickness of the arch is never seen completely and appears as an elegant side view.

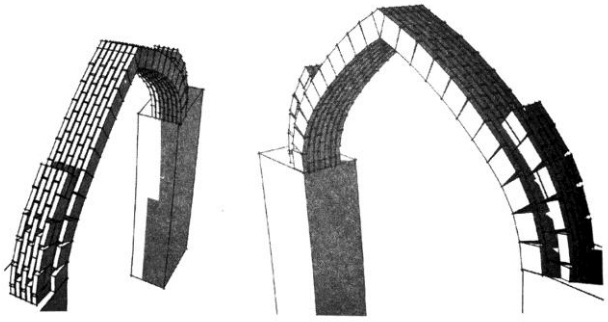

Figure 25: Transvers arch

3. Simple and Combined Arches: In simple arches, the collection of curve lines, make an arch. Combined arches are obtained from the combination of two kinds of arch.
4. Ogive, raised, drop, segment arrangement Arches: This classification is used for all kinds of pointed and catenary arches. Here, the criterion is haunch of the arch. Each arch can be made in these four formations. (Memarian, First part, summer 2012)

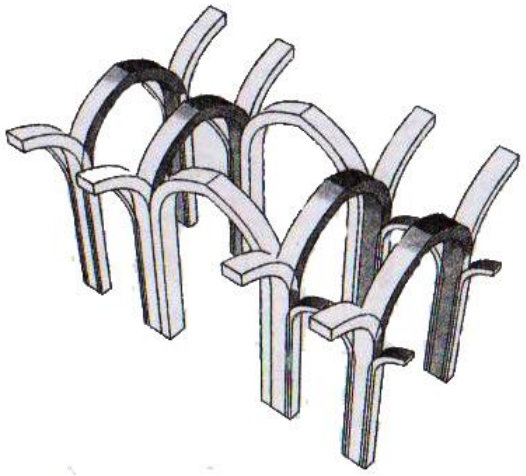

Figure 26: Combined arch

2-2-4: Execution of Arch using Iranian Method

It is not well-known to the addresses of the third millennium that why and how Iranian architects could execute such unique structure arches; but we can somehow approach a better understanding, using some hypothesis.

One of the hypotheses is that Iran is a dry country and not having access to the required amount of wood had made architects think of some other ways for covering spans and spaces. This hypothesis is based on locational forces. If so, the question will arise that why it did not happen in other countries with similar characteristics?

And if we suppose that there were enough woods in Iran as there were in ancient Rome, would Iranian architects have used wooden frameworks to execute arches?

This method requires a great deal of wood and it cannot be done as simple as the Iranian method. Iranians have used a simple method, chalky framework, and supplied an interesting solution to the world of architecture (Kashani, 1996)

2-2-4-1: Iranian solution: centering rib

What is centering rib? A simple chalky arch of favorable size is called centering rib. It is a non-structure simple organ and is applied in executing arch, vault and dome. Two applications can be specified for centering rib:

1. Guiding applicability
2. Leaning applicability

Guiding applicability is one of the significant responsibilities of centering rib to be able to execute the main bricked arch with one of the introduced side views. First the chalky sample will be made. The drawing method of Iranian arches is somehow complicated which is difficult to be executed in the space. The Iranian solution is to make a chalky sample on the land so as to work on the arch after it is transferred t the place. The centering rib has both leaning and guiding applicability. It is this kind of applicability which makes it possible to execute the arches, especially using shiner method. As centering rib has weak resistance against the imposed loads, it cannot tolerate rows of brick; for this reason, the architects first affix a row of bricks to the whole body of centering rib. This bricked row will be a resistant frame and can tolerate the next rows of brick. Here, the centering rib has both guiding applicability and also leaning one for the rows of brick. (Memarian, 1988)

2-2-4-2: Formation of centering rib

Centering rib is composed of chalk and bulrush. Chalk is the main formation element and bulrush is its skeleton. First half of the side view of the mentioned arch is drawn on the land. Parallel to the first side view and with 10 to 15 centimeters distance, another side view is drawn. Brick will be put on the drawn lines; so as to empty the distances between the lines.

Here, a bricked frame is made. Little sand will be poured to the surface of the frame so as not to let centering rib stick to the ground after drying. Then on, the bulrushes are inserted in the frame and two chalky frames will be added to it. After being dried, half of the frame is maintained; the other half will also be executed I this frame. In order to have equal and complete halves of the arch, a semi-frame was used. After one half of the centering rib was finished, the next half was made exactly based on the first formation and based on the same frame. (Memarian, 2012)

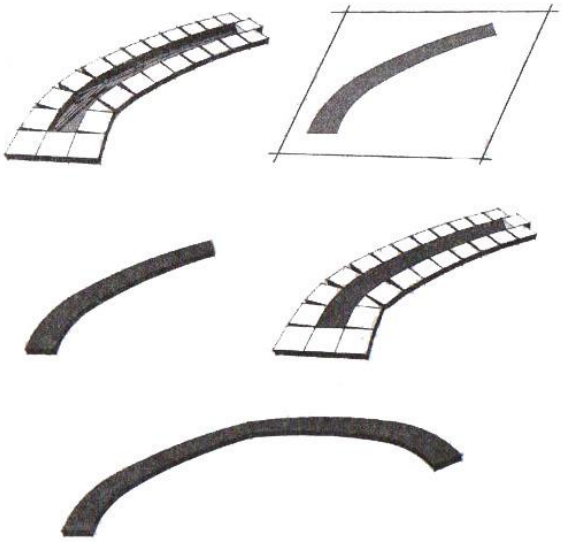

Figure 27: Formation of centering rib

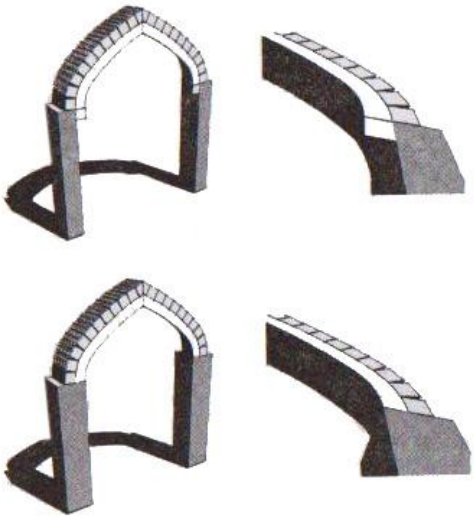

Figure 28: Location of the centering rib

2-2-4-3: Location of the centering rib

After the preparation of centering ribs, they are put in the place of execution of the arch. Centering ribs can be placed in three places.

1. Below the bricked arch
2. Beside the bricked arch
3. Inside the bricked arch

In the first mode, the centering rib is placed tangent to the bricked wall, beside the arch. The reason is that the centering rib will be used, again. To do so, the centering rib, along with some chalk elements, is put in the place of execution and the first row of bricked arch is added and the work continues. Then the centering rib is removed and used somewhere else.

In the second mode the centering rib is put on the wall and the first brick rows are affixed to it from the sides. Then other brick rows are put and centering rib will remain.

Third mode: in this mode, after the preparation of the matches, they will be put to the space in the place where transverse shelves shall be placed. This method is called بِEfrizپand is done as follows: a layer of brick is affixed to the centering ribs, and then the sides will also be affixed (like shiner arch). In the next step, the surface will be soldier with a certain thickness, like Soldier arch. By so doing, transverse shelf will be made. (Pirnia, 1994)

2-2-5: Bricking of the arches

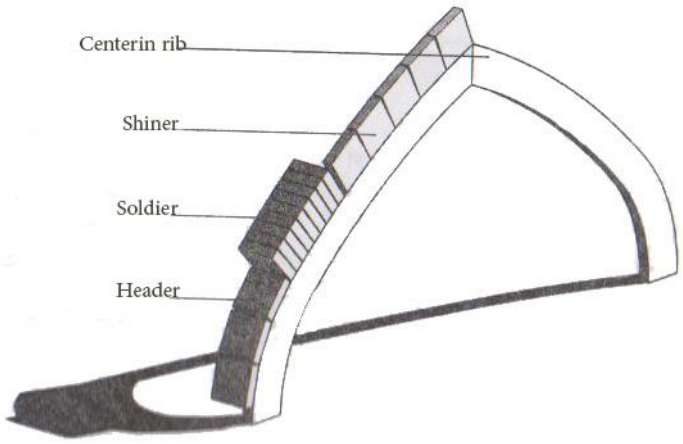

Figure 29: Bricking of arch

A) Shiner arrangement

It is a common method of executing arches in Iran. First, a centering rib is put on the wall or abutment. Then the first layer of the bricked arch is put on it. Each layer starts from Impost and ends in the shelves. Then, the second layer is put parallel to it and it will be continued till the considered spot.

Shiner bricking in the building is identified based on the size of the brick. For example, if a 20*20*5 centimeter brick is used, a 5*20 centimeters size will be vertically seen on the horizon line.

Shiner or Pari method of execution has an ancient background. One of the oldest samples is seen in Khoozestan and Haft-Tappeh (Iran). In a tomb, named Tabbati Ahar, about 1270 A.D. a barrel has been executed, using shiner method. This date for Iran, using shiner method will be 3270.

In Islamic era, this execution method has been used in beginning of Islam buildings such as Fahrej Jame Mosque, Damghan Obscura and Naein Jame Mosque. Then on, samples of arch, using shiner method, are seen in various buildings such as Isfahan Jame Mosque.

The shiner method is a fast one. But as brick rows are put on each other in parallel layers and each layer can be unified with the neighboring layer ad are not tressed well, the solidity of the arch will be decreased.

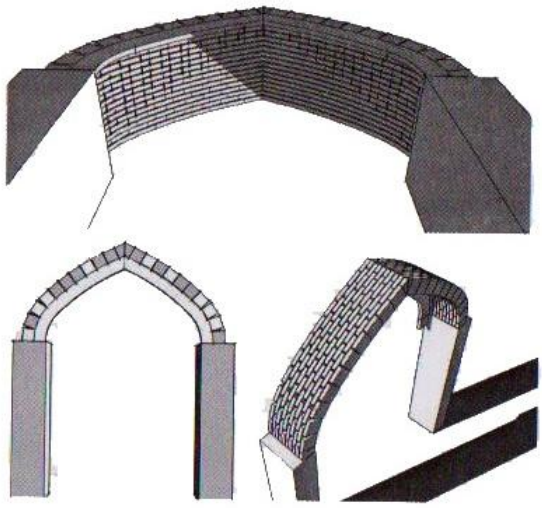

Figure 30: Shiner bricking from different views

B) Soldier arrangement (Ilamid or Soldier)

Execution of this kind of arch is done through two parallel centering ribs. One of the centering ribs is inserted at the beginning and the other one is inserted to a depth equal to that of concave. Here, the brick layers are horizontally put and are continued towards the shelves of the arch. For example, if a 20*25*5 centimeters brick is used, in the front sight a 20*5 centimeters brick will be seen.

There is an important difficulty in executing (Soldier) soldier arch. While putting the brick rows in Springer angle (5.22 degree) the bricks cannot lean on anything and fall. In order to keep the shoulder of the arch firm, wooden stanchions are used. The deceased, prof. Senmar, one of the Isfahan-based architects describes an interesting method. In such a way that in order to insert the wooden stanchion, the semi-span will be divided to three parts; the place where it intersects the arch, will be the leaning point for the wooden stanchion. Arches will be more durable if using soldier (Soldier) method; because in this method the bricks are tressed. One of the oldest samples of executing soldier method can be seen in Choghazanbil temple from around 1250 B.C. this building has been built 1200 years before building the first vault structures by Soldiers. At that time there was not the Soldier civilization and about 1100 years later, the Soldiers establish a new civilization in the west. Therefore, it is not correct to name this method as Soldier, in etymological point-of-view. Then after, this method has been used in various buildings. There are some stony arches in Firooz-Abad fire temple and Sarvestan Palace in with this method has been used. After the emergence of Islam also some samples of this method can be seen in buildings such as: Shah Esmail Sasani graveyard in Bukhara, Qaboos Dome, Golpayegan Jame mosque and Qazvin Jame Mosque.

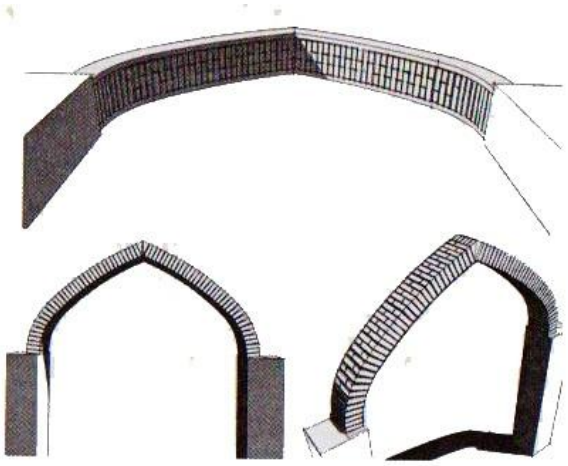

Figure 31: Soldier bricking from different views

C) Header arrangement (Blade)

This method is mostly used while executing vaults and not that much used for arches. If the basis of the work will be a 20*20*5 centimeters brick, some bricks will be seen in the side view of the arch, of which the 5 centimeters side in the first row will be placed on the Impost and the 20 centimeters side moves along with the arch curve. Pirnia has also chosen بِ Bladeپorبِ header names for this method. Transition tier bricking is not that firm and is normally built in different layers.

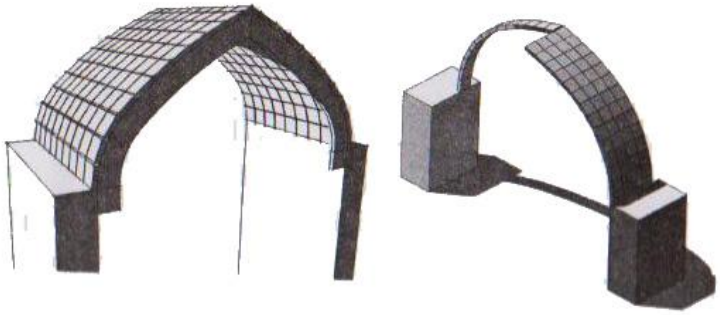

Figure 32: Header bricking

D) Header-soldier arrangement

Header-soldier method is a difficult one for execution of arches. In such arches, the bricks in the inner view have been placed in header-soldier or shiner mode. That is what is seen in the view and it might be possible that the transverse part of the arch is of the other kinds. Sample of this method is seen in estrade Hakim of Isfahan Jame Mosque.

E) Mixed arrangement (soldier-shiner)

پAt times, in order to increase the firmness and transverse ability of the arch, a mixture of shiner and soldier (Ilamid) methods are used to execute transverse shelves, which are of different kinds. One method which is mainly used in building the shelves is to execute the core of the shelf, using shiner method; then the surrounding will be filled by soldier; by so doing, the shelf will be really firm and resistant against the imposed stressesپ(Pirnia, 1994, p. 58)

2-2-6: Stagnation of the arch

Here, we will discuss the method of transference of the forces, in a simple language.

Structure behavior of each arch is related to the specification of its components. To be more accurate, the following point can be referred to:

1. Arch curve
2. Arch thickness
3. Imposed loads on the arch
4. Row kinds of the arch
5. Arch basis

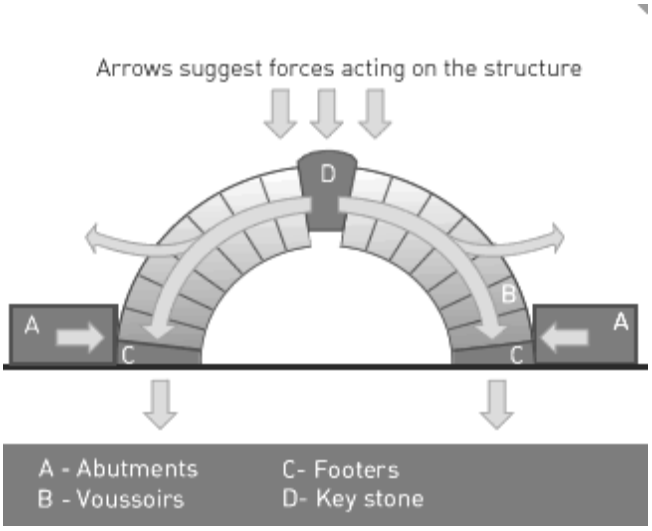

Figure 33: Arch Diagram

As it was mentioned, arches are divided to two kinds: transverse and formation. The less the jumping of the arch, the more the strains on its basis. Edged and sharp arches which have more jumping are classified into the arches with less run power. It has been proved that oval curve is one of the most suitable arches for transferring run power to the basis. The closer this curve to the semi-circle or parts of the circle, the more the imposed strain of the basis.

The imposed loads on the arch are considered while estimating the transferred forces to the basis. Here is the hierarchy of load transference: the weight of what is behind the arch is imposed on brick rows. Each brick row has a certain weight and sum of brick rows is transferred to the basis.

Basis of the arch tolerates weight of the arch and the loads on it. Ancient architects have both thought of the execution of arch and size of the basis. All the forces, whether vertical or horizontal, are transferred to the basis. Any problems in estimations will raise some problems regarding the stagnation of the arch.

To put it simply, force transference in an arch can be shown in a stony row (or brick row). As it can be seen in the figure, a brick row has a certain weight. This weight has been shown in its gravity center in B point with P1 vector. P1 force has been analyzed to two components of R1 and s1. (Catelli, 1979, p.62)

Sum of the R2, R1 and ه f orces which are transferred to the bottom of the arch make a polygon which is namely termed Strain Force. Its location has a significant role in the equilibrium of the arch. Is the thickness of the arch is divided to three parts or the view of the arch from concave to convex is divided to three parts, the strain curve must be put inside the central one-third. In this mode, different parts of the arch will be affected by the strain. If the strain curve goes out of this distance, torque will be made in the arch and the equilibrium will be lost.

In estimation of the strain curve, one other significant note shall be heeded. Strain curve is estimated in 30 degree angle in proportion to Impost to the shelf of the arch. This angle is the breaking point of the arch in the lowest point in proportion to Impost. Hence, beginning from Impost up to this angle is taken as parts of the basis.

2-2-6-1: Run Repulse

The curve formation of an arch has a great role in transferring forces to the leaning point. Slow arches impose more run force to the basis. More run force means horizontal strain on the basis and making torque which will lead to the ruin of the arch. Based on experiment, Iranian architects executed the basis thickness in its most accurate size. The main aim of the builders was guiding the middle 1/3 force of the basis thickness of the arch. If this force is not imposed in this part, the basis will not have equilibrium. There were various solutions for this problem which will be introduced:

A) Increase the basis thickness of the arch

One of the solutions was thickening the basis of the abutment and wall (to where the force is placed in the middle 1/3 environment). At points where the architects felt that the run force may damage the structure, they have increased the basis thickness. It is mostly seen in the spans beside the walls, behind of which is empty. In buildings such as Niasar fire temple, as the reason of cautious, the size of the span of the arch and the basis beside it is equal.

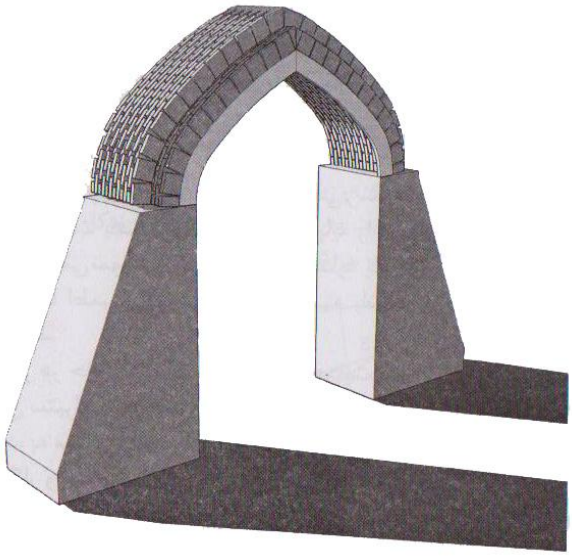

Figure 34: Buttress; An important member of run repulse

B) Minaret beside the arch of the verandah

One of the other solutions which had apparently affected the equilibrium of large verandahs was the minarets beside the verandahs. In the architecture of Teimoori and Safavid era, mosques and schools were equipped with some large verandahs in some of which two minarets were placed in the two sides of the verandah which both added formation to the building and also repulsed the run of the arches of large verandahs. Minarets of Ghebleh verandah in Goharshad mosque of Mashhad or Isfahan Jame Mosque are samples of using this method.

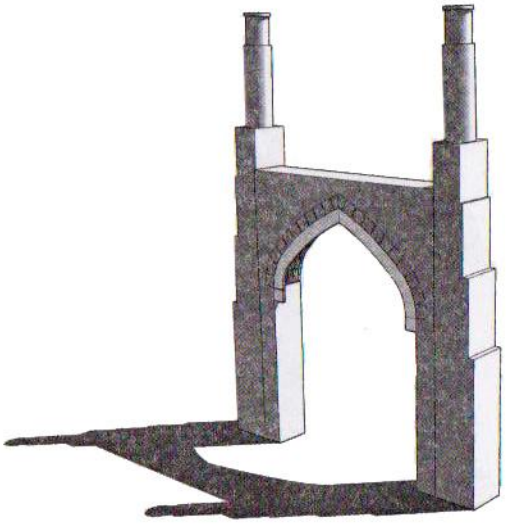

Figure 35: Minaret beside the great veranada as run repulse

C) Tensional elements

The solution applied to Impost of the arches or a little above them was putting a tensional element. Wooden or metal halter application to solve run power is seen in both the world and Iran architecture. As seen, the transferred forces to the basis are analyzed in two horizontal and vertical components. The strain of horizontal component or run force can be decreased, using a tensional element. It will be done with the stipulation that the wooden shaft is stuck inside the Impost of the arch. If it is just inside the wall, it cannot absorb the run force. This method has been used in Iranian architecture from Qajarian era onward. It affects the space and decreases the beauty. In this section, it was clarified that Iranian architects proposed their own special methods for building arches, a method which was different from the other countries at that time. Breakages of the arch curve, both in labyrinth and shelve method, were Iranian-based. In the Iranian method, not using so much wooden frames had a significant role on centering ribs and bricking of the arches. That was why centering ribs were utilized as a guiding element and at times a leaning point for brick rows. (Hami, Ahmad, 1372)

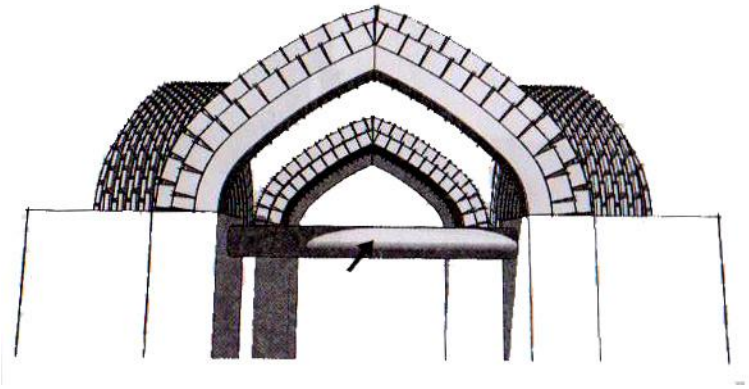

Figure 36: Wooden beam function as run repulse arch

2-3: Vault

The Iranian world of vaults is full of beauty, variety and wonder. One cannot easily find architects from other countries with such ennoble culture which could bring about such beauteous marquees.

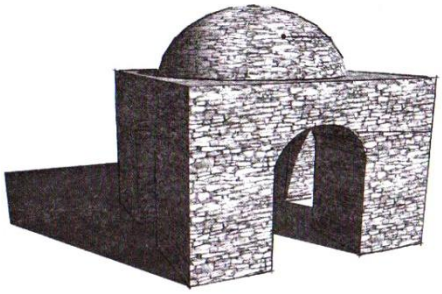

Figure 37: Four vault

2-3-1: Kinds of vault

Vault is a structure organ which is put on each space or component of space in need of coverage. Here, component of space means part of a larger space, such as four-pillars which make a square-shaped map and the imposition of these square-shaped formations make a complete space such as seraglio. Developmental history of vaults in Iran is divided to two parts: before and after Islam.

Vaulting broadens in Iran before Islam and in Partsب ۀa. As it was mentioned in the previous section, in the first millennium B.C in Choghazanbil there were some vaults and after that, there are some documents referring to vaulting in Nooshijan and Persepolis; Of course, in Achaemenid era, using large shafted buildings was more common. In addition to different kinds of arch, Parts and Sasanid applied vault and dome in space coverage and invented some executive and structure organ methods.

In Islam era, vaults and domes developed to a great extent and were regarded as parts of the Iranian architecture culture. In the first four Islamic centuries, many varieties were added and some vaults such as Vaulting, Patkaneh and Karbandi were introduced to the world of architecture. To take a sample, we shall take a glance at the Isfahan Jame Mosque. About 470 of the vaults have been built, using ten different kinds of vault, each of which has different design, decoration and fiber.

The Iranian vaults include the following:

- Barrel vault

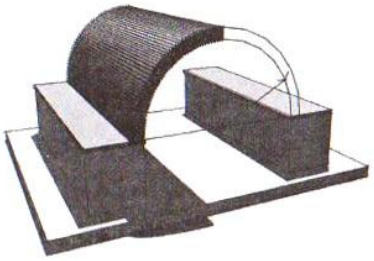

Figure 38: Barrel vault

- Coved vault

Figure 39: Coved vault

- Four-part (Groin)

Figure 40: Groin vault

- Domical Type (1)

Figure 41: Domical type 1

- Domical Type (2)

Figure 42: Domical type 2

- Welsh

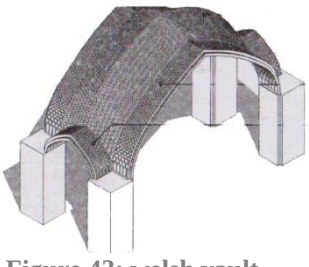

Figure 43: welsh vault

- Khancheh-poosh

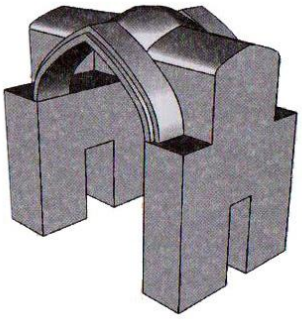

Figure 44: Khancheh-poosh vault

- Ribbed

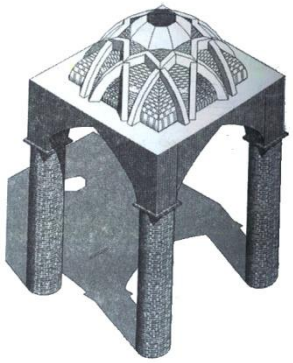

Figure 45: Ribbed vault

- Patkaneh

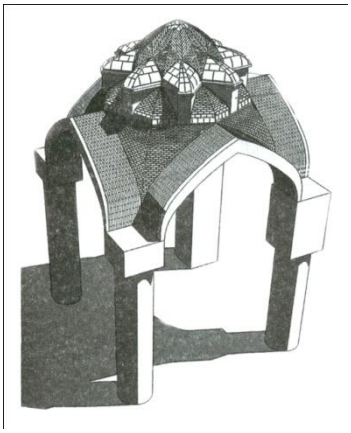

Figure 46: Patkaneh vault

- Karbandi

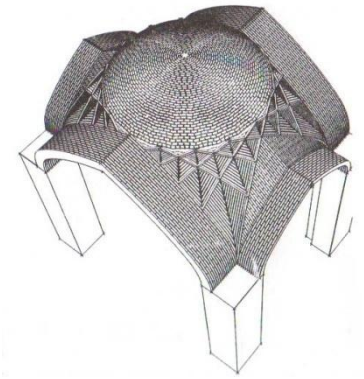

Figure 47:Karbandi vault

These vaults can be classified to simple and complicated vaults, in formation point-of-view. The first six vaults are included in the first classification and the last four ones are of the complicated type. Khancheh-poosh vault is a combinatory vault which is composed of two barrels and another vault in the middle and the last three vaults have their own complicacies, as they are built by the movement of a rib in the space and make a geometrical polygon shape in the space. (GholamhussseinMemarian, Iranian Architecture Niaresh, summer 1391)

2-3-2: Obvious and conceald of the vaults

As regards the vaults, although the thickness of the vault is hidden behind it, Iranian architects normally tried to hide unseemly structures behind coverage elements in some vault types, such as Karbandi and Patkaneh. Godard, by describing chapire sazi in Islamic era domes, gives the reasons for hiding structure elements, as so: بRibs from outward are normally hidden below the decoration of the walls. Inside the building is also like that. The accurate thickness of these arches is not that overt. At times, it happens that ribs or even the dome, itself, is hidden under stalactite works, such as in Sheikh Saffi graveyard in Natanz. Because it can be stated that Iranians have always been divaricated from gibberish works in literature and architecture. What the architect and in fact, Iranian artist follows is the elegance of thought and sense, accompanied by simplicity.پ(Godard, 1369, p. 95) To this aim, Iranian architect uses hidden structure. Hidden structure is the transverse part of the coverage which holds what is seen in overt.

Iranian vaults are executed using simple methods. Even Karbandi which has a complicated formation is made by centering ribs. As it was mentioned, there are no traces of using wooden frames which were used by western architects to build arches, in Iranian architecture. Iranian architects used local elements such as bat, brick and at times stone in central parts and the combination of chalk and soil had a great role in fast execution of their work. (GholamhusseinMemarian, Iranian Architecture Niaresh, volume one, summer 1391)

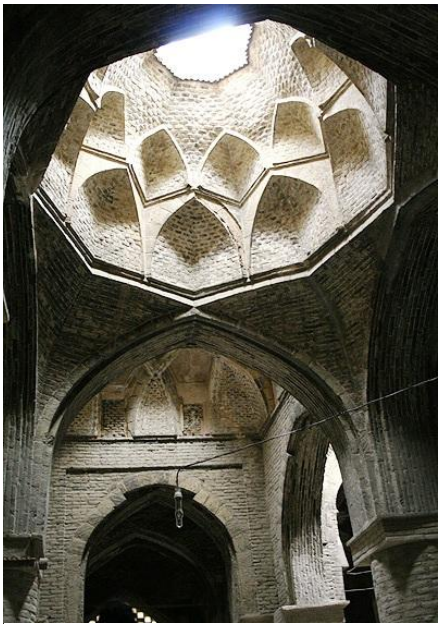

Figure 48: Patkaneh vault, Jameh mosque, Isfahan

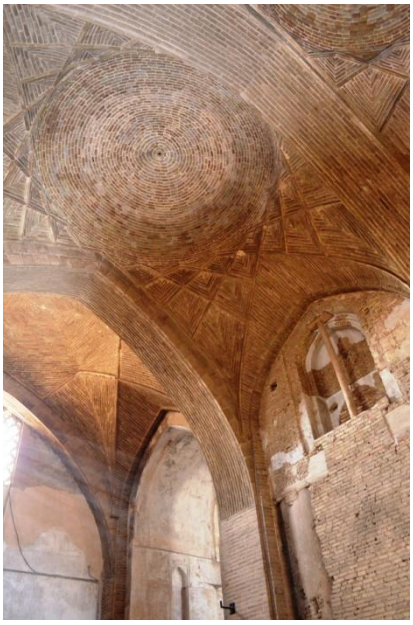

Figure 49: Karbandi vault, Jame mosque, Isfahan

2-4: Domes

Dome, vault and arch have an old background in Iran. Ancient architects have made wonderful samples in the bottom graveyard of Choghazanbil (the elements of which was used for Choghazanbil building) and graveyards surrounding Dorantash City and Sistan ruins and Komish Cemetery of Damghan (since second millennium till the beginning of Pars Kingdom). Such executions continued till the time when local architecture was common. Dome is one of the most wonderful occurrences of architecture and there are various reasons to trace it back to Iranian innovation. As it was difficult to cover large spans with wooden shafts and because of the problems which are made due to the existence of various pillars in the halls, the significance of dome coverage can be understood, well. Dome can cover a large span wholly and from one wall to the other. (Mohammad KarimPirnia, Gifts of Iran to the World of Architecture, Journal of Art and People, 1973)

Figure 50: Baze-hoor fire temple, Khurasan, first sample of dome on square plan

2-4-1: Geometrical description of dome

In geometry, a dome (shell) is a geometrical location which is made from a certain arch rotation on an orthogonal axe. Hence, all kinds of curve can be used to build dome, in formation point-of-view. And under this frame we can have different kinds of plans, such as four-side, circle, pentagon, six-side and octagon. This rounded frame when put on each of these plans, needs a transference location, named Transition tier which conveys the bottom formation to a hemisphere.

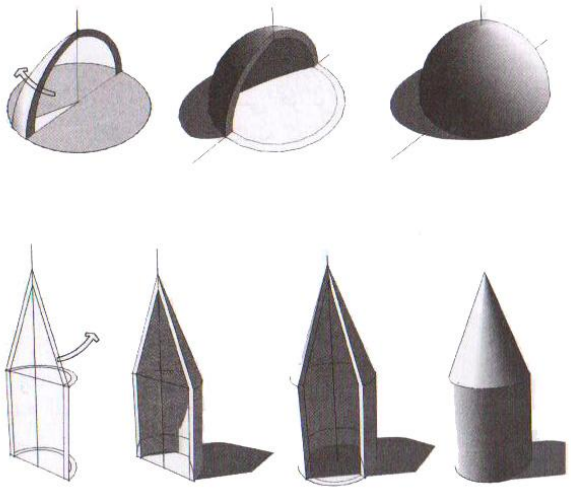

Figure 51: Formation of dome according to Ghias-aldin

In architecture language: dome is a coverage which is built on a rounded frame.

Dome is composed of three parts:

1. Cupola
2. Drum: the part which is inserted on the plan surface, in rubric mode, one or two sides of which are open (in pre-Islam domes, all the four sides were guided towards the open spans).
3. Transition tier: compounded

As round plan is scarcely seen in Iranian architecture and normally, the end part of the body is square and at times rectangular shaped, it will be made into circle by corbeling, then the dome will be inserted on it. That is why the compounding stage is important in vaulting, because the potentiality of having a rounded frame makes it possible to execute the final stage of the dome coverage. (Mohammad KarimPirnia, Vault and Dome, Journal of Art and Architecture, No. 10-11, 1350, pp.31-40)

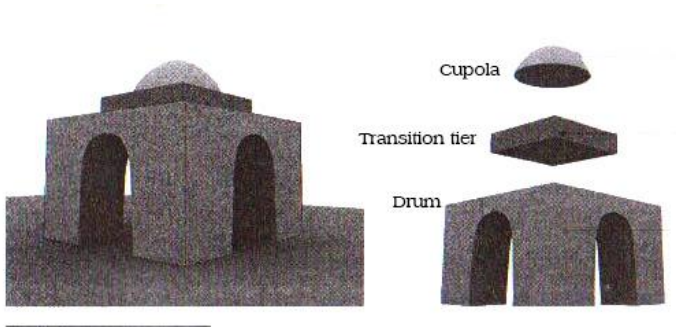

Figure 52: Dome component

2-4-2: Different kinds of dome

Each dome has two aspects: formation and building. Except for conical dome, the other ones are built by the movement of a curve in the space. May be the simplest method for the classification of the domes is based on the side view of the applied arch. But there arises a problem: in most domes, the formation of the outer and inner shells is not the same. In this mode, different kinds of inner and outer shells shall be identified.

Based on what has been discussed, building kinds of dome are as follows:

1. Shell domes
2. Continuous double-shell domes
3. Coved domes with rib
4. Conical domes
5. Onion domes
6. Three-shell domes

Figure 53: Shell dome

Figure 54: Continues double Shell dome

Figure 55: Coved dome with rib

Figure 56: Conical dome

Figure 57: Onion dome

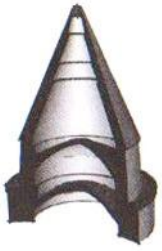

Figure 58: Three shell dome

One of the other significant points regarding building domes is false-domes. False-domes are formed by putting stones on each other, like pseudo-arches. Here, the transference of the forces is not completely done based on the strain curve. (GholamhusseinMemarian, Iranian Architecture Niaresh, second volume, summer 2012)

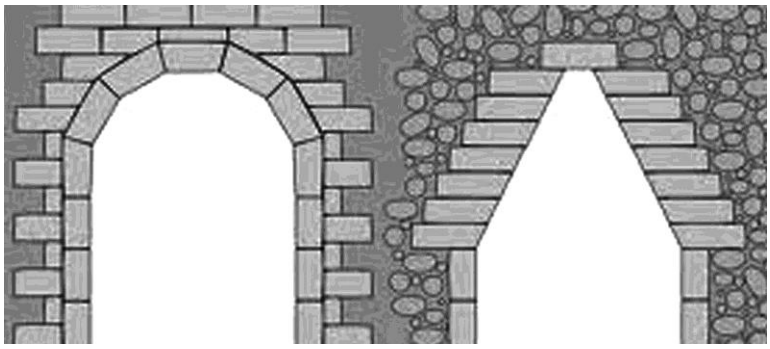

Figure 59: False arch

2-4-3: important factors in designing and executing domes

History of the building: It shows the timing space of the building. Referring to this point is of utmost importance to us; because it is history which specifies the proportion of Iranian architecture development to the other architectures at that time.

Span of the dome: It is an important factor in building dome. It means solving the special execution-stagnation problems of the dome.

Thickness of the dome: It is one of the other important variables in building dome. Accessing the proper minimum thickness was one of the best achievements of architects in the world.

Rise: Height of the curve from the center to the shelves is one of the other important examined specifications in Iranian domes. Proper height had significant role in the equilibrium of the dome.

Curve or hunch of the dome: In Iranian architecture, side view of the certain arches have been applied to build domes. These side views not only address formation and geometrical style, but also help the equilibrium and stagnation of the dome. (GholamhusseinMemarian, Iranian Architecture Niaresh, second volume, summer 2012)

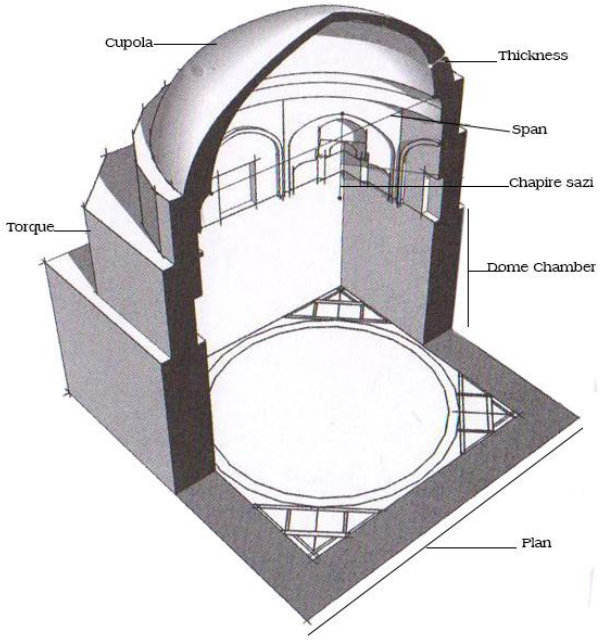

Figure 60: Logography of dome

2-5: ChapireSazi[1]

Chapire sazi means building and conveying the four-side frame of the organ to eight-sides and then, respectively to 16, 32 and 64 corners and finally circle and conveying a square-like rectangular shape to 6 and 12 corners and finally oval shape. In this mode, the proportion of the side sizes of the body rectangular shall be in such a way as to be simply conveyable to six-sides. For example, the proportion of 4 and 4.3 is dividable and can be made by covering the corners. (Mohammad KarimPirnia, Vault and Dome, Journal of Art and Architecture, No. 10-11, 1871, pp. 31-40)

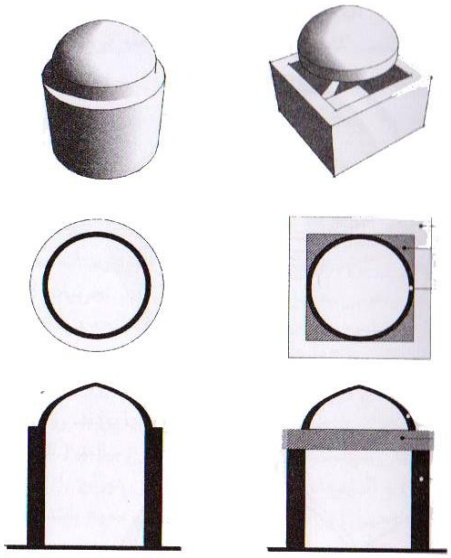

Figure 61: Cupola on clynderal drum comparison to cupola on cubic drum with chapre sazi

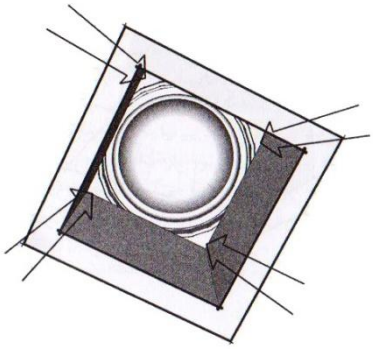

Figure 62: Location of chapire sazi in dome chamber

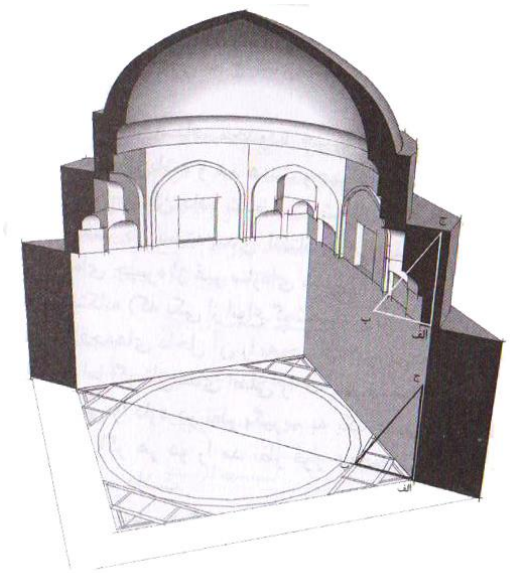

Figure 63: Chapire sazi zone

2-5-1: Different kinds of chapire Sazi

In order to form a Transition tier, the two aspects of structure and formation, shall be simultaneously heeded. The structure aspect is related to tolerating the corner weight of the dome load. Very heavy domes need a leaning point. Four leaning points are put on the four sides of the dome body and the four sides will be covered by four vaults; But still the problem has not been solved at the formation problem is remaining. When the transverse vault is executed in the corner, there remains a hole, in the distance from the shelves of the arch to the corner of the body. Different methods of filling this hole are one of the other responsibilities of the architect. Therefore, when each kind of Transition tier is spoken about, both structure and formation aspects shall be heeded. By so doing, a structure-formation border can be drawn between pre and post Islam transition tiers:

A) Structure-formation (no corner vaulting)
   This group is also composed of different kinds of Transition tier:
   - Filpoosh (Firooz abad fire temple)
   - Se-konj (sarvestan palace)
   - Patkin (Baze-hoor Fire temple)

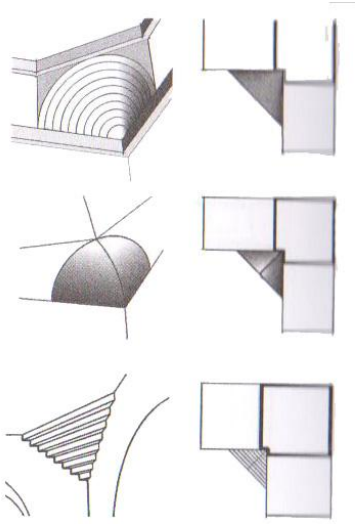

Figure 64: Structure-formation chapire sazi, without vaulting

In this group, it is difficult to recognize the border between formation and structure ones. As in this kind of corbeling, vaulting is not used, the main arch of Filpoosh and Chapire sazi corbeling is unified with the walls beside it and just the concave line can be seen. It is just in wooden Patkincorbeling that the big shaft of the corner has a certain border with the wall.

In pre-Islam architecture three kinds of Transition tier can be seen: wooden Patkin, Filpoosh and Squinch. Wooden Patkins are placed on each other so as to reach the frame below the dome. One example can be Baze-hoor fire temple. Filpoosh of Firoozabad fire temple diagonally goes up the corners till it is conveyed to a complete arch below the dome. Bezanval who thinks of the first application of Squinch in ancient east as that of Sarvestan Palace, believes that Chapire sazi corner in this building is the mother of corbeling in Islamic buildings. (Bezanval, 79, p. 233)

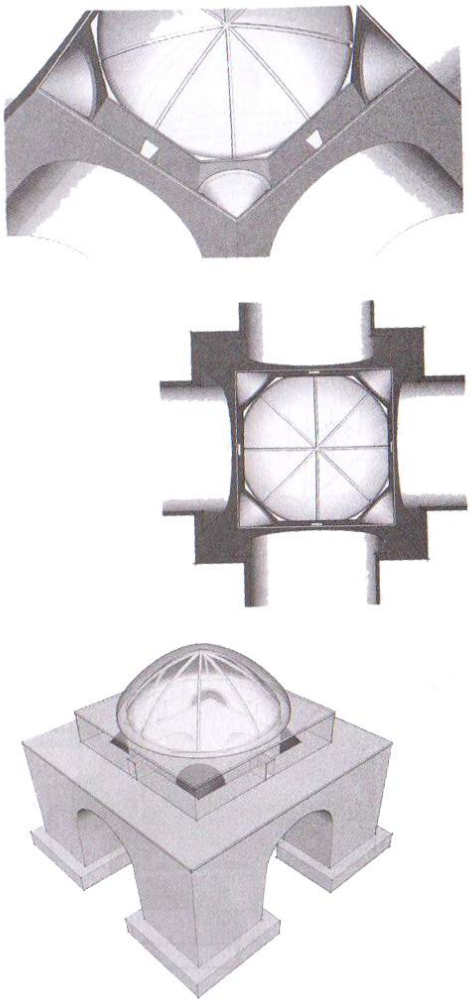

Figure 65:Filpoosh chapire sazi in Niasar fire temple

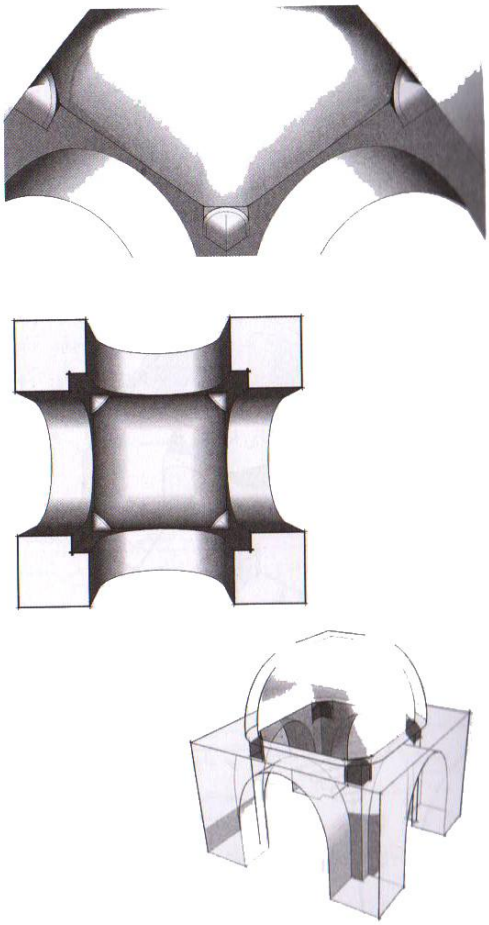

Figure 66:Se-konj chapire sazi in Kooshir fire temple

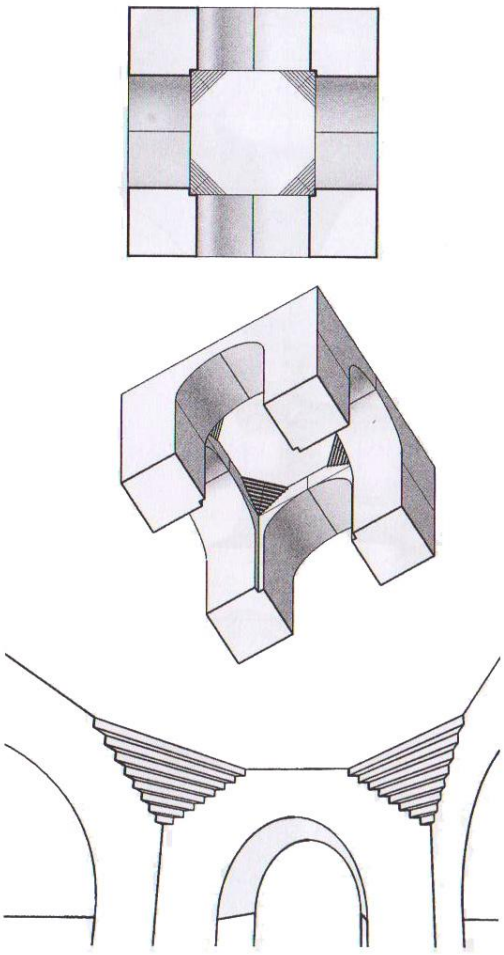

Figure 67: Patkin chapire sazi in Baze-hoor fire temple

B) Structure-formation Transition tier with corner vaulting

In thismethod which was common in Islamic era, four vaulting are completely placed in the corners which act as structure organs. What remains inside the hole below the vaulting is a formation organ. What is important is the fact that four kinds of chapire sazi in group A can also be placed in this hole, on formation point-of-view. Therefore, different kinds of Transition tier of group B can be taken as the mixture of vaulting with the following formation organs:

- Vaulting- Filpoosh
- Vaulting- Squinch
- Vaulting- Patkin
- Vaulting- Rip
- Vaulting- Patkaneh

- Foming- Stalactite

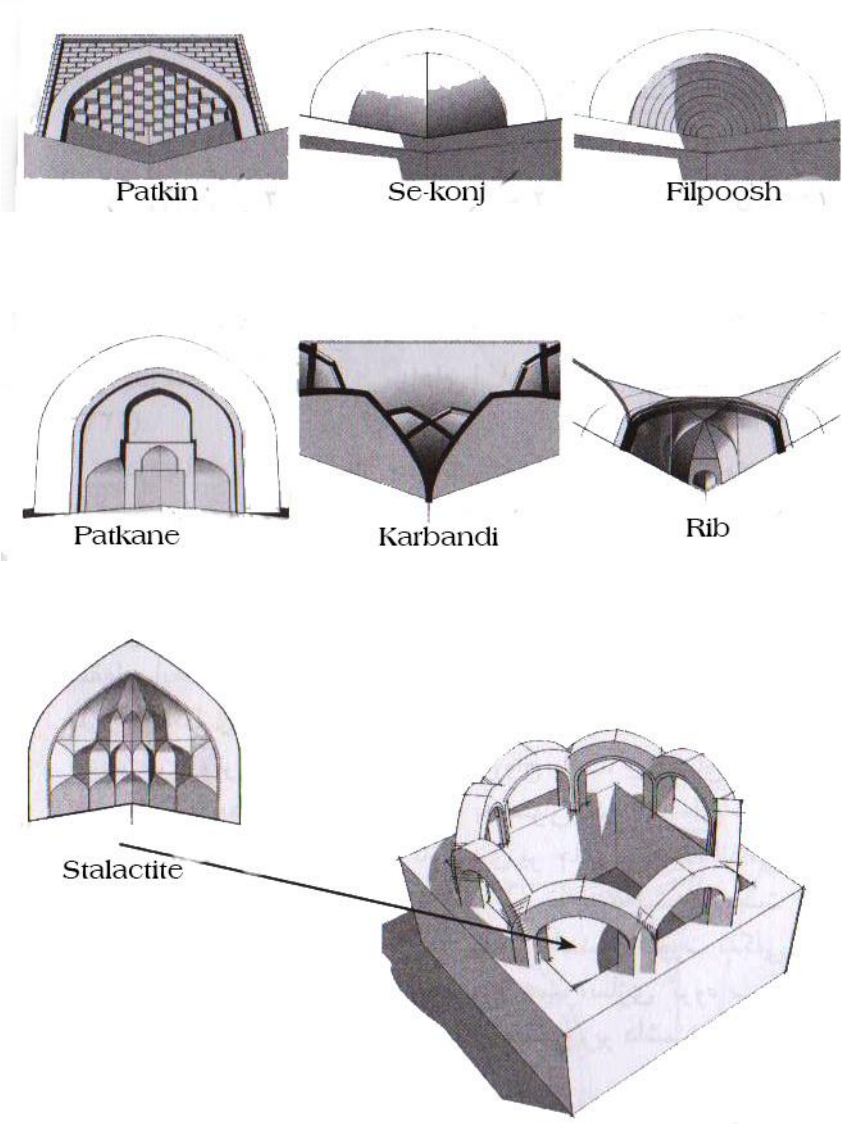

Figure 68: Chapire sazi with vaulting

In Iranian Islamic architecture, Transition tier is regarded as parts of architecture art. Dome is the symbol of the sky and its imposition on 8 sides can be indicative of the concept of Empyrean on the shoulders of 8 angels. May be such attitude motivated the architects to think and work on this important organ. Therefore, in the Islamic era, various combinations of Transition tier are observed. This variety in style is done through different factors. Arch vaulting type is the first one. Vaulting is made by different shelved arches. Shelved arch is longer that pre-Islam arches. Also, in some cases, the convex and concave of the arches has been shown. One of the other factors for the variety in Transition tier in post-Islam buildings is the formation inside the

vaulting hole. In post-Islam buildings, these holes are filled with different shapes. Some of which include Se-konj(Chapire sazi), Patkin, Patkaneh, rib and Karbandi.

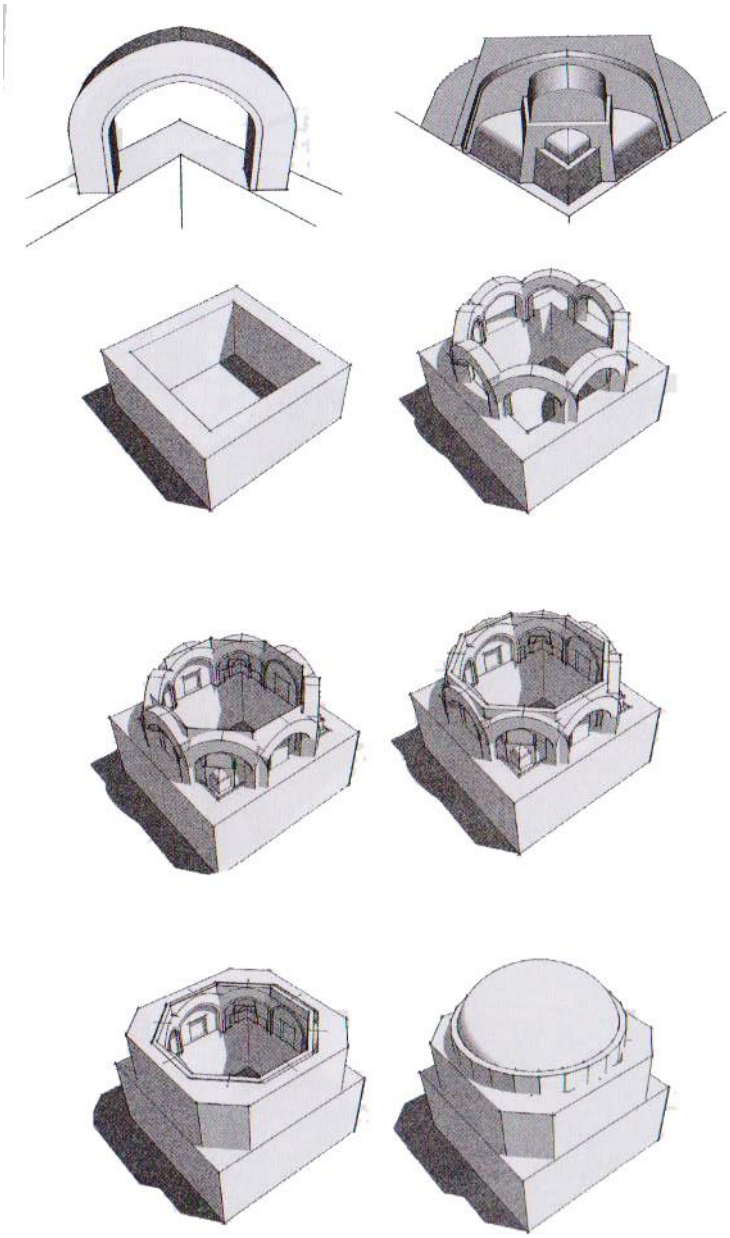

Figure 69: Stages of formation the chapire sazi with transverse arch

C) Structure-formation Transition tier with Karbandi

Karbandi is one of the significant and developed methods of vaulting in Iran and the whole world. By the conversion of foursquare to circle in Karbandi, new formations are brought about. As stated earlier, Karbandies are composed of some elements, named بKarپ In the arches, calotte is placed on the Kars. In this kind of Transition tier four vaults are put on the four sides of

the square plan of the tholos; but the other arches in the corners are deleted and Kars and other components such as Pabarik, Shaparak and Sanbooseh are replaced (GholamhusseinMemarian, Iranian Architecture Niaresh, second volume, summer 2012)

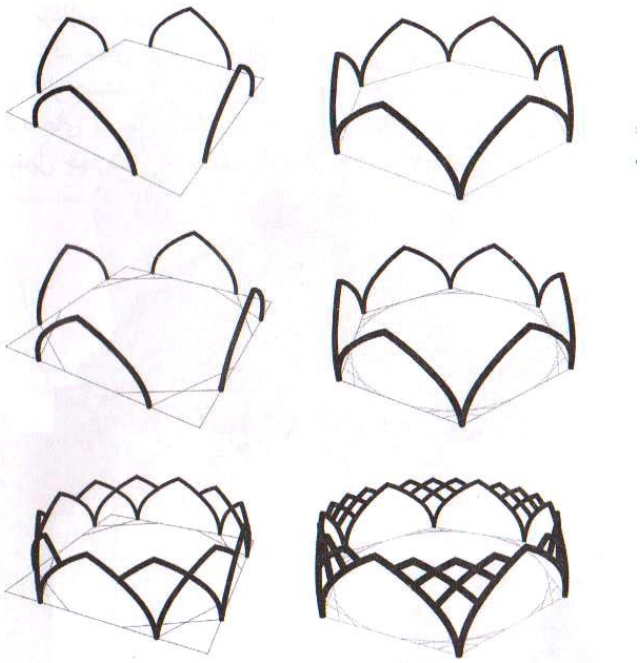

Figure 70: Comparison between two ways of Karbandi chapire sazi

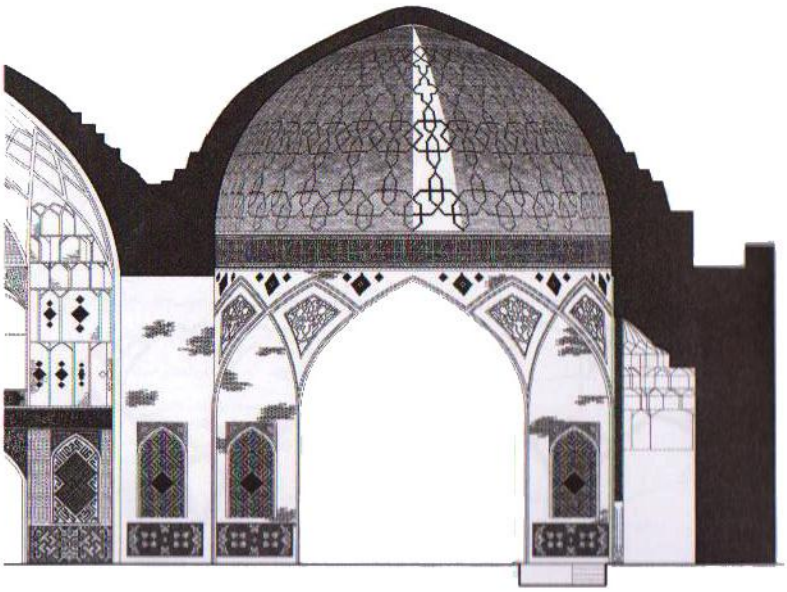

Figure 71: Karbandi chapire sazi, hakim mosque, Isfahan

2-6: Summary

In this section, the background for the formation of dome and vault overage in Iranian architecture has been introduced and discussed and later on, it has been attempted to carefully examine the components of vault and dome in formation and structure. Also, introducing and detecting arches and ribs in domes and vaults is one of the controversial issues I this section. By briefly looking into the most important Iranian vaults and domes, it has been attempted to give a more suitable understanding to the reader for the sections on examination of the formation system of ribs in curve coverage.

Keywords: Arch, Vault, Dome, Chapire Sazi, Centering rib

Chapireh(n): Transition tier, A series of architectural elements in Persian Architecture which act instead of pendentive

1-Chapireh Sazi(v): A series of chapires at corners of drum which transform square plan to octagonal plan before circular base of dome

Chapter Three: Theoretical framework

Rib: Concept, Geometry

3-1: Introduction

In different fashions and reflections on architecture, the coverage تhe upper part of the building which does also include the space underneath- plays a significant role in the quality of the space. As the looking orientation of the observer, whether inside or outside the space, is towards the skeleton peak of the building, the architect does always attemptto show his/her creativity in coverage, more than in anything else. But the issue becomes more significant when applied to Iranian architects. The Iranian architect uninterestedly passes the bottom and focuses his/her attention on the marquee. That is why various samples of coverage have broadened in Islamic architecture and were considered as a part of Iranian culture in such a way some arches such as Doming, Patkanehand Karbandi were introduced to the world of architecture. They are somehow complex and are made of the movement of a Rib I the space and form a polygon in the space.

On the other hand, the importance of the Rib in vault coverage becomes more obvious as Mr. Pirnia thinks of Ribbed domes as different from other domes and takes its structural behavior as a special one. He further states that slip of the arch breaks the flat surface of the domes of a shell and in his proposed typology, thinks of Ribdomes as having a special place which we will be referring to as the text continues.

Itبsobvious that no structure had the applicability and improvement of Rib which is a significant component in building and development of complex vaults and domes. In fact, recognition of vault and dome and their differentiation with similar samples and meticulous investigation of a special kind of them necessitates a definite description of the unifying components, understanding their significance in architecture and recognition and classification based on the kind of construction. In the current section the mentioned subjects will be manipulated and also attempts will be made to detect the statue of Rib in different kinds of vaults and domes.

3-2: Rib in vault coverage

3-2-1: Background

One can denominate the origins of Rib as Iran. One of the ancient samples in which the notion of the formation of Rib can be seen, is the four-vault of Niasarپ(around 224 Gregorian). In this small dome two special characteristics are seen; namely, webs of the domes and using slips of the guide domes among webs which had led to the regularity of bricklayer and formation of the dome.

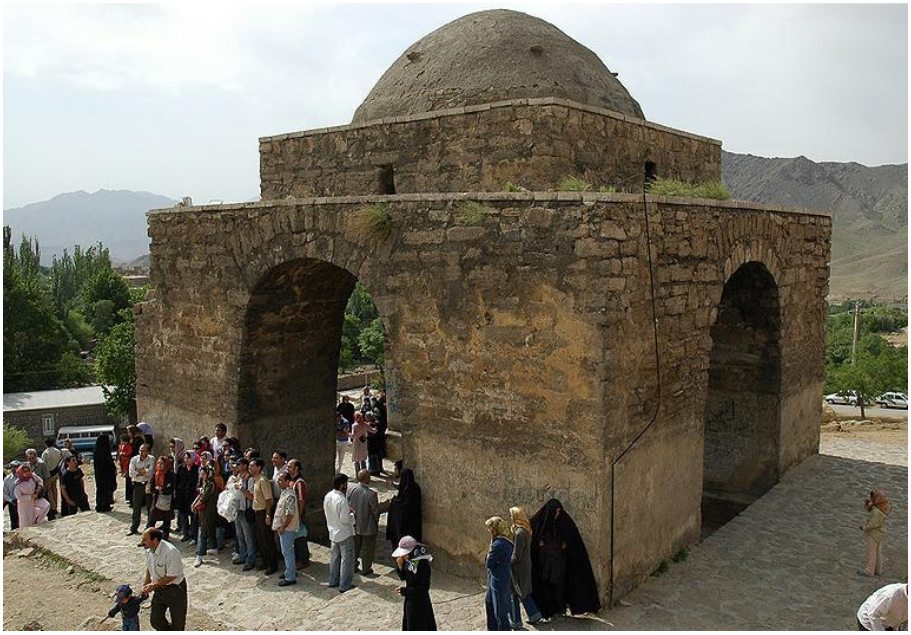

Figure 72: Niasar four-vault, Kashan, 50 BD

Figure 73: Niasar four-vault, beneath the vault

One of the oldest vault samples or Rib samples is a structure in Karkheh Verandah[1] which is a building belonging to the Sasanian era in the fourth century of which unfortunately not much has remained.

Pictures related to 1340s Solar Hijri shows that on part of the two slips of the parallel vaults, a barrel vault moves and that is what forms a Khanchehpooshvault. In this vault, the first Iranian structure vaultsare seen which are placed on the doorway.

According to Papa Dopolo بConverting structural material to decoration is a main principle in Islamic architecture which is seen everywhere (including in the vaults)پ (Papa Dopolo, 1368, 87) On the other hand, by referring to apseof TarghobeJame Mosque, Hilen Brand refers to بambiguity between structure and decorationپas one of the characteristics of Islamic architecture. (Hilen Brand, 1378: 2-26) Boorhat refers to the role of complete formation in slipped vaults as more important than porterage and states that (contrary to Goting) the Iranian kind or in other words, Islamic Tartagh, broadens from up to down so as to gradually reach بpolygon formationپ.

Also, in order to better display the place of Rib in doming we would examine the history and formation-structural effects of it in different kinds of Covedvaults, Rib, Patkanehand Karbandivaults which are brought about by the movement of a Rib in the space and make a geometrical polygon with its own complexities.

3-2-2: Coved vault

Webs in vaults are said to parts of a whole, by the unity of a certain quantities of which coverage can be obtained.

Webs of a Coved vault are obtained using other methods. In case two barrel vaults of 90 degree collide and pass each other, a Covedvault or four-part will be made from their junction. There are two principles behind their formation. The first one of which is a 4 to 8 polygon in which each of the webs form one of the sides. The second one is the circle principle which is somehow similar to Rib. (Memarian, Gholamhossein, 1370)

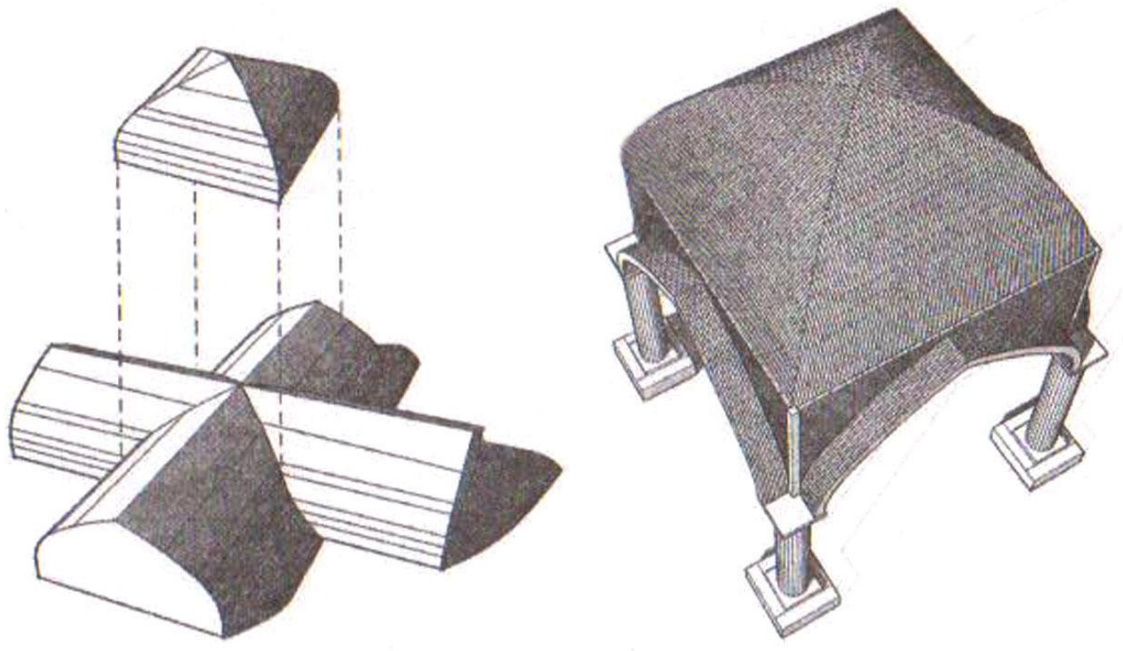

Figure 74: Execute coved vault

Covedvaults are mainly applied in seraglios of the mosques. Small rooms in village cottages are also sometimes covered with this kind of vault. Generally, it has less been used for the coverage of dominant spaces.

We don بthave any information regarding the oldest sample of Covedvault; but the oldest existing Coveddome in Iranian architecture is Dome 2 which is composed of 8 webs. The building was built in about 220 Gregorian and is regarded as one of the oldest Coveddomes of the world.Memarian believes one can find a relation between three corners, which are one of the important materials in converting a foursquare to dome, and Covedvault. Squinch, the oldest of which is found in Sasanian buildings, is obtained from the combination of two webs. These webs are made from the conjunction of an arch in the edge of main Squinch to the corner or top of a triangle. In case a hypothetic square is drawn in this corner and a hypothetic arch is connected from the edge of the arch to the top of the square, a four-webvault will be built. (Memarian, 1391)

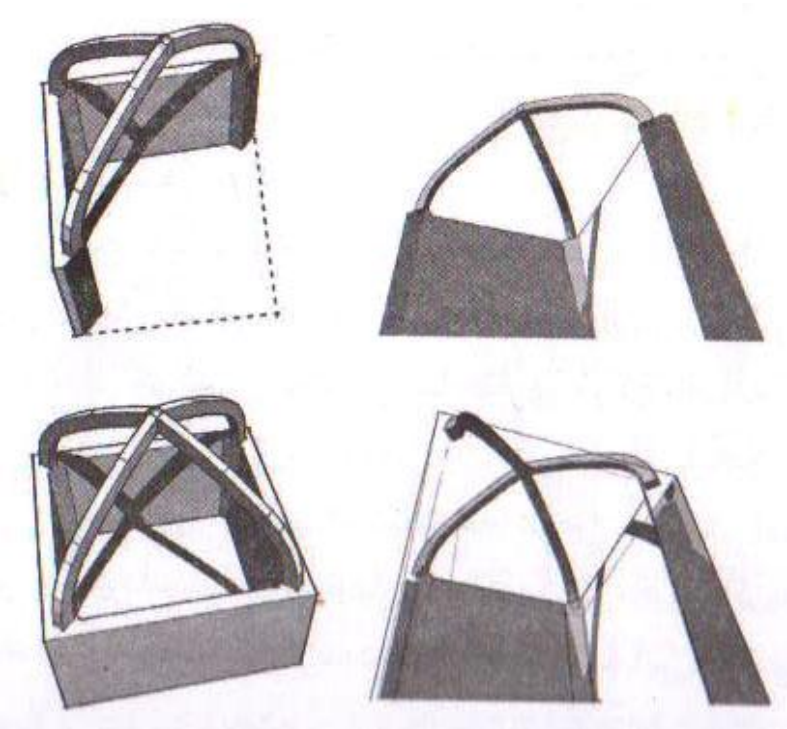

Figure 75: Execution se-konj gushe sazi for four web vault

3-2-2-1: Formation of Coved domes

There are several kinds of Covedvault in Iranian architecture. These vaults can be divided to two kinds: simple Covedvault and Covedvault with Rib۵ Simple Covedvaults are the

ones with a diagonal simple line between the two webs, just like diagonally folding a paper and after opening it, the folds will be seen from inside.
Simple Covedvaults are made on square and rectangular surfaces in three kinds: four-web, six-web and eight-web.

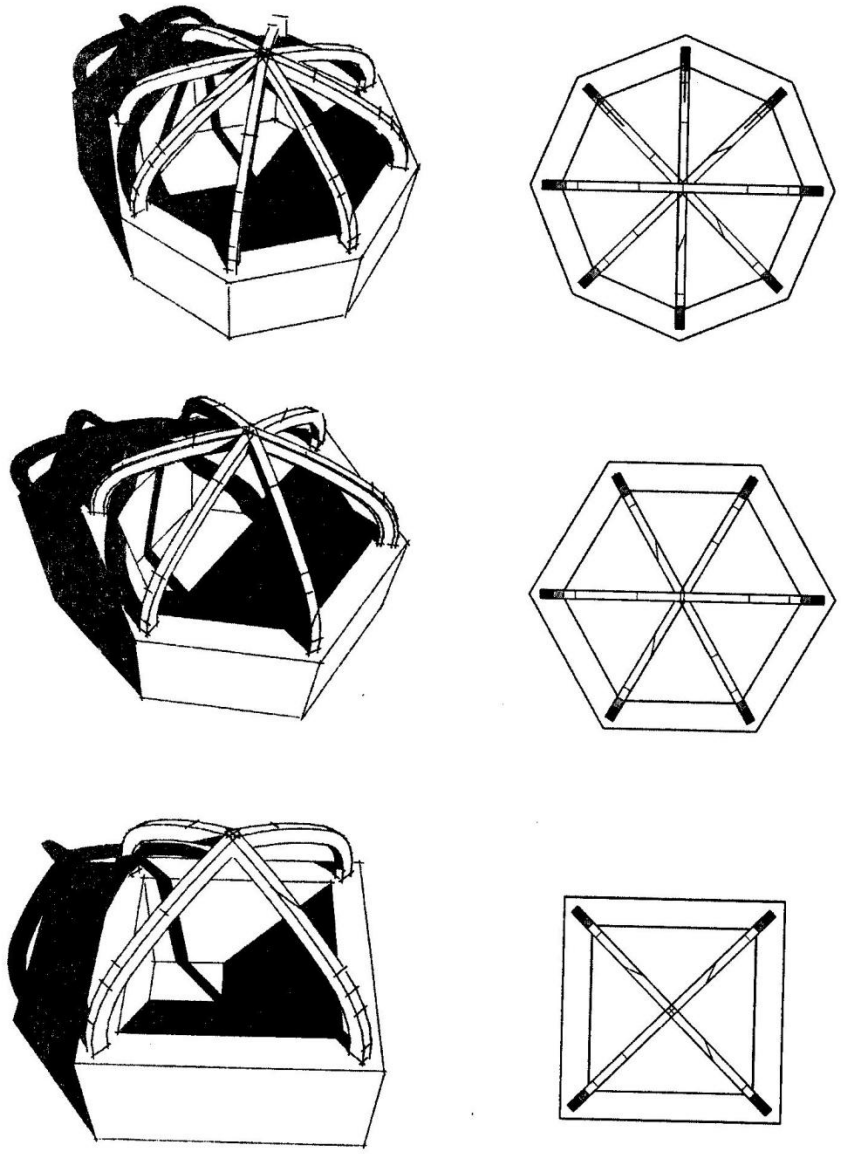

Figure 76: Different types of coved vault

Covedvault with bricked vault is another kind of Covedvault which is similar to the simple one in formation; having the difference that Ribs are added to formation and structure combination of the webs which makes some changes in doming method. Ribs are bricked ones with different bricked width. Ribs are both placed in vault diagonal and

perpendicular on two sides of the vault. Slips of additional vaults have been applied in different parts of Jame Mosque.

Maintaining Covedvault needs a guiding material, like any other kind of vault.

As mentioned by Pirnia and Andre Godard, centering Ribs which are taken as guides to arch curves, are placed in vault diagonals. These matches are placed so as to be removed after construction. In the other kind, centering Ribs can be lost inside Rib. (Godard, Andre, 1369).

3-2-3: Ribbed Vaults

Vaults with Rib are among the most important Iranian vaults which were formed in this country and later on was transported to north Africa, Spain and Europe. What is vault with Rib? As we know, vault is a structure organ for space coverage and simply saying, Rib is a transverse vault. When this arch is not placed on the doorway, but on a space and is combined with other arches and they wholly cover a space, a figure is realized which cannot be totally called a vault; because the surfaces between the arches. After filling in the places with bricked shells the vault is completed and it can be named a vault (Memarian, 1391)

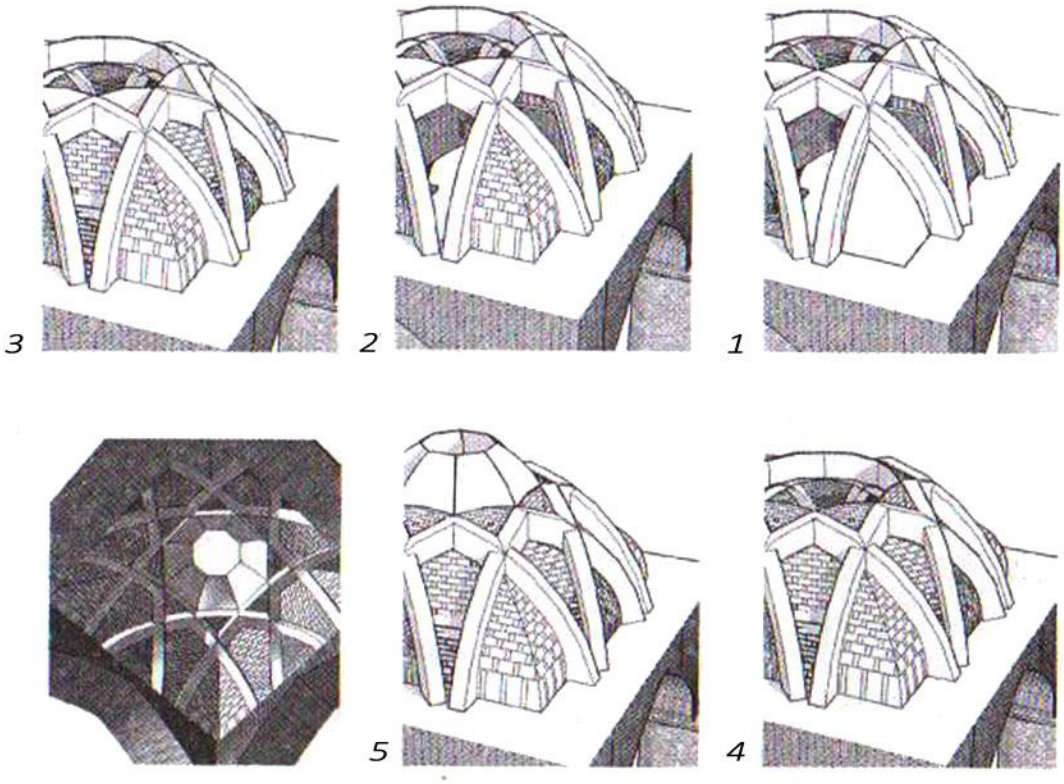

Figure 77: Execution of Ribbed vault

Rib has structure applications in other vaults such as Coved vault, vaulting(sekonj), Karbandi and Patkaneh.

3-2-3-1: Formation system of Ribbed vault

The geometry of a vault with Rib can be classified to different criteria:

1. Vaults in which Ribs are parallel, in pair and each pair vertically cross each other.
2. Vaults in which Ribs are parallel, in pair and each pair, in combination, vertically cross each other.
3. Vaults in which the slips are placed radially.

First type: Vaults, in which Ribs are parallel, in pair and length and width of the frame of the vault which are normally foursquare, are divided based on the quantities of Rib (normally two ones). For example, in the seraglio of southeast of Isfahan Jame Mosque, sides of the vault numbers: 25 and 27 have been divided to three parts and two slips of each side move parallel and cross each other. The space between Ribs and secondary Rib are filled. In the middle span a simple Karbandi has been applied.

Second type: In the other type, slips of the parallel and crossed vaults form a regular polygon. Crosses of these Ribs make formations which are similar to parts of Karbandi such as Shaparak, Sanbooseh, Pabarik and Soosani. In the vault number 60 in southeast of Isfahan Jame Mosque these parts are seen. (Pirnia, Karim 1373)

In the second type of vault crosses, the formation is seen two by two. In the first figure, thecross-line is seen in all of them and parallel and bent Rib is observable in all of them. In the other figure, some parts of the Ribs are hidden and the observer will lose it by following the vault from bottom to up. The stolen part is called بvault thiefپ

Such losing is not indicative of any deficiencies of the vault, but the architect places it behind a layer of brick, in other words, the structure is complete but because of the formation or may be the aesthetics, most of the work has been hidden behind.

Type three: Rib is placed on a polygon or circle frame and they reach each other in the center of the arch (Pirnia, Karim, 1373)

3-2-3-2: Static ability

When Rib is made, an arch will be framed. Arch transfers forces to two base points. Therefore, Ribs (or transverse vaults) transfer their forces to different spots on the base surface of the vault or Rib. In this system, force transferred to bases is spot-based not on surface level. Also, the shells between Ribs put their weight on Rib and this weight will be added to transfer force of the slip of the arch and will be transferred to Impost of slip of the arch.

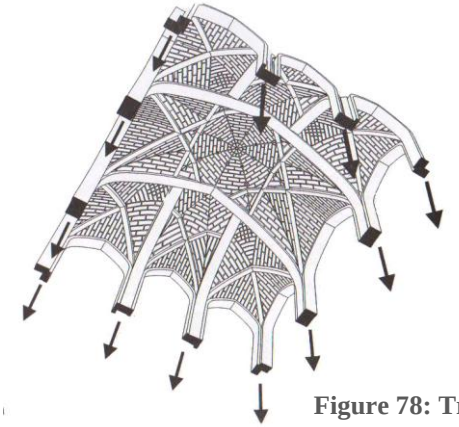

Figure 78: Transferring forces

3-2-3-3: Spatial ability

To simply descRibe space, one can say space is composed of vertical shells which confine parts of the natural environment. At the upper surfaces, the space is confined with the marquee. Unity and proportionality between vertical shells and the marquee are one of the important notes which the architect shall take into account. Unified and symmetrical vault coverage requires special vertical surfaces. The bottom space of a unified vault follows its unification. When formation variety takes place in the vault, it can be generalized to the vertical or even horizontal surface of the floor. Then on, Rib lines of the space shell can be framed and remove the unification of matched partitions.
One of the other significant points is the ability of light transfer. In a dope with Rib, some lights can be made between the two Ribs. Quantity of the lights depends on the quantity of Rib and the more their quantity, the more the quantity of the lights. In Isfahan Jame Mosque there are 12 lights in a vault with Rib (Kashani, Ghiasaddin, 1375)

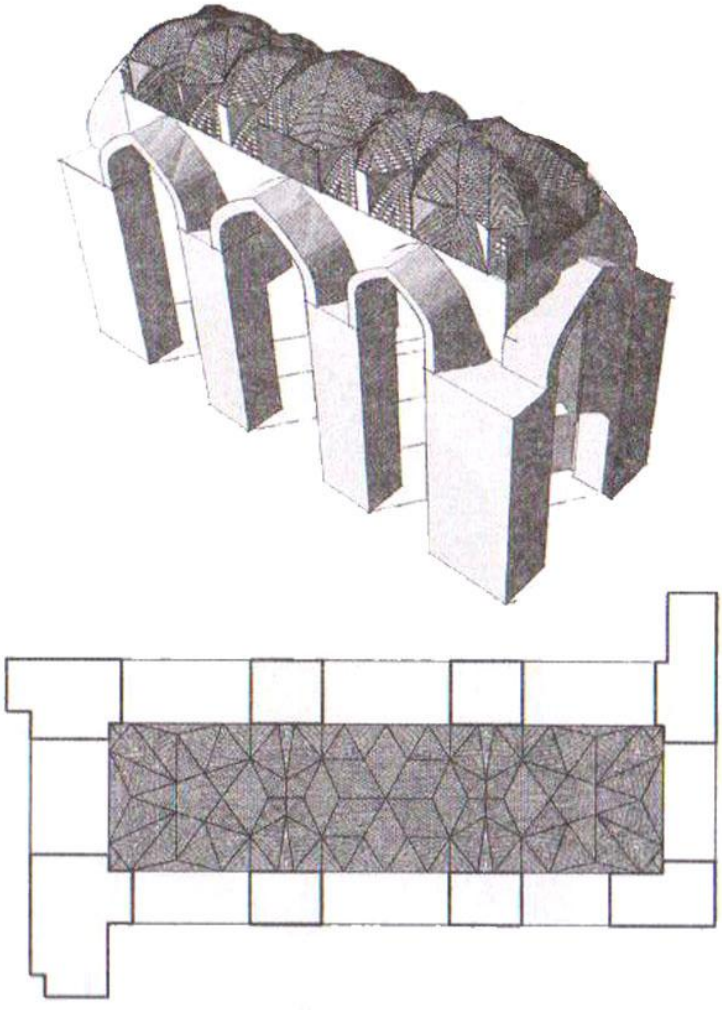

Figure 79: Patkaneh vault in Jame mosque, Isfahan

3-2-3-4: Formation ability

Rib is displayed as a curved line in the space. In a vaultwith Rib, some parts of its thickness are seen in the view. The combinations of Rib, like Karbandi, allow various polygon formations to be designed in the coverage shell. May be having this ability can be taken as one of the reasons for the common use of vault with Rib and Karbandi and Header-soldier. This ability makes it possible for the architect to think of the marquee of the building as his/her imaginative sky. In this sky at times the movement towards a spot which is indicative of the uniqueness of God and the source of all the lights is displayed well. (Memarian, Gholamhussein, 1367)

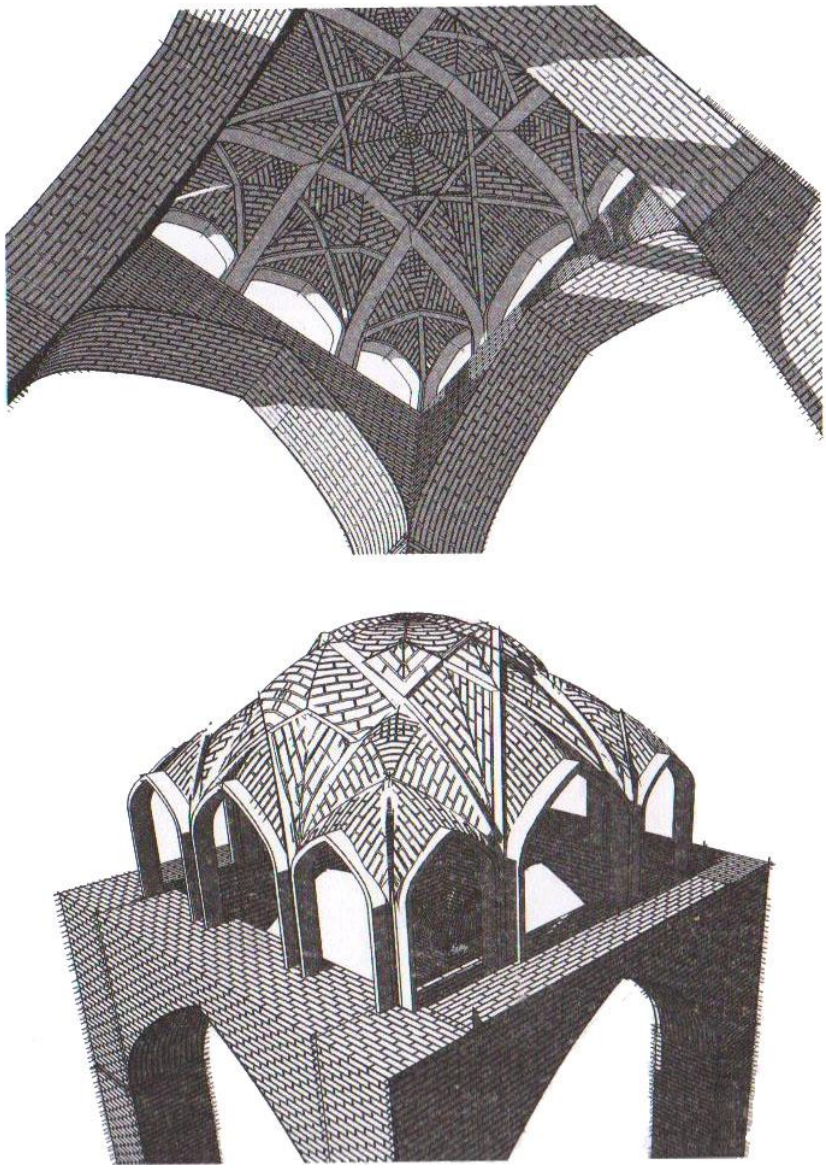

Figure 80: Ribbed vault, Jame mosque,Isfahan

3-2-3-5: How to execute

In vaults with Rib, first Rib which are transverse skeleton are executed and then inside shells are placed between Rib.
Rib is made using a simple method. First, a centering Rib is placed on the Impost of the vault. This method is used when they want to lose the centering Rib inside the Rib.

In case they want to remove the centering Rib when the work is finished, they place it in the inner edge of the arch. An arch having the thickness of a brick is added to this centering Rib. This bricked arch will be the basis for the execution of Rib. It will be reinforced by adding other rows beside and on the arch and finally a transverseRib will be formed.
This simple execution method belongs to Iranian architects and in western architecture wooden frames were used for the whole vault, just like other vault structures.

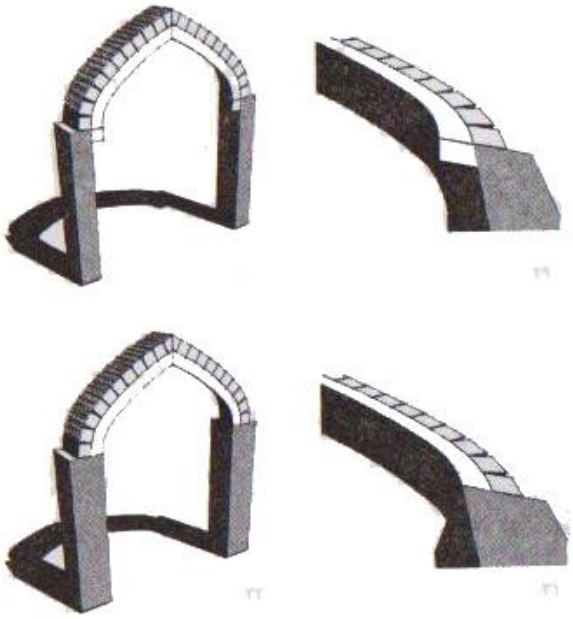

Figure 81: Execution of Rib

3-2-3 : Patkaneh vault

Patkaneh an organ specified by its structure and geometrical specifications and includes rows of shelf which are put there based on a geometrical logic. This collection can be taken as chapireh sazi or space coverage (semi-open or semi-close). Structure specifications of Patkanehcan be classified to two groups of formation-structure and formation Patkaneh. In structure-formation Patkaneh, shelves are filler surfaces which are

put on slips of the backed vaults. But in formation Patkaneh, the shelves are hanged on another structure (Based on Pirniaبsclassification, this kind of Patkaneh are closer to Stalactite). (Pirnia, Karim 1382)

3-2-3-1: Formation background

Some preliminary samples of chapireh sazi can give us a better understanding of Patkanehroots. To this aim, chapireh sazi in tholos of governmental and religious buildings at the end of Parthian and beginning of Sasani eras will be examined. Iranian architects of Parthian era have thought of a solution to place circle of the dome on the square, for the first time. Hence, the invention of such chapireh sazi belongs to the end of Parthian era which was complemented in Sasanian era, especially in the Islamic period. First solutions were using Eave (Patkin) method. In Sasanian era some other more comprehensive solutions were used to convert square surface to octagon and different chapireh sazi techniques such as Filpoosh and Squinch were used.

Therefore, it seems that Patkanehcan be regarded as the forming domain for Squinchchapireh sazi. بSquinch is composed of two diagonal vaults which have crossed each other on a spot (to be more accurate, on a line). Intersection of two vaults brings about this type of transitionپ(Pirnia, 1370, p. 22). The result of the intersection of these two vaults will be the formation of curved triangular shelves in the space which are named Taseh. Development and complementation of Squinch and its shelves in later eras can be considered as a base model for Patkanehproduction.

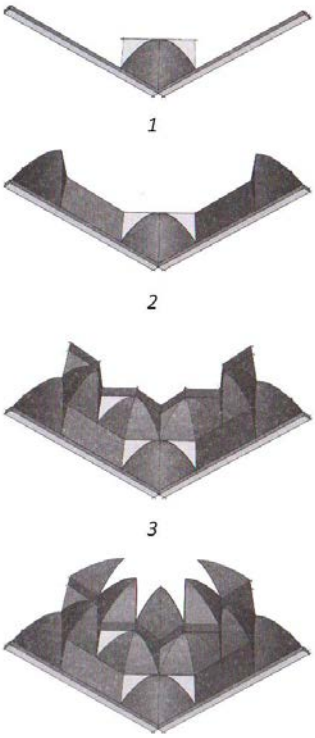

Figure 81: Stages of formation Patkaneh

Chapireh sazi in Amir EsmailSa dome tomb is one of the first samples displaying Sasanid methods using Rib. Here, slip of the transverse vault is still displayed and the middle surfaces are covered with shelves. This sample can be taken as the first step of the formation of Header-soldier.

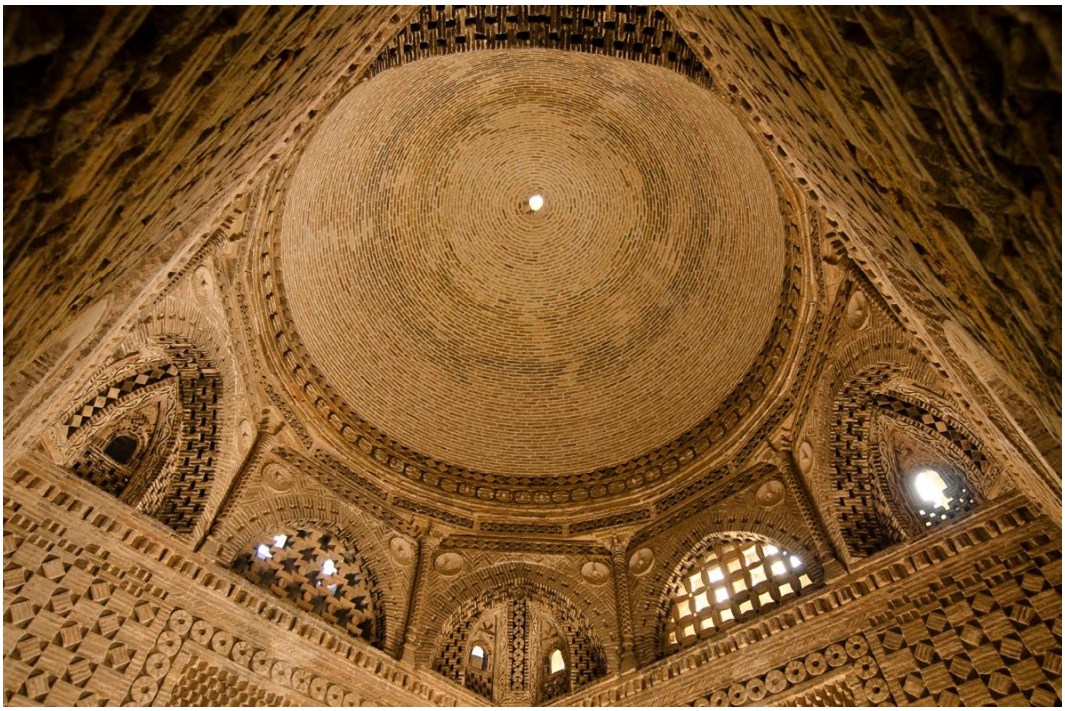

Figure 83: Amir smaeil samani tomb, Bokhara, 884-933 AD

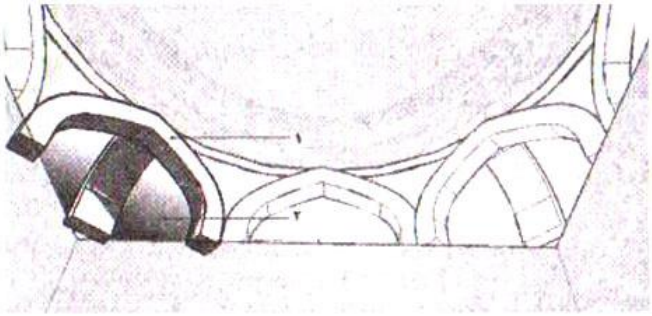

Figure 84: Amir smaeil samani, se-konj gushe sazi

The next sample is Jurjiv mosque (the present location is called Hakim Isfahan) which was built in Al-Buyeh era, along with the development of Isfahan Jame Mosque, in 327 Solar Hijri. The only part remained from this building is a valuable faـade in which the three-corner chapireh sazi is not similar to that of the previous ones inside the tholos.

Here, the faغade is placed inside the Roman arch. This sample is also different from the chapireh sazi of Amir Esmail Samani dome tomb, in structure point-of-view. Instead of using an arch behind the transverse arch, two arches have been used. In result, the middle space in the center of three-corner is opened outwards and displays the sky frame. Two shelves are placed in the two corners of this frame. The opening between the arches and shelves makes it more beauteous.

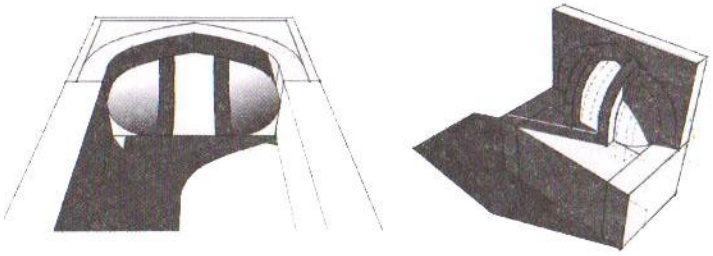

Figure 85: Giorgir mosque, opening, Isfahan

After Jurjiv mosque, another sample can be referred to with considerable development in Patkanehapplication. For the first time (second half of the fourth century Solar Hijri) in Naein Jame Mosque, Patkanehdevelops from being an organ in the space corner to a kind of coverage. In this mosque, the first samples of Patkanehapplication are displayed. (Pirnia, 1382, p. 148)

Another vault in Naein Jame Mosque is placed on the northern verandah. Here, Patkanehis formed on a square frame and geometrical discipline of the design is more obvious. In the first row, eight shelves (on each side, two similar shelves) have been placed. The compatibility of the reverse roof and plan design in this vault shows that this vault is also composed of four Ribs in the four corners. Here, the vaults are really ennobled in geometrical point-of-view.

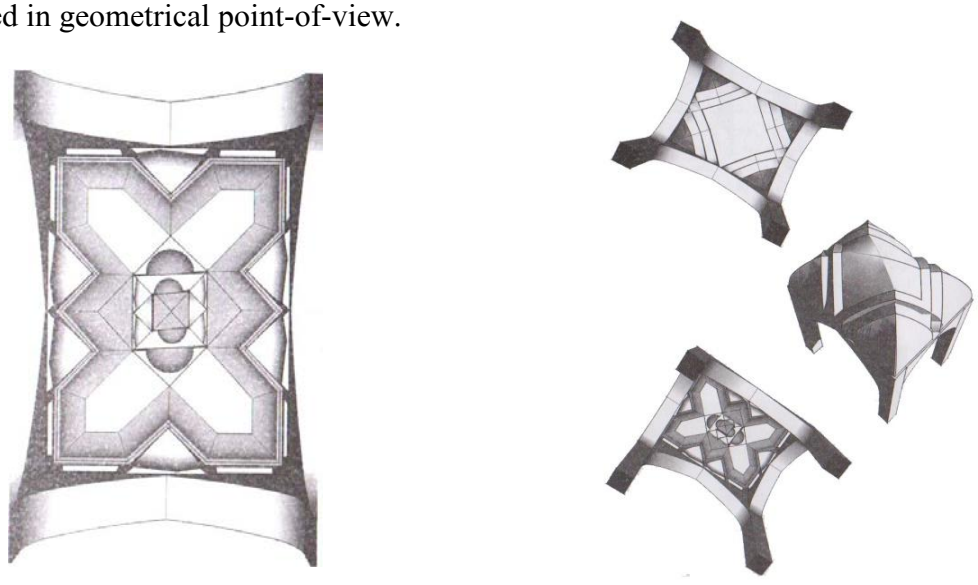

Figure 86: Naein Jame mosque, covering mihrab

3-2-3-2: Patkaneh ability

As seen in the given samples, on one hand, Patkaneh is able to cover corners of the space and on the other hand, it can make coverage. Such application has made the formation of a collection of vault and dome coverage in semi-open and close spaces.

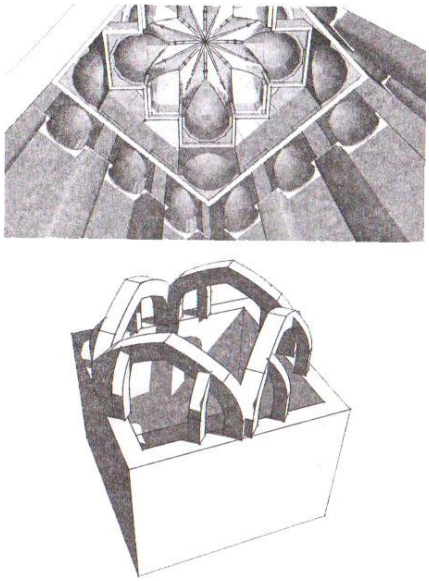

Figure 87: Naein Jame mosque, northen Isfahan, Patkaneh

3-2-3-3: Structure behavior

Understanding Patkanehstructure behavior is complicated and ambiguous for some architects. Occasionally regarding Islamic formation this ambiguity arises as to whether they are just decorative or non-decorative and there are many samples which are a combination of these two modes. (Edwards, 1999:68)

In fact, when the Muslim architect became well aware of Niareshi necessities of building, (based on Pirniaبsdescription, in ancient times, it was technical and included todayبs static and studding knowledge, namely what hold the building) structure formation was formed. Abolghasemi states this issue so بMost works of architecture which is done for the sake of structure, later on become decorative in aesthetics point-of-view. Originally, Patkanehwas used for coverage and was part of transverse structure. (Abolghasemi, 1384, pp. 83-84)

One other characteristic is the fact that Iranian architects tried to hide unseemly structure elements behind coverage ones. Such complication and ambiguity in understanding structure behavior of Header-soldier, makes it difficult to have a definite classification in this regard. But in case it is not taken so difficult, Patkaneh can be classified to two groups of formation and formation-structure (combinatory) in load transfer point-of-view.

3-2-3-4: Formation group

Patkaneh of this group do not play any role in load transfer point-of-view and are regarded as part of the formation of the building. In other words, in this group, the geometry of Patkanehis a means for forming the outer layer of the space. Formation Patkaneh have a behavior similar to that of stalactite in structure point-of-view and are hanged from the original structure but are different from them, geometrically. The most important difference between decorative Patkaneh and stalactite is the fact that they are normally composed of vertical shelves and do not have horizontal elements.

There are different kinds of formation Patkaneh and include a small chapireh sazi to coverage of close or semi-open spaces or coverage of sanctuaries, edge of the saucers and minarets. (Pirnia, 1382, p. 148)

Figure 88: Decorative Patkaneh, Minaret of Jame mosque, Naein

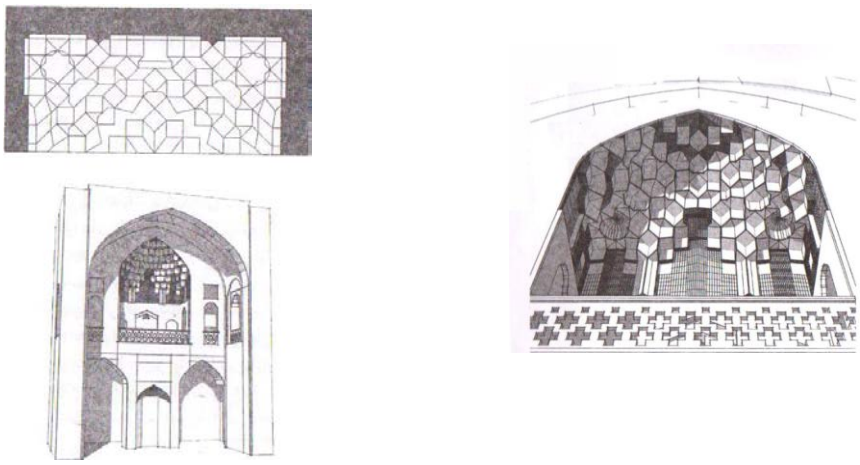

Figure 89: decorative Patkaneh,northen Isfahan, Jame mosque,Natanz

A: Formation-structure group (combinational)

Patkanehs of this group have both geometrical pattern and structure role and carry the imposed forces from the other components and the gravitational forces. Samples of this group can be examined in the following sub-groups:

B: Patkaneh with Rib and shelf

In these samples, the structure element is some Rib behind on which the shelves lean.

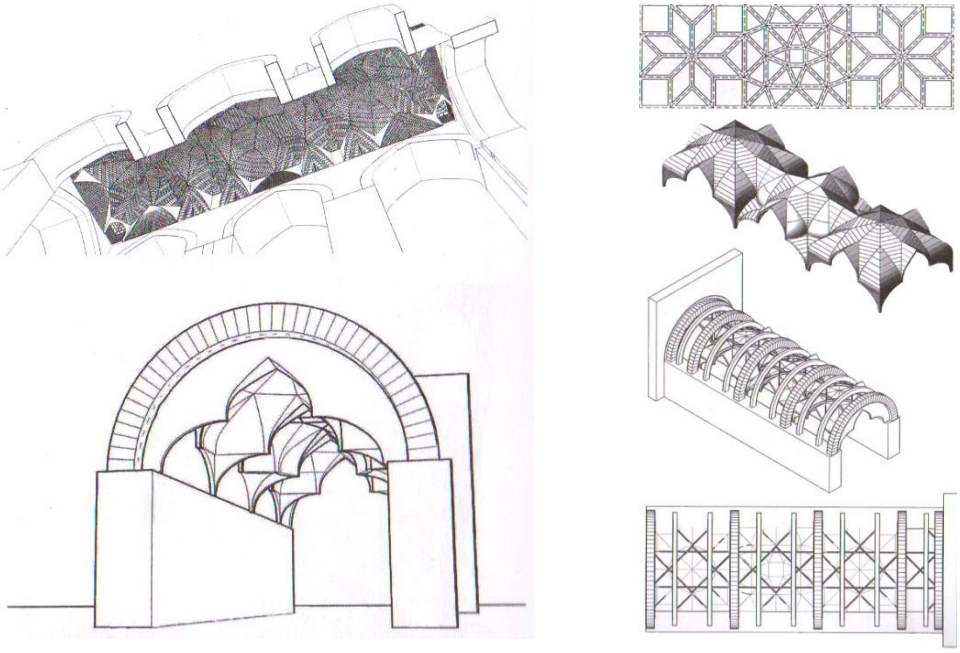

Figure 90: Patkaneh vault, shagerd Isfahan,Jame mosque, Isfahan

3-2-3-5: Patkaneh applied in chapireh sazi

In continuation of the preliminary samples, Patkaneh played the role of chapireh sazi. After Jurjiv faغade, the following buildings can be mentioned: Isfahan Jame Mosque, ZavarehJame Mosque and BersianJame Mosque.

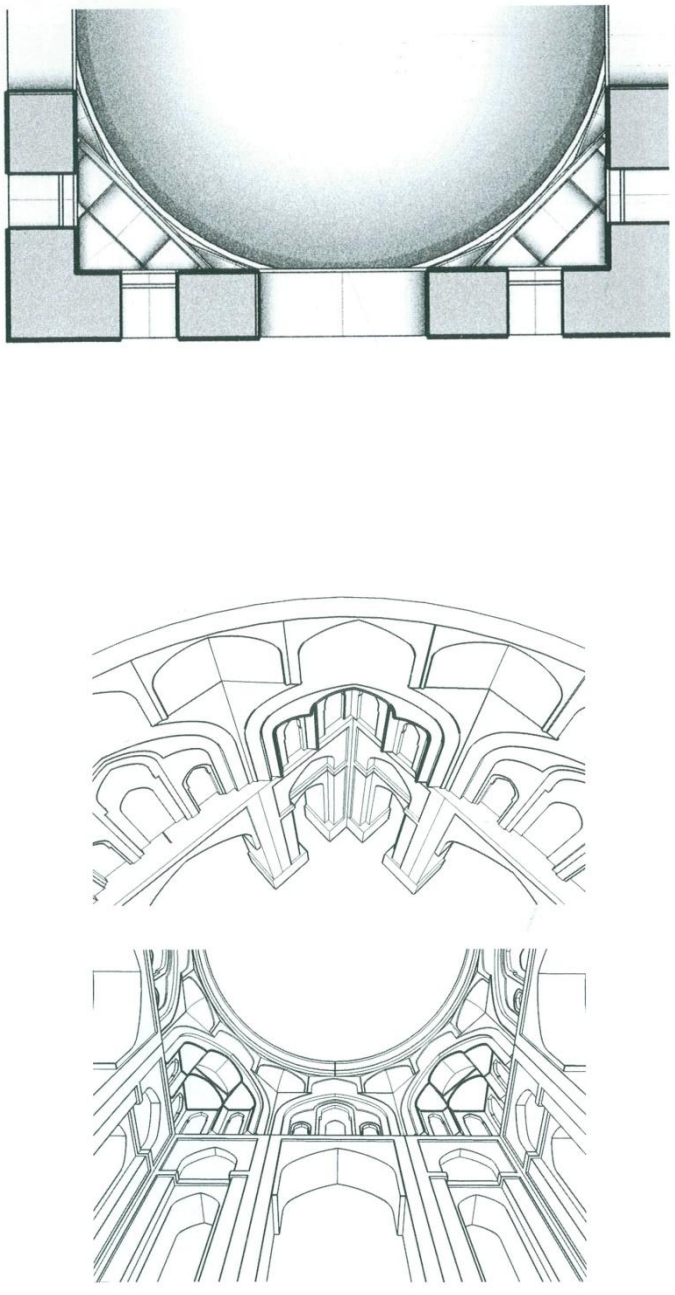

Figure 91: Chapire sazi Patkaneh, nezam-almolk mosque ,Isfahan

Figure 92:Tajolmolk dome, Jame mosque,Isfahan

3-2-3-6: Patkaneh applied in the space

Familiarity of Iranian architects to Patkanehabilities in different buildings was helpful in developing this organ from a small element of chapireh sazi in dome to curve coverage. Spatial ability of Patkanehmade it possible for this organ to completely cover the closed space. It was a considerable improvement in the development of Patkanehand made it a spatial and structure element. By the development of Header-soldier, this formation ability made a collection of dome and vault coverage in semi-open and close spaces.

A: Close space coverage

Patkaneh applied in close space coverage appear in vault and dome frame. In these samples, slip of the surface vaults is paced behind the shelves and the shelves lean on them. Ribs are combined with a geometry the lines of which are displayed in the geometry of the shelves. Difference in geometrical design makes different combinations which affects the combination of Ribs and shelves. Central symmetry of these Patkaneh differentiates the structure behavior of these ones from the other kinds of Patkaneh. In these samples, the symmetrical arrangement of Ribs and shelves makes it possible to repulse the inside force of each element by the opposite element and in other words, let the shelves lean on each other (Memarian, Gholamhossein, 1367)

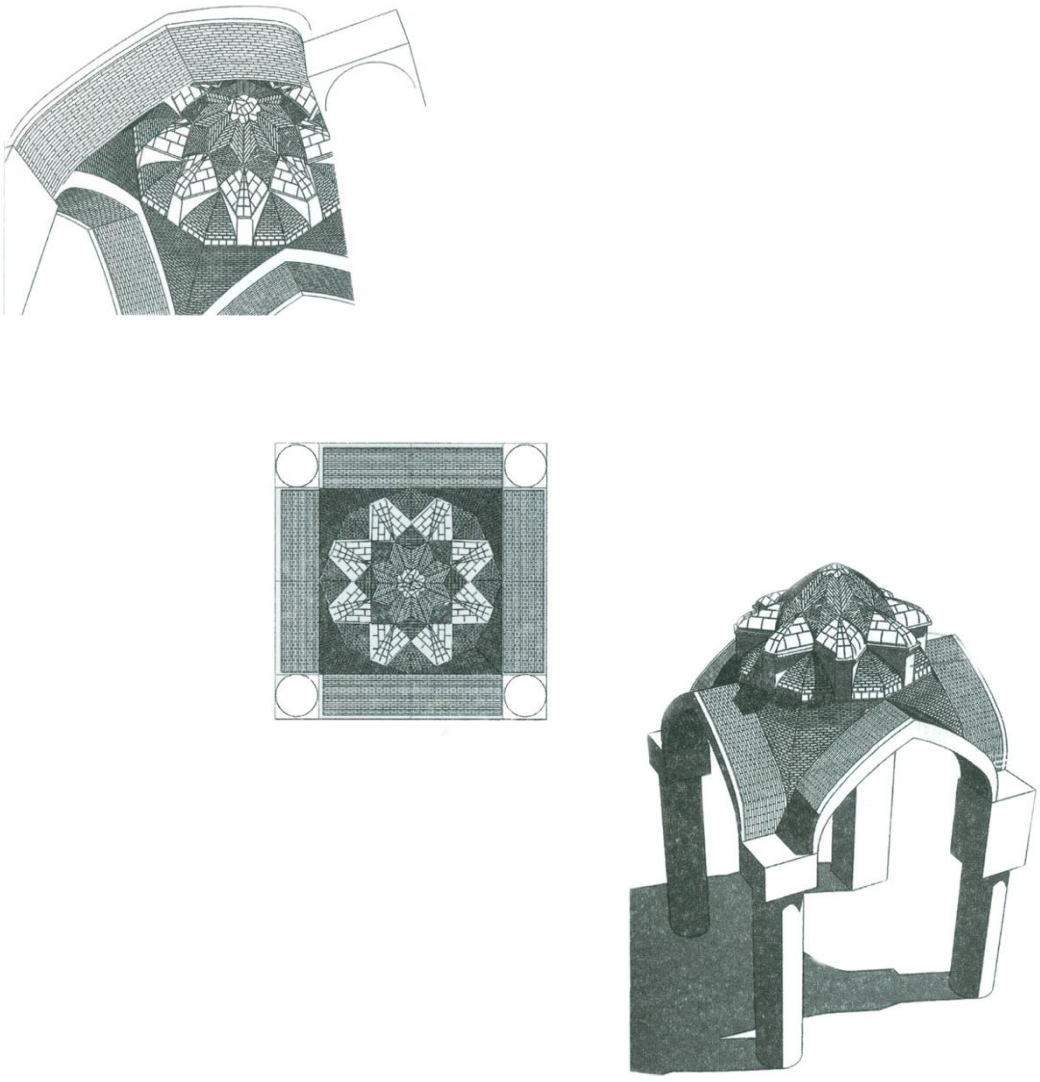

Figure93: Patkaneh vault,Jame mosque, Isfahan

B: Patkaneh in a semi-open space

The most striking samples of Patkanehappear in the form of verandah coverage, late in the fifth century, Solar Hijri. In this stage, Patkanehdevelops from an organ for chapireh sazi to a complete marquee which can cover broad spans. Two of the most important ones of this Patkanehare the eastern coverage of Isfahan Jame Mosque (end of the fifth century) and western part of this mosque. Both coverageare equipped with large shelves which has made them a unique sample of ancient curved coverage. In sum, these two vaults have the following unique specifications:

These two works show the utmost ability of coverage for large spans by Patkaneh. Apart from the size of the span, length of the coverage is also unique. High length of the coverage has made the architect think of such large shelves and by so doing, present coverage in proportion to the scale of the space. (Pournaderi, 1379)

Size of the span and length of the coverage have led to the fact that the common geometry on how Ribs are combined would not be that applicable. Hence, slips of the large vaults have been combined using a modern geometry, special to structure formation in these two coverage. (Memarian, Gholamhossein, 1391)

Figure93: Patkaneh vault,Jame mosque, Isfahan

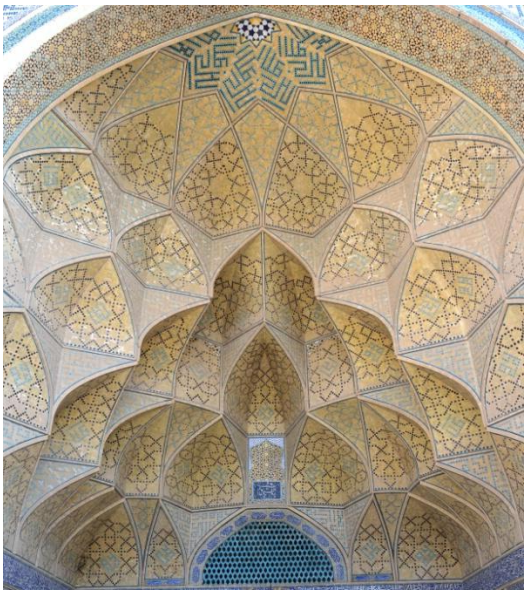

Figure 95: Close view of Patkaneh in Isfahan

3-2-4 Karbandi

Karbandi of the building system has intersecting slips with starred geometry which is considered as an important pattern in ancient architecture roofs. (Raبisi Article)

Pirnia taught of Karbandi as the result of Iranian intuition (Pirnia, quoted from: Bozorgmehri, 1385:1) and takes its introductory phase as chapireh saziof the Sasanid domes in which the architect has tried to transfer the square domain to octagon and circle Impost. He states that the first one has begun in third century Solar Hijri and states بthe sample of complete Karbandi in the fourth century in the palace-like dome of NaeinJame Mosque.پ(ibid 2-5) and regards this time period as the developmental stage of Iranian vaults, such as Karbandi (Pirnia, 1386: 163) and considers the later periods as the disciplined periods (Bozorgmehri, 1385: 6-7)

Hence, it can be said that the root of this vault can be traced back to Iran and in case it is seen in other countries, we should look for its roots in Iran. This kind of vault is seen in some current neighboring countries which were once parts of Big Iran, including: Samarkand, Bukhara, Heart, Iraq, India and ه This issue is of importance in two aspects: On one hand, Karbandi is one of the striking techniques which has developed after Islam. On the other hand, it contains some inner durable values which have made it possible to be variously patterned in contemporary works.

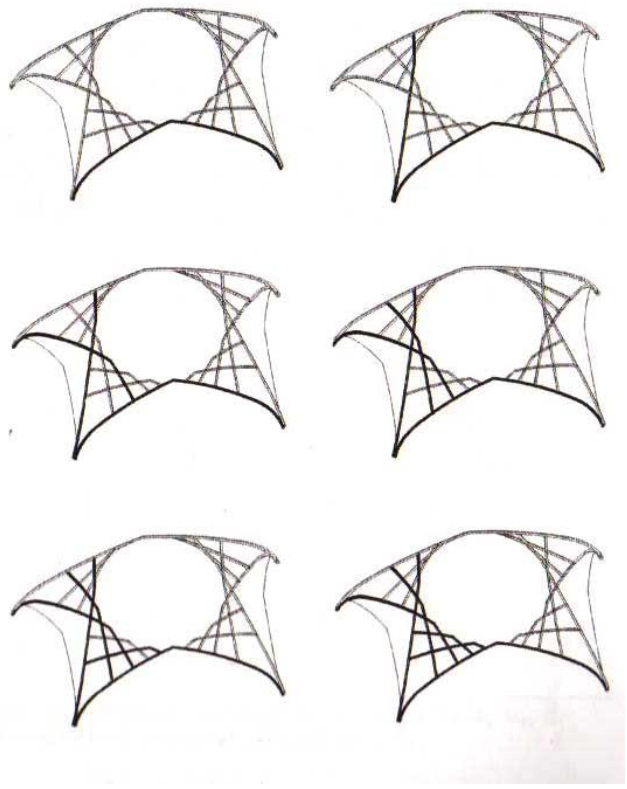

Figure 96: Chapire sazi karbandi

3-2-4-1: Karbandi elements

What is apparently seen in Karbandi includes some curved lines with different sizes. As for its etymology, the act of blocking them together is called Karbandi and can be considered as a complete coverage in case a calotte is used.

3-2-4-2: The formation border of vault with the Rib and karbandi

In Karbandi, such bottom to up combination makes elements such as: Soosani, Shaparak and Sanbooseh. In the center of the vault a calotte will be placed. These elements are special of Karbandi. That is while vault with Rib, at times do not have the mentioned elements and are just a combination of some parallel and crossed Rib and the shells among them.

Vaults with slip have some certain transverse elements which is displayed in most cases. And even when parts of them are not shown, the moving line of the Rib is observable with a bricked streak. But transverse elements of Karbandi have some hidden Rib to which dis-transverse formation elements are connected. Hence, what is seen in the building is not necessarily indicative of moving lines of transverse lines of Rib and at times, some of them just have formation role. (Bozorgmehri, 1385)

Kar (the main part of Karbandi) is part of an arch which is divided to one-foot-in-the-air or two-foot-in-the-air Kars. These Kars lean on the main shelves; that is while the main part of the vault with Rib is slip of the transversevaults.
The geometrical system of vault with Rib is also different from that of Karbandi. In vaults with slip of the dope, the imposition of Ribs can take place based on the simple divisions of frame sides of the vault. This simple geometry can be conveyed to more complicated formations and by the division of a circle and imposition of the base formation, the formation of the vault can be obtained. But in Karbandi, the close union between the base and divisions of circle arches in that side is the basis for the formation of geometrical lines and on this basis, Karbandi elements such as Shaparak and Sanbooseh will be obtained. (Lorzadeh, 1384)

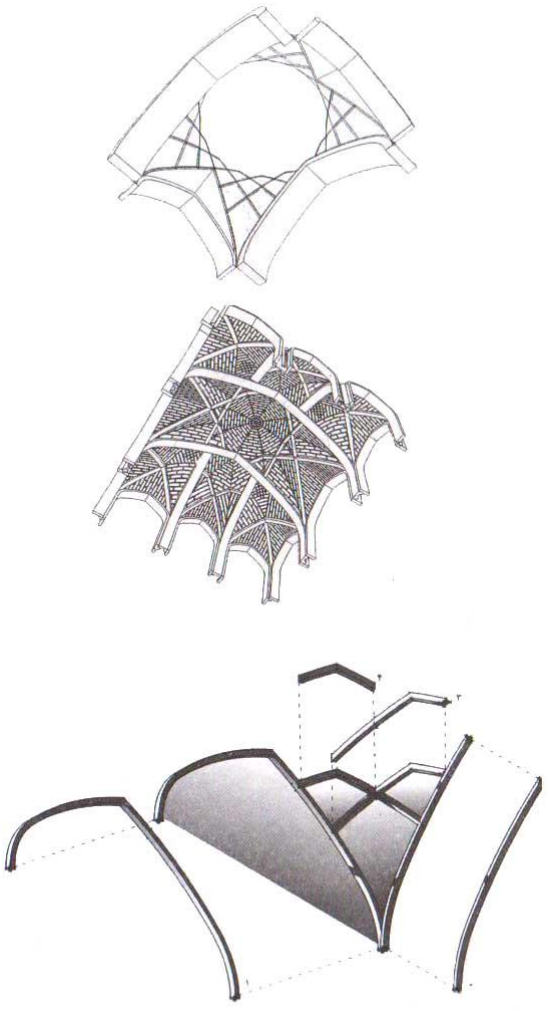

Figure 97: Formation border of Ribbed vault and karbandi

3-2-4-2: Formation and components of Karbandi

As the result of the tressed Kars in Karbandi coverage, some surfaces will be brought about among intervening Kars which forms the whole components of the Kar. Iranian architects have chosen interesting names for these elements. In formal and semi-Karbandies, the components are respectively, from bottom to up, as the following:

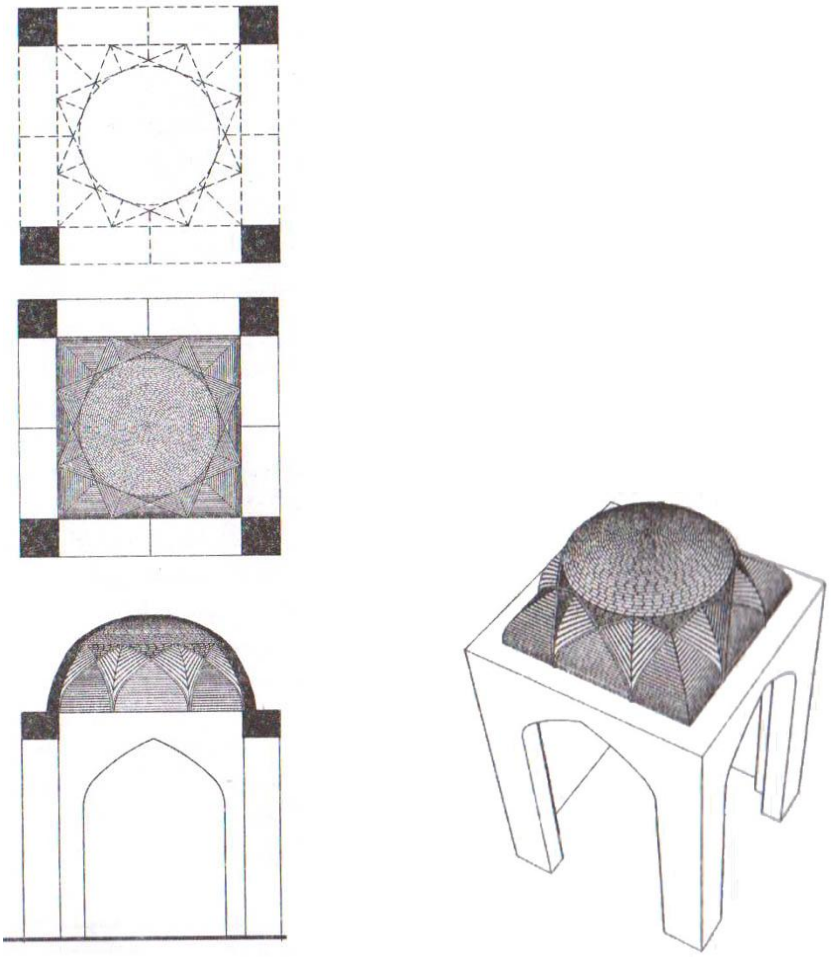

Figure 98: Formation of karbandi,Jame mosque,Isfahan

Zir-hafti: a complete arch which is used as the formation basis for producing Kars (smaller Kars are parts of this Zir-hafti.)

- Soosani: In formal Karbandies, in order to take the Kars to the Sun in the middle of Karbandi, a middle organ is needed on which one-foot and two-foot in the air Kars are placed. This component is called Soosani.

- Pabarik: It is a rhombic-shaped formation in the bottom corners of Karbandi, having two long and two short sides.
- Shaparak: Small rhombic, the sides of which are parallel to linear axe. Shaparaks can be repeated in rows.
- Sanbooseh: in the distance between two sides of the Shaparak and the frame, the calotte of a triangle is made which is called Sanbooseh.
- Sun roundel: It is formation similar to sun which is obtained from the combination of Sanboosehs under the calotte.
- Araghchin: It is a coverage which is put on the Sun of Karbandi. This coverage may be simple or web. (Pirnia, Bozorgmehri, 1360, p.11)

Except for Zir-hafrti and Calotte, the other organs are formed by the movement of the Kars in the space. Kar can be shown by a simple drawing. As centering Ribs are used to execute bricked Kars, these Kars are seen in the formation of centering Ribs. Kars can be divided to two kinds of one-foot or two-foot in the air which are both parts of an arch, in formation point-of-view. One-foot-in-the-air Kars includes a complete arch and a small piece of the arch. But two-foot-in-the-air arch is composed of two incomplete arches.

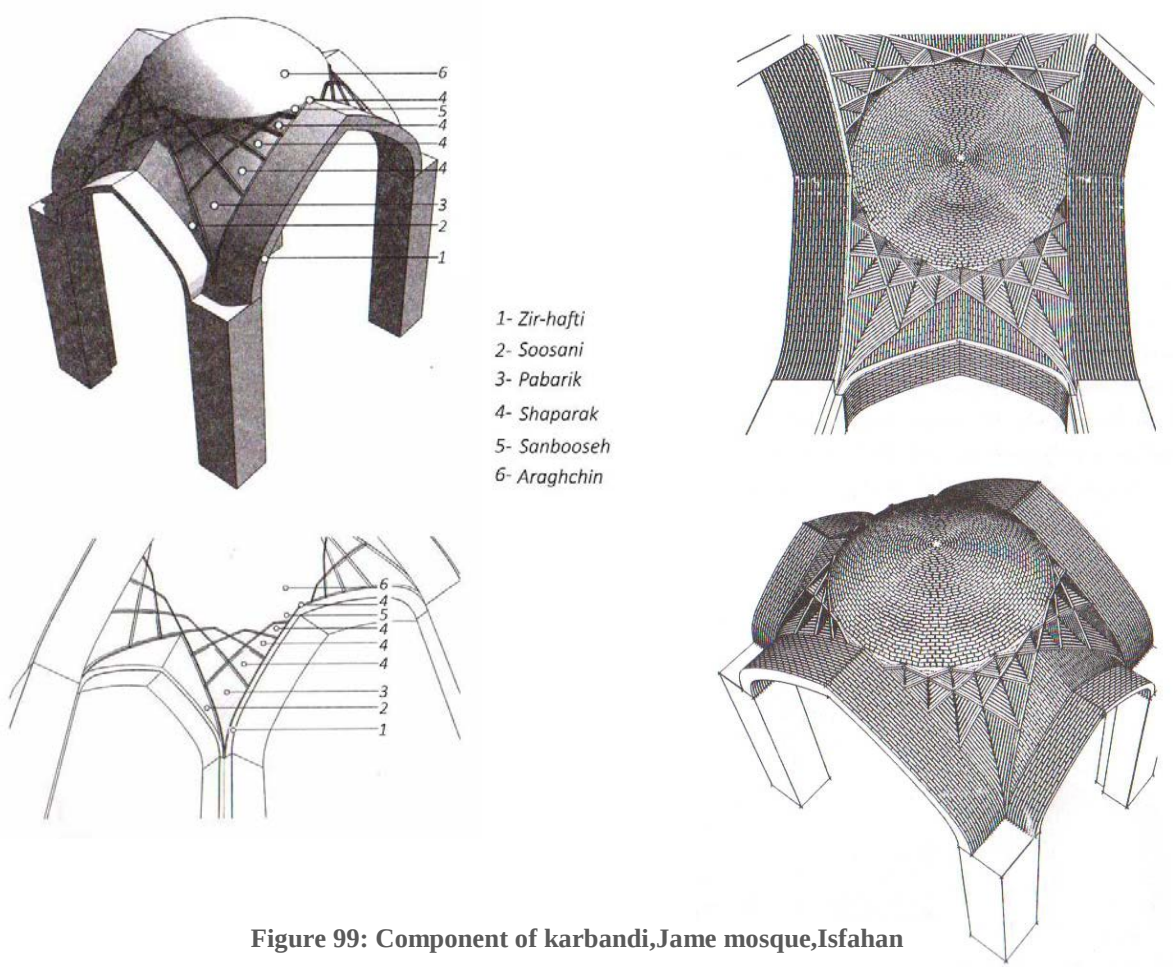

Figure 99: Component of karbandi,Jame mosque,Isfahan

3-2-4-3: Spatial ability of Karbandi

Karbandi is a coverage which can cover the marquee of all kinds of space. To be more accurate, it can be said that Karbandies cover the space in two kinds:

1. Fully closed space, the frame of which is square, rectangular, octagon, jeweled, semi-octagon, GooshehPakh and one side jeweled and semi-octagon. The rectangular spaces are covered with Karbandi, starting from rectangular close to square and large rectangular.
2. Semi-opened space, which can be seen in verandahs. This kind of Karbandi is called semi-Kar which is named based on its type. For example, in case a Karbandi is composed of 8 Shaparak, it will be called 16. (Lorzadeh, 1358, p.16)

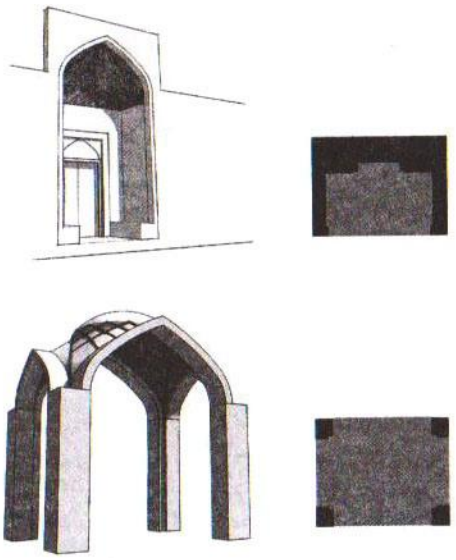

Figure 100: karbandi in closed and semi open spaces,Jame mosque,Isfahan

3-2-4-4: Karbandi Types

Karbandivaults can be classified on spatial, executive and geometrical basis.

1. **Based on the formation and type of the space it covers: fully-closed or semi-closed space:** On this basis, Karbandies will be divided to two groups: Complete and semi-Kar, which has already been mentioned.
2. **Based on the imposition of the Kars in the space:** On this basis the Kars can be classified to two groups.
3. **Different kinds of Karbandi can be classified based on their formation.** Proportionality of the frame (proportion of the sides of the frame) is one of the

effective factors in this classification. On this basis, two groups of official and stellar can be introduced.

Rasm: It refers to Karbandies which are executed in rectangular shape, and especially large rectangular, surfaces. In this mode, in order to match the Kars to the middle Sun, Soosani is formed in the two small sides of the rectangular. Officials are executed, using two frames: Shaghooli and Hard. In case the Karbandi is executed in octagon frame, it will be called official widening. When two official Karbandies vertically cross each other.

Stellar: This kind of Karbandi is mainly used in square or square-like frames. Stellar is done in two formations of unified and separated. Its drawing method is simpler than that of Officials. The separated stellar is obtained from the movement of a square inside a circle. Unified stellaris obtained from the movement of a line inside a circle. This line connects arches of the circle so as to connect them 5 by 5 to reach their first spot.

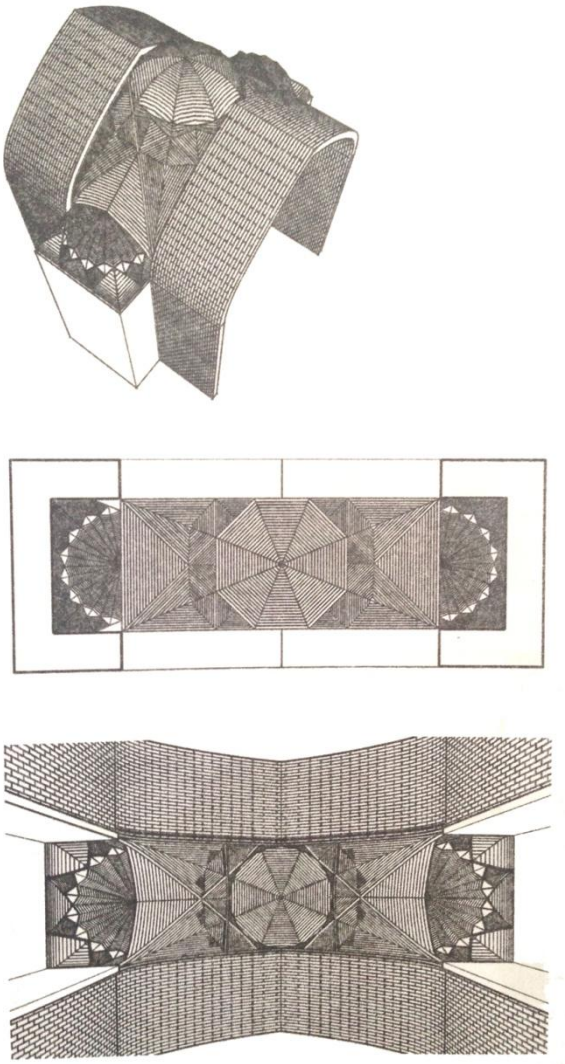

Figure 101: Akhtari type of karbandi,Jame mosque,Isfahan

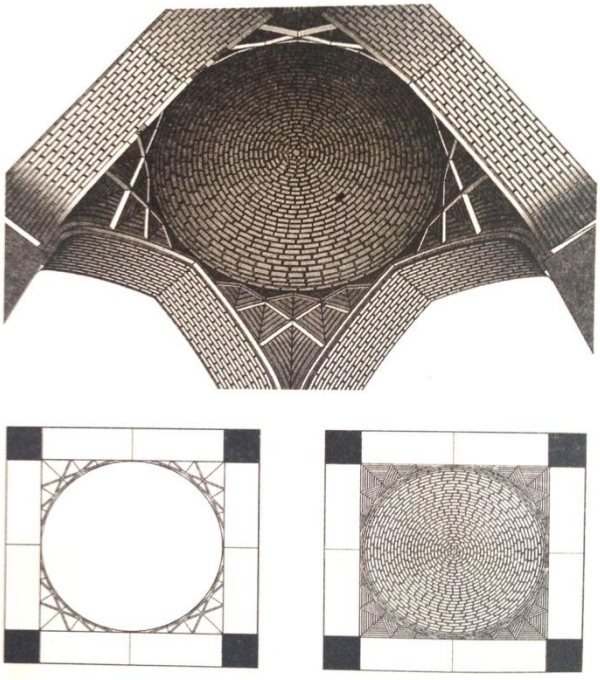

Figure 102: Rasmi type of karbandi,mosque,Isfahan

- Karbandies under the dome: For converting the octagon under the dome to a formation with more sides and bringing it to the circle surface, Karbandi is also used, the most common of which is Stellar 24. Apparently in all eight sides, two Shaparaks are seen which make a 24 sides of the bottom domes of a shelves. (Pirnia, Bozorgmehri, 1360)

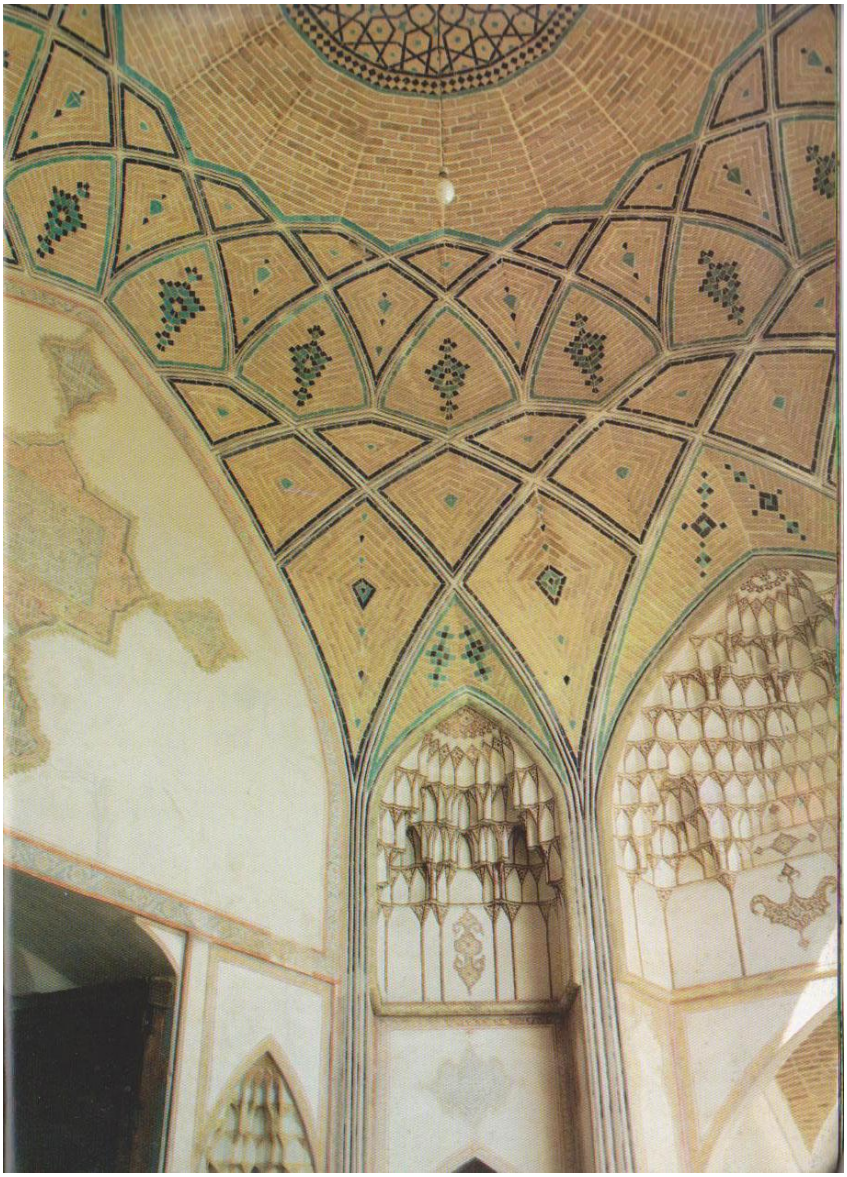

Figure 103:Karbandi dome,Charbagh school,Isfahan

3-2-4-4: How to build Karbandi

Rib includestransverse elements of Karbandi. Rib which are called main bricked frames of Karbandi, are curved ¼ bricked elements which are executed for the certain amounts and secondary Ribs lean on them.

Size of the Ribs depends on the execution of whole Karbandi. If Karbandi is taken as the main coverage, the vaults will have ¼ more thickness which at times comes to 60*60 centimeters. Size of the Ribs in Karbandies which are not the main coverage is less and at times it is just as thick as a brick (5*20 cm). In this mode, a main vault will be executed on the considered space. Here are the stages:

1. Execution of pre-vault
2. Holding chalky frames (or metal ones, in modern Kars)
3. Execution of Rib
4. Execution of secondary Rib and filling the surfaces among Rib (Pournaderi, 1379, pp. 26-32)

Pre-vault is the main transversevault which covers the space. In Karbandi, a semi-Kar of a semi-arch is like a semi-Domical and in complete vaults, it is a domicalvault or simple vaults which can tolerate weight of the structures and bricked frames which are in need of pre-dope support.

As we have already seen, a Karbandi is composed of Pabarik, Shaparak and Soosani components. These components are obtained from the intersection of Rib with main bricked frames and secondary bricked frames will be obtained.

In hard frame semi-Kars in which main bricked frames lean on the metal torque, first the torque is connected to the pre-dope by chalk (Poornaderi, 1379, p. 27). Then the chalky frame or centering Rib is placed on one hand, on the torques and on the other hand, on leaning walls. On this frame, a bricked-like layer with the considered thickness of the Rib is placed. After removing the chalky frame, the Rib will itself stand and then the space between the main bricked frames will be filled by secondary bricked frames.

3-3: Rib in dome coverage

3-3-1: Coved dome with slip of the arch

As it was mentioned in dope section, Coved dope is composed of a number of tracks and dope with slip of the dope is composed of numbers of slip of the dope and the shells among them. Both of these characteristics are maintained in a kind of dome called Coved or RibDome.The emergence date of this dome in the world is one of the most controversial issues because western researchers believe it to be a western innovation and some others believe that it has originally been made in east.

Coved domes have all the formation, symbolic, statement and spatial characteristics of other domes; but their composition parts are different. These components are primarily building components; meaning that dome is made by them. In some domes, it has been attempted to hide these components, such as SultaniehDome in which the vaults cannot

be seen in its inside and outside surface and in some others like BersianJame Mosque, the formation effect of Ribs has been shown.

Coved dome or Rib has three main components:

1. Rib: Rib is a structure organ. In fact, it can be regarded as a transverse arch or shelf. For example, an arch with the deepness of five or six rows of brick and thickness of four rows of brick compose a Rib. Ribs are divided to two groups: main and secondary. Slips of the main vaults are thicker and slips of the secondary vaults are imposed among slips of the main vaults. In domes, 8 to 16 main Ribs are utilized.
2. Web: Webs are bricked shells which fill in the Rib. Bricking of the webs is done via different methods of simple, header-soldier.
3. Summit: It is a bricked element to which the shelves of Rib in the center of the dome depend. The mixture of webs and Rib will obtain the main skeleton of the dome and the webs will be converted to some light surfaces, some load of which will be conveyed to the base of the dome by slip of the dope. The other part of the load is directly inserted from the shell to the frame of the dome. (Pirnia, 1374)

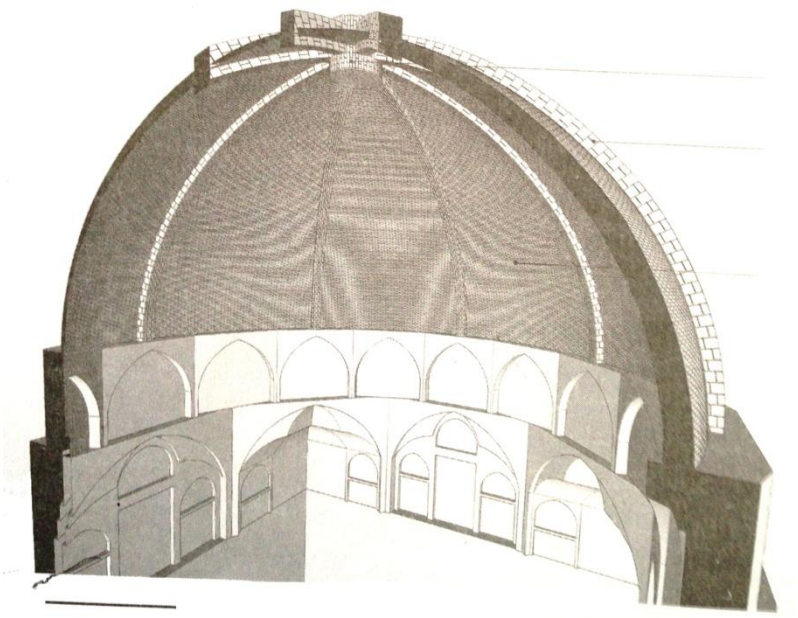

Figure 104: Component of coved dome, nezamolmolk dome, Jame mosque,Isfahan

The main specification of the domes with Rib is their better control of tension (meridional) forces. This issue which has always been one of the main challenges of domeproducershas been more heeded in domes with Rib (both in webs and Rib). In single-shell domes because of the flatness of the shell, the whole frame will be under the tension of tension and run forces; but in domes with Rib, the main meridional tensions

are transferred from Rib to bottom abutments. Using this method, the main tension field will be decreased from the whole dome frame to 8 or 16 leaning spots. Also taking into account the decrease in thickness of the shell in webs, less weight will be transferred to Rib and frame of the webs and finally the problematic forces will be decreased.

3-3-1-1: How to execute Coveddome with Rib

The execution method of this dome can be classified to two parts:

A) Domes with few to middle spans: about 15 meters
B) Domes with large spans: above 15 meters

For the first one, a simple but innovative method has been used.
Here is how a dome is made:

1. Building the tholos till getting to the Impost or frame of the dome.
2. Execution of Rib
3. Execution of the webs (with the shells among Ribs)

After preparing the tholos till the stage of dome execution, centering Ribs, equal to the half of domespan, are made and their Imposts are put on the wall. If the span is small, a vertical wooden mast will be placed on the floor and shelve of the centering Ribs will be placed on it. Centering Ribs are proper leanings for a row of multiple vaults. On centering Ribs, a bricked arch is converted to a firmer frame. This arch is reinforced with some brick rows and is made into a strong transverse slip of the arch.
For bigger spans, may be up to 15 meters, the same method is done with some differences. Andre Godard displays the method of building such Rib by some pictures on how an Abanbar in Tabriz is built. The difference between this method and making small Rib is in using a large bricked pillar instead of a wooden mast in the center of the dome. Based on what Godard maintains, these are the stages for building such domes (Godard, 1369, pp. 139 to 144)

1. A bricked pillar (minaret) is placed in the center of the dome.
2. A bricked Summit is built on it.
3. Chalky frames or matches are placed on the dome frame and the shelf leans on Summit.
4. A row of bricks are put on the centering Rib.
5. A row of bricks is put on the bricked arch, and will be reinforced by two brick rows in the sides.
6. At the time of execution, different parts of the arch will be reinforced with more bricks and the centering Rib will be lost in slip of the arch.

7. At the last stage the webs will be made.

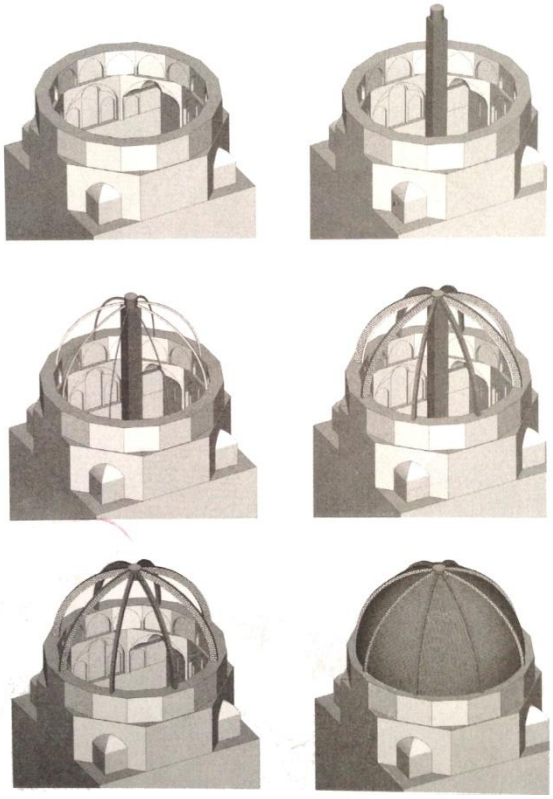

Figure 105: Stages of formation Ribs with dome,tajolmolkdome, Jame mosque,Isfahan

It seems that the present method cannot be used for domes with large spans such as Sultanieh dome which has a 26 meters span, because if half of the span is made with centering Rib, it would be 13 meters long and because of the weakness of the chalk and bulrush, this centering Rib will break.

Pirnia believes that while working on large domes, centering Ribs were divided to some parts on the land and were imposed on what had been built. پIn long domes, Coved (Rib) is made into pieces and are inserted on and beside each other so that upon reaching a certain height of the dome, some similar vaults were put alongside and covered the surroundings of the dome. Then another series of (Rib) which included the next height of the dome was put on the bottom row and rowing was made continuously up to the time that the height of the dome was completed. In order not to make any disorders, all the guiding centering Ribs were built on the land and later on, gradually put them on the dome in different stages of fits formationپ (Pirnia, 1370, p. 116-118)

Based on this method, the dome is arranged as the dome of a shell from its Impost and the same time Ribs are made with the shells and in order to execute the curves of Ribs accurately and correctly, centering Ribs which composed parts of the main centering Rib, were installed in different heights and the dome was executed till the shelves. Finally, a

system of Ribs and shells was made which had the same stagnation applicability as that of the previous one but was different in point-of-view. In other words, in large domes, Ribs did not have simple components as those of middle or small domes.

3-3-1-2: Historical samples

To introduce Coved or Ribdomes in a better way, they will be classified into the following groups:

1. First group: Coved or Ribdomes with a single-shell building like Isfahan and Ashtar janJame Mosque.
2. Second group: Coved or Ribdomes with two unified shells, the inner shell of which is built with Rib.
3. Third group: Coved or Ribdomes with two unified shells, the outer shell of which is placed on the Rib.

Four-vaults of Niasar, the dome of which is Coved, but does not have slip of the transversevaults, is a building which can be taken as an introduction for Coveddomes with Rib. Four-vaults of Niasar belongs to the second or beginning of the third century (around 220 Gregorian), near Kashan. It is not big in size but the used construction methods are remarkable. Span of the dome is about 6 meters and height of the shelf is about 12 meters. Walls of the tholos have 2 meters thickness. Stone is the main element and in restoration of parts of the tholos, brick has been used. The arches have oval curves. Transition tier is placed in a rectangular cube formation and the small dome starts from the top of the Transition tier.

This dome traces the background of building Coveddome with Rib in Iran to about 1800 years ago. Centering Ribs had been used to build domes. There are 8 matches and their feet on the frame of the dome and shelf reach each other at the center of the dome. These centering Ribs make 8 webs, among which stony webs have been imposed.

The first Coveddome with transverseRib has been built in 473 Hijri (1051 Gregorian) in Nizam-Almulkdome of Isfahan Jame Mosque. Seraglio mosque, belonging to second and third Solar Hijri century is converted to other designs in the fifth century. In the new design, some pillars have been removed and tholos with 15 meters span has been replaced. In the first design, the tholos was open from three sides and large abutments tolerated the dome. Transition tier of the dome is of Patkaneharching type. The dome is composed of 8 webs and 8 Ribs. Galdieri, by conducting many researches, indicated that these Rib are covered with a layer of chalk formation; but in fact, Rib have the width of 3 bricks in the building and the thickness of five bricks (Galdieri, 370, p.105)

Bersian Mosque from 491 to 493 Solar Hijri (1097-1099 Gregorian): The mosque is of the two-unified-shells with Rib in the inner shell type. Up to now, the tholos and parts of the verandah are remaining. Abutments of the tholos have about 2 meters thickness. Conversion of foursquare to dome circle has been done using Transition tier, arching and

Header-soldier. The dome is equipped with 8 Ribs which have been shown inward. The span of the dome is about 10 meters. Height of the inner shell is about 19 meters and the outer shell is about 21 meters.

3-3-1-2: Examination of the historical role of Sultaiehdome

Sultaniehdome has been built in (1305-1313 Gregorian). This dome is one of the most controversial Iranian buildings because as one of the great Italian researchers, San Paulzi, claims, it has been effective in the building of Santa Maria Delfin Ware Dome and it was about three decades ago that the theory of the impact of Sultanieh dome building on the Santa Maria Delfin Ware Dome has been discussed by prof. San Paulzi, former chief of Architecture faculty of Florence university and chief of Restoration Institute of the mentioned city and was published in a book in Persian language (San Paulzi, 1975). He had been studying Santa Maria Delfin Ware Dome for about thirty years; but after observing and studying about Sultanieh dome wondered about the various similarities between these two and came to the conclusion that Sultanieh Dome has been effective in the architecture of Brunelski dome. He states the following regarding Iranians: ِIranians, by their mere perseverance and inner Middle-Eastern talent shall be regarded as the nation which has exported special forms in literature and art to other countries, namely poem, methods of classical architecting and technical phenomenon and thoughts. (San Paulzi, 1975, introduction)

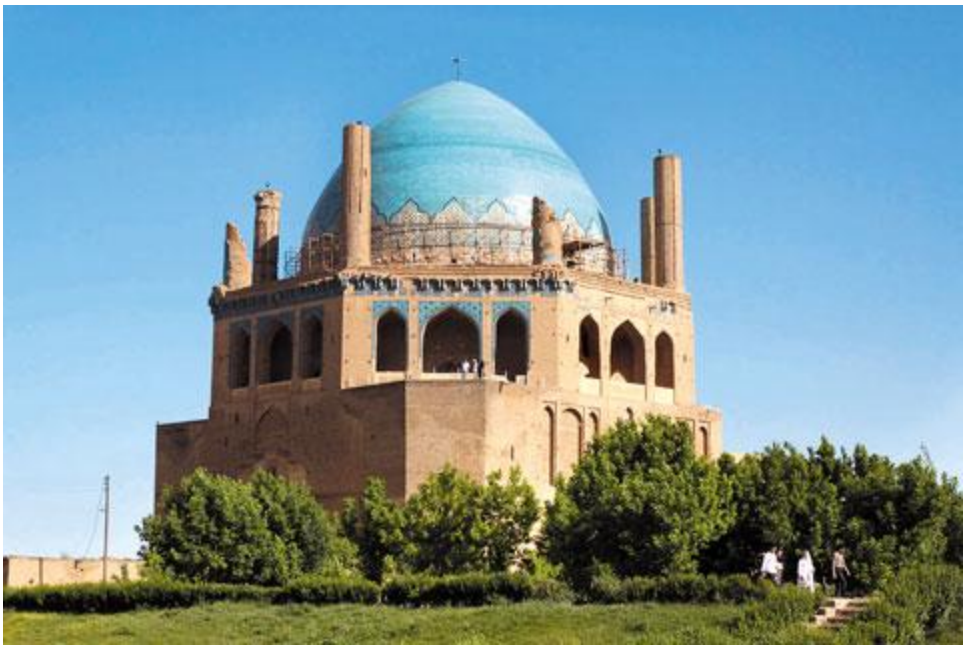

Figure 106: Soltanie dome, 1288-1292 AD

He discussed some similarities such as having two shelves, octagon shaped, main and secondary systems of Rib and Patkanehkind of brick and except for the octagon shape, believes the root of the others to be Iranian architecture.

San Paulzi states various reasons for the transference of Sultanieh Dome to Florence; reasons such as the existence of Iranian traders in Iran of the time, visit of some historians and tourists such as Klavikou in 1402 Gregorian of Sultanieh building and universality of the fame off Sultaniehdome as the third largest dome in the world, after Panteon and Istanbul EyaSufia Mosque (San Paulzi, 1975, p.42)

The building of Sultanieh graveyard building which lasted for 9 years is an octagon, the inner span of which is about 26 meters and there is about 42 meters distance between its two outer sides. There are no Transition tiers to place the dome on the octagon. A dome with Chamaneh curve is placed on the body, the height of which is about 50 meters. This dome has some remarkable characteristics:

1. It is a unified two-shell dome.
2. Ribs are composed of eight main Ribs and 16 smaller Ribs.
3. Ribs are unified with the inner shell.
4. The outer shell is placed on the Ribs.

The dome is not two-shelled till reaching 2 meters height of the Impost and has the thickness of about 1.50 meters. The shells are separated from the four meter height onward and the thickness of the inner shell will be 60 meters and that of the outer shell will be 40 centimeters. The more closer to the shelves, the less would be their thickness. The space between the two shelves is 50 centimeters and the closer to the shelves, the lesser would be the distance between the two shells. There are 8 main Ribs. Each octagon starts from the peak and the dome is continued till the central Summit. The sizes on the maps show about 40*80 centimeters. There are some smaller vaults between the two main Ribs. It has been designed in such a way that the numbers will decrease in upper heights. There are totally 16 small Ribs from Impost to the half of the dome. Then on, there will be 8 ones. Small Ribs are orbital unified with some archesپ(Pirnia, 1370)

The second shell of the dome will be placed on these Ribs which had been previously decorated with beauteous tiles and have now completely gone through restoration. In the outer peak of the octagon, there had been eight minarets. These minarets are exactly placed following the 8 Rib in the main web. Based on the run force obtained from Rib, it can be assumed that these minarets had been effective in repulsing the run force.

3-4 Conclusion

The present section has deeply studied the role and background of Rib in convext coverage. Ribbed vault, Coved vault, Patkaneh vault, Karbandi vault and Coved dome are the most significant Iranian vaults and domes on which Rib plays a significant role. Investigation and understanding structure behavior and the imposition of Rib in the geometry of the mentioned vaults is one of the remarkable issues in this section as because of the existing formation complicacies in Iranian vaults, the ambiguity arises that

whether the forming elements are decorative or merely used as transverse. Also, in this section it has been attempted to give a comprehensive understanding of how these vaults are executed and by investigation of the stages and classification of the formations, a better understanding of the combination of Rib in curved coverage will be obtained which will be an access-point for the next section in which the main Iranian samples of these coverage from the third millennium, Gregorian year, up to the present century will be classified and compared based on the hierarchy and development trends of the imposition of Rib.

Keywords: Ribbed vault, Coved vault, Patkaneh vault, Karbandi vault, Coved dome

(1) Khancheh-pooshvault of Karkheh verandah

Karkheh verandah is a building belonging to the fourth century (Gregorian year), not much of which has unfortunately remained. Coverage of the marquee of this Sasani building is Khancheh-pooshvault which has been introduced for the first time by Madame Diolafva in her book. Andre Godard tries to investigate the roots of this vault in middle-east to prove that it originally comes from France. He structures the root of this vault as follows:

1. The first samples have been seen in Jerusalem and Moran.
2. Later on, some other samples have been seen in Syria, the two main shelves and the outer surface had been covered with stone
3. In Parts period, it has been transferred from Syria to Mesopotamia and was applied in Alhazra palace.
4. It has been transferred from Mesopotamia to Ashoor and it was executed with a bricked coverage, over there.
5. Later on, in Karkheh verandah, the Mesopotamian method was applied.
6. In the Islamic era, it had been applied in some places. For example in Ovkhidar, Shiraz Jame Mosque and Khan Artameh, in all of which the mimicry aspect is recognizable. (Godard, 1358, p. 317)

Seyed Mohammad TaghiMostafavi, great Iranian archeologist, descRibes the building as follows: ابIn twenty kilometers to the ruins of Shush and approximately to the same distance in southwest of Dezfool City, there are great masterpieces of Sasanian era on the right side of Karkheh river. The dwellers of the surrounding call it: Koot Karkhehپ Beside the existing masterpieces, there is some great remaining which surrounds the palace and on each side there are gates, with certain distances. In the eastern side of the palace, with about three hundred distance of the southeast corner of the building there is a long bricked building, more than half of which has nowadays been ruined. Based on the remaining half, it can be understood that there has been a building with the height of 46 meters and width of 14.5 meters on the eastern side of this environment and taking into account the bricked round vault and other specifications of the building, it can be indicated that it has composed a magnificent hall from which the flows of Karkheh water and wide Khoozestan Plain could be seen. (Mostafavi, 1318, p. 94)

The specifications of the building elements of Karkheh Verandah which had been introduced in 1349 are as follows:

- Width of the remaining footstep: 2.35 meters
- Length of the remaining broken wall: 18 meters
- Width of the northern abutment footstep of the building from the western side: 7 meters.
- Width of the remaining wall in the northern side of the building: 5.35 meters
- Five square-shaped shelves: 2.30*1 meters (in which the light of the verandah is below the vault) (Ahmad Eghtedari, 1353, p. 40-44)

The reason behind going deeply to these details is to show Godardِ lack of understanding and even not observing Karkheh verandah. If Iranian architects wanted to cover the 80 centimeter span between two main transverse shelves, the width of each was 1.60, by wood, why should they built a wall having the thickness of 7 meters and 46 meter length so that the main shelves, having 1.60 width, be inserted on them and finally cover them by wood. This is indicative of the superficial understanding of Iranian architecture and Niareshi logic to which Iranian architects paid so much attention. If they wished for building a shaft-covered building, they could have done so, using lighter walls.

Existing pictures from 1340 decade of Solar Hijri indicates that a barrel vault moves on parts of two parallel shelves and that is exactly what forms a Khancheh-pooshvault. By so doing, the theory of wooden coverage on shelves which had been proposed by Andre Godardwill be questioned.